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The Mu-Opioid of the People

Rituals and the Psychobiology of Social Bonding

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Short Abstract

What are the cognitive and neurochemical mechanisms that allow religious ritual to lead to a sense of bonding with others in attendance? In this thesis I conducted five studies to answer this question. In an international field study, I found that those attending religious ritual did experience a higher sense of social bonding with others in attendance compared to before the ritual, and that this was predicted by positive affect, a connection to a higher power (something bigger than oneself), and a proxy measure for mu-opioid release (pain threshold). I then conducted two double-blind randomised controlled studies. In both studies, I found that a mu-opioid antagonist drug, Naltrexone, lead to a significantly lower level of social bonding after the ritual than before, compared to placebo, suggesting that mu-opioids play a key role in ritual social bonding.

In two other studies, one conducted in a naturalistic setting and another in controlled conditions, I compared religious ritual to secular ritual to examine the specific role of spiritual/religious components of ritual on social bonding. In both studies, positive affect, and a connection to something bigger than oneself predicted social bonding, irrespective of the spiritual or secular nature of the ritual. This suggests that, while the spiritual/religious nature of the ritual does not play a key role in ritual social bonding, rituals that are better able to create a feeling of connection to something bigger than oneself, be they spiritual or not, are better able to produce the social bonding effect. Finding efficient and effective means to socially bond played an important role in human evolution. As religious rituals more explicitly aim for a connection to something bigger than oneself than secular rituals, this could explain the universal prevalence of religious rituals, and their continued survival compared to the lower longevity of attempted secular counterparts.

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Extended Abstract

Group living is one of the most, if not the most, significant development in human evolution. It is our ability to live in groups, and act as social animals, that has helped us not just survive, but thrive over millennia. However, group living comes with time and energy costs as well as benefits. Humans have evolved a 'bonding toolkit' (a suite of behavioural and affective mechanisms) by which social bonding is more easily enabled. The elicitation of positive affective states, as outlined in the 'Broaden and Build' theory, is thought to be one major part of this bonding toolkit. Yet, the neurochemical underpinnings of the bonding toolkit are less well-understood. The brain-opioid theory of social attachment claims that the behaviours and positive affective states that make up the bonding toolkit rely heavily on the endogenous opioid system, especially mu-opioids, to cause bonding.

Sociologists and anthropologists have noted for over a century that religious rituals appear to reliably lead to social bonding. More recently, psychologists have suggested this is because religious rituals include or evoke several behaviours and affective states that are part of the bonding toolkit (e.g., shared goals, positive affect, and synchronised movement). However, little research has yet been conducted to explicitly assess the psychobiological mechanisms underlying the role of religious ritual in social bonding.

In this thesis, the major question I sought to answer was "what are the psychobiological mechanisms underlying social bonding caused by religious ritual?" To answer this question, I conducted five studies, across both naturalistic settings and controlled conditions, with UK and Brazilian populations. The first of these studies, an international field study which included 24 ritual sites, provided support for the 'Broaden and Build' theory as well as for the brain-opioid theory of social attachment. Additionally, I found an unforeseen mechanism – a connection to something bigger than oneself – predicted levels of social bonding in those attending ritual. However, results on the role of religiosity on the strength of the bonding effect were inconsistent.

To help address these inconsistent findings, two studies that compared religious ritual to behaviourally similar (study two, in a naturalistic setting) or behaviourally identical (study three, in

controlled conditions) secular ritual. These studies directly assessed the role of the religious component of ritual on social bonding. The findings from these studies demonstrate that the positive affect and connection to something bigger mechanisms play a significant role in social bonding both in those attending religious rituals and those attending secular rituals. This suggests that, while the exact nature (secular or spiritual) of the ritual does not play a role in social bonding, rituals that are better able to create a feeling of connection to something bigger than oneself, be they secular or not, are better able to produce social bonding.

However, in study three, evidence collected via a proxy measure of mu-opioids did not provide support for the brain-opioid theory of social attachment. To address the inconsistency between the results from study one and study three, two follow-up placebo-controlled, double-blind studies using Naltrexone, a mu-opioid antagonist, were conducted as a more direct method of assessing the role of mu-opioids in ritual social bonding. In both studies, there was a significant interaction effect of pill type (placebo compared to Naltrexone) and time (before compared to after the ritual). This demonstrated that mu-opioids play a necessary role in the way rituals lead to social bonding.

As part of this thesis, I also addressed a gap in the literature highlighted in past research: the lack of a reliable measure of quality/strength of a social bond. I addressed this gap by producing a novel, reliable and valid measure of social bonding that measures the quality of a bond. The findings from this thesis, alongside the contribution to the social bonding methodological toolkit, provide a significant contribution to the psychology of religion, and the psychobiology of social bonding fields.

Contents

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Preface

I studied psychology and neuroscience at both undergraduate and master's level. After this, I worked briefly in the private sector, both as a self-employed business consultant and as a data analyst for a then-start-up company, now international firm, in Central London. Over that time, I also taught myself how to play guitar, wrote music, and created bands that had moderate success. However, what I always wondered about was "how is it that listening to and playing music can make me *feel*". Consequently, during my master's degree, my focus was on the neuroscience behind music's effect on emotion. There was so much that I learnt in this time, but I also realised that there was so much that was still yet to be learnt. One of the most important aspects of the modern music experience is attending/performing concerts. Seeing a band you love play live, or playing the music you love in a live environment provides a feeling of bonding with others in attendance so strong that it was impossible for me not to be curious and ask the question "how?". This curiosity led me to read Robin Dunbar's work on social bonding and music making, some of which he published alongside my MSc dissertation supervisor, Dr Lauren Stewart. Separately, but relatedly, I grew up in a family from a Jewish background in North London. I was brought up going to Hebrew classes on Sundays and was exposed to religious rituals of various types – Christian and Muslim via the cultural osmosis that takes place in London, and Jewish from my own family. One thing I had noticed during these rituals was that a strong sense of community clearly forms during those who take part in these rituals.

After completing my master's degree, while working in Central London, I realised that I still had no complete answer to the question "how do music, and rituals, cause social bonds form?" I searched for more recent work by Robin Dunbar to see if new work had been published and, instead, found that there was a PhD programme on offer with the aim of understanding how social bonding might form during religious rituals, with Robin as a supervisor. I immediately applied for the position with a proposal of a series of studies, which I felt could help answer the questions I had. I was thrilled to be taken on by Coventry University, under the guidance of Miguel Farias, Valerie van Mulukom and Robin Dunbar. After incorporating ideas provided by the panel of esteemed academics that were also working on the Religion and Social Brain project, funded by Templeton Religion Trust, I managed to include a multitude of methodologies and theoretical perspectives that provide the backbone of this thesis. I sincerely hope that the work I have produced within this thesis is of interest not just to psychologists of religion, but also to psychobiologists, those interested in the science of emotion, and those with an interest in rituals outside of a religious context.

Chapter 1. Introduction

1.1. Background

Religious ritual is considered to be one of the few human behaviours that is ubiquitous across all known cultures (Brown, 2000). In fact, "the absolute ubiquity of religion, however defined, supports the attribution of such profound significance to it. No society known to anthropology or history is devoid of what reasonable observers would agree is religion." (Rappaport, 1999, p. 1). For a behaviour to be ubiquitous across all human culture it likely confers some kind of evolutionary advantage (Dunbar, 2017b). Durkheim (1912), in his sociological description of religion, suggested that religious ritual provides something to those in attendance that is more than simply the underlying belief system: "…the practices of the cult, whatever they may be, are something more than movements without importance and gestures without efficacy. By the mere fact that… they at the same time really strengthen the bonds attaching the individual to the society of which he is a member." (p. 226). The name Durkheim gave for the strengthening of bonds effect that religious ritual produced was 'collective effervescence' (Durkheim, 1912) [1]. In short, Durkheim believed that the function of religious ritual was to help create and/or strengthen bonds between those within a group. While initially proposed by Durkheim over a century ago, this idea is still very prominent (e.g., Dunbar, 2017b; Sosis, 2000, 2005; Sosis & Ruffle, 2004).

Why is social bonding important? The ability to live and work in groups is a fundamental part of being human. In fact, "group living is thought to be one of the most significant evolutionary mechanisms by which human beings have survived and thrived" (Taylor, Dickerson, & Klein, 2002,

[1] It is worth noting that Durkheim's (1912) description of "collective effervescence" encompassed more than just the strengthening of social bonds. According to Durkheim, it included things such as causing ritual participants to enter into a trance-like state, having them experience various positive emotions, as well as various other things. For the purposes of using the term here, I am focusing on the feeling of bondedness that "collective effervescence" has most often been used to mean e.g., as "a feeling of belonging and assimilation" (e.g., Stein et al., 2021, p. 116) or as "forging communal bonds" (Lang, 2019, p. 235). For this reason, I will mostly use the term "social bonding" throughout the thesis. Unless otherwise specified, for the remainder of the thesis, where the term "collective effervescence" appears, it is only the social bonding aspect that is being referred to.

p. 556). Our ability to operate in groups is the basis of calling humans ‘social animals’ (Aronson & Aronson, 2018), and the extent to which humans, in particular, participate in group behaviour has caused some to describe us as ultra-social animals (Tomasello, 2014). Being a social animal is thought to be evolutionarily advantageous: examples of tasks where group behaviour is evolutionarily beneficial include improved capacity for child rearing, food collection, and lowered predation risk. However, group living comes with issues as well as benefits (Dunbar, 2012): group living often requires limitations be put on one’s behaviours for the sake of others. For example, one cannot eat more than their fair share of the food collected by others, as this will mean others are less able to survive. To actively engage in behaviours that helps others at the expense of oneself is known as engaging in “prosocial behaviours”. Such prosocial behaviours have been the subject of many studies for decades (e.g. Bar-Tal, 1976; Batson & Powell, 2003; Thielmann et al., 2020). A common finding is that the willingness to engage in prosocial behaviours stems from the ability to create a bond with others in the group (e.g., Taylor & Davis, 2018).

Moreover, separate from the evolutionary benefits of group living, there is a wealth of evidence demonstrating the positive health outcomes related to human social bonding (For reviews and meta-analyses, see Holt-Lunstad et al., 2015; Holt-Lunstad et al., 2010; House et al., 1988; Sarason & Sarason, 2013). Despite these clear advantages of social bonding, a major issue still exists: each bond formed comes with a time, energy, and cognitive cost (Machin & Dunbar, 2011). Thus, there will always be an equilibrium between the number of quality bonds one can form and the overall beneficial effects of bonding. The existence of this equilibrium means that, over time, activities that enable bonding to occur in a more effective and efficient manner would become more likely to be passed on. Given Durkheim’s (1912) observations that religious ritual leads to social bonding, it is unsurprising that there are those who believe that religious ritual may have evolved as a mechanism to help foster these group bonds (Dunbar, 2017b).

However, when it comes to assessing this idea, things get more difficult. As many have noted (e.g., Fischer et al., 2014), is difficult to operationalise a term as opaque as “collective effervescence”, in its original sense. Consequently, psychologists, and others who study human social behaviour, have since come to use the more specific term “social bonding” for the feeling of connection to others (Gangestad & Grebe, 2017). A social bond has been defined as a close interpersonal relationship, in psychobiological literature as a *feeling* of closeness to someone else (Gangestad & Grebe, 2017), or, in evolutionary psychology, as “the formation, strengthening and maintenance of affiliative connections (‘bonds’) with certain conspecifics” (Savage et al., 2020, p. 2). In other literature, such as sports psychology, social bonding has been defined as the *sense* of belongingness to a group of people, with an emphasis, or requirement of, a specific location (Raymond et al., 2010; Scannell & Gifford, 2010). In all of these definitions, social bonding is considered a *state* (cf., trait; Gangestad & Grebe, 2017). For this thesis, I will be synthesising these definitions, among others that are elaborated on in chapter 2.1.4, into the following working definition for social bonding: *social bonding is an emotion that enables the formation, strengthening, and maintenance of affiliative connections to others*. Under this definition, social bonding encompasses the feelings that occur between mating partners, family members (e.g., parent-child, sibling-sibling), *and* unrelated adults (Silk et al., 2010; Snowdon, 2015; Ziegler & Crockford, 2017).

To bring this back to the ubiquity of religious ritual, while there is a growing body of empirical evidence that religious rituals appear to promote prosocial behaviour (Friese et al., 2014; Greenway, 2020; Ruffle & Sosis, 2007; Sosis & Ruffle, 2003; Sosis & Ruffle, 2004; Xygalatas et al., 2013), there is less work that focuses on the feeling of social bonding it may cause. That is to say, while there are sociological and anthropological accounts of feelings of connection growing after religious ritual, especially high-intensity ritual (Whitehouse, 2004b; Whitehouse & Lanman, 2014; Xygalatas et al., 2013), there is not much *empirical* evidence of a strengthening of the participants’ feelings of bondedness with others. Consequently, I feel this leads to the question: ‘*Does religious ritual reliably lead to an increase in the feeling of bonding with others?*’ Given the ubiquity of religious ritual across human cultures, the fact that it is deemed “indispensable to the species” (Rappaport, 1999, p. 2), “without equivalents or even…satisfactory alternatives” (p. 31), and the importance of social bonding to human life (highlighted above), I believe that answering this question should be of interest to all those who study human social bonding, not just those with an interest in the psychology of religion.

As will be elaborated when defining religion in section 2.1.1. of Chapter 2, Durkheim's (1912) description and definition of what makes a ritual religious would likely include many activities and behaviours that the average person may not describe as – or consider to be – 'religious'. This is true even if the average person might describe the behaviours as ritualistic. Examples of what Durkheim might deem a 'religious ritual' that a layperson may not would include things such as a weekly dinner party, or a sports team's pre-game morale-boosting chant. On the face of it, neither a weekly dinner party (a regular get-together of friends at the same time and place for specific set behaviours – cooking and eating), nor a pre-game chant (where a group of fans regularly sing in time to achieve a communal goal of communicating with their chosen team before a game[2]) are explicitly religious[3]. If these activities – that are typically regarded as non-religious – also cause collective effervescence (as Durkheimians would argue they may do), this leads to an important question: is there something special about *religious* ritual, in particular, that leads to social bonding? In other words, is the religious component significant in fostering social bonding?

To answer these two questions scientifically, one needs to understand what mechanisms underly the social bonding experience during religious ritual. From a psychological standpoint, understanding the cognitive-behavioural mechanisms (beliefs, emotions, and actions) underlying the phenomena of religion and religious rituals is of most importance. From a biological perspective, understanding the neurochemical mechanisms underlying these phenomena is of most importance. However, to only focus on one of these perspectives would not provide a full answer to these two questions. In my mind, the best way to approach answering these two questions is to consider both perspectives, together. This is described as a psychobiological approach. So, from a psychobiological

[2] A real-world example would be the "Mull of Kintyre", sung by fans of Nottingham Forest Football Club in the UK before every home game.

[3] These apparently non-religious rituals were chosen because they do have religious counterparts: While a weekly dinner party among friends isn't a religious ritual, Friday Night Dinner within the Jewish faith would be considered a religious ritual. Similarly, singing a pre-game song for your local sports team every week may not be considered to be religious, but a weekly prayer group who sing a hymn before their prayer meeting would be considered religious.

perspective, understanding both cognitive-behavioural *and* neurochemical mechanisms is necessary to answer the two major questions raised so far: (1) “Does religious ritual reliably lead to an increase in social bonding?” and, if it does lead to an increase in social bonding, (2) “Does the inclusion of a religious component, in particular, lead to greater levels of social bonding?”.

It has been shown in past research, conducted both on how social bonds form (Machin & Dunbar, 2011; Pearce et al., 2017) and the ways in which we foster stronger social bonds (Dunbar, 2017a; Tarr et al., 2014), that a variety of behaviours (e.g., teamwork, synchronised movement or music making) can lead to social bonding. As behaviours that could foster bonds most efficiently are those more likely to be passed on, it is thought that this is one reason these behaviours became human universals (Savage et al., 2020). Religious rituals are included in this but, in the context of psychobiology, the idea that religious ritual leads to social bonding is under-explored.

Prior to the psychobiological approach, most research on the causes of social bonding was broken up into two, discrete levels of interest: (1), the neurochemical mechanisms (e.g., oxytocin, dopamine, or opioids) by which social bonding occurs, and (2), the cognitive-affective processes and behaviours that lead to social bonding (e.g., shared goals, positive affect, or synchronised behaviour), that is, the psychological mechanisms. There is some work that seeks to explicitly explore both mechanistic levels simultaneously, i.e., those that take a psychobiological approach (Launay et al., 2016; Manninen et al., 2017; Nummenmaa et al., 2016; Pearce et al., 2016). However this research has largely focused on behaviours that can be easily studied in controlled conditions, such as exercise (Cohen et al., 2010), dance (Tarr et al., 2015) and music making (Weinstein et al., 2016). Religious ritual, a behaviour that is less easily studied within controlled settings, has received less research focus (albeit with notable exceptions, e.g., Fischer & Kruekaew, 2020; Fischer et al., 2014; Singh et al., 2020).

While not specific to religious ritual, one of the major psychobiological models explaining social bonding is the brain-opioid theory of social attachment (BOTSA; Machin & Dunbar, 2011). This model states that the body’s opioid system plays a key role in social bonding. BOTSA focuses on the mu(μ)-opioid receptors, suggesting it is μ-opioid receptor activation that leads to social bonding.

To my knowledge, at the time of writing this thesis, no other research has tested BOTSA in the context of religious ritual. In his critique of the current state of the scientific study of religion, Dunbar (2017b) noted that the psychobiology of religious ritual has three major questions that are still to be explored regarding social bonding: (1) Does religious ritual attendance reliably lead to feelings of social bonding? (2) If so, what are the psychobiological aspects of religious ritual that predict social bonding? And (3) Does the religious or spiritual nature of the rituals play a significant role in the experience of social bonding? These three questions highlight major gaps in the current psychobiology of religious ritual literature, and echo the questions already raised so far in this chapter. This thesis aims to tackle each of these questions to help address these gaps in knowledge.

Before outlining the complete aims of this thesis, I should first note that there are some other gaps that exist within the social bonding literature that are pertinent to the psychobiological study of social bonding in the context of religious ritual, which this thesis will also seek to address. The first of these pertinent gaps was noted by Holt-Lunstad and colleagues (2010) in their meta-analysis of the health impacts of social bonding. Holt-Lunstad et al. (2010) found that the effect of social bonding could not be fully determined in their meta-analysis due to the lack of a reliable, comprehensive measure of social bonding that also assesses the strength/quality of the bond (as opposed to simply a binary measure of the presence of any social connection). Another important point is that there is no agreed-upon paradigm that can be used to study social bonding in the context of religious ritual within a controlled setting. As such, this thesis will have the secondary aim to address these two gaps within the social bonding literature.

1.2. Aims and Objectives

The main goal of this is to address the current gaps in the scientific study of religion outlined by Dunbar (2017b), with a secondary aim of addressing gaps from the social bonding literature noted by Holt-Lunstand et al. (2010). More explicitly, the primary aims of this thesis are three-fold: (1) determine if a feeling of social bonding can be reliably found to be caused by religious ritual; (2) To assess BOTSA in the context of religious ritual; i.e., whether the body's μ-opioid system plays a key role in social bonding that occurs during religious ritual; and (3) determine whether the religious or spiritual components of ritual play a significant role in the feeling of social bonding.

The secondary aims of the thesis are: (a) To create a reliable, comprehensive measure of social bonding that measures the strength/quality of the feeling of social bonding, which can be used across settings, and (b) the creation of a novel paradigm in which one can study religious ritual's role on social bonding in controlled conditions, while still providing some level of naturalistic validity. Together, these primary and secondary aims seek to develop and build upon the empirical investigations of biopsychosocial mechanisms underlying social bonding within the context of religious rituals.

1.3. Structure of the Thesis

Chapter 2 is focused on providing a wider theoretical background to contextualise the research that seeks to address the five aims (the three primary aims and the two secondary aims) of the thesis. In Chapter 2, I provide definitions for religion, ritual (and, thus, religious ritual), as well as social bonding. I then provide a state of the art about the current proposed neurochemical and psychological causes of social bonding, generally, and relate this to religious ritual more specifically. Chapter 2 finishes with a brief discussion of the need for a comprehensive, and concise method of measuring social bonding that can be applied in religious ritual settings and explains how this measure – used throughout the thesis – was constructed.

Chapters 3 through 6 are focused on the experimental phase of the thesis and is made up of modified versions of published and submitted peer reviewed research. All chapters are modified for the thesis to ensure they make sense within the context of the thesis as a whole. I am the lead author on all articles that these chapters are based on. As these research projects were collaborative work, appropriate credit will be attributed to the co-authors. To do so, at the start of each of these chapters a table providing a clear picture of the roles each co-author played in the research will be provided. These tables are formatted following the CRediT taxonomic system (see https://casrai.org/credit/ for more information on the contributor roles)

Chapter 3 describes a largescale, multi-national field study in which the role of pain threshold – a proxy of endogenous opioids – and positive affect were able to predict social bonding occurring at religious rituals. This chapter is adapted from the submitted academic article "Religious Rituals Increase Social Bonding and Pain Threshold". The other co-authors were Dr Valerie van Mulukom, Dr Miguel Farias, Revd. Jennifer Brown, Romara Delmonte, Dr Everton Maraldi, Dr Leon Turner, Dr Fraser Watts, Dr Joseph Watts, and Dr Robin Dunbar.

Chapter 4 describes a smaller field study that was conducted in Sunday Assemblies across the United Kingdom (UK). Outcome measures were compared with matched churches, taken from the UK group from study one. The aim of this study was to examine the role of the religious component of ritual on social bonding outcomes. It is adapted from the published article "United on Sunday: The effects of secular rituals on social bonding and affect" (Charles, van Mulukom, et al., 2021). The other co-authors were Dr Valerie van Mulukom, Revd. Jennifer Brown, Dr Fraser Watts, Dr Robin Dunbar, and Dr Miguel Farias.

Chapter 5 outlines a five-week longitudinal study that was conducted in controlled conditions to further examine the specific role of a religious component within ritual on social bonding outcomes. The aim of this study was two-fold. (1) To examine the role of a religious component of ritual under controlled conditions, to support the findings from Chapter 4, and (2) to produce a research paradigm where one can conduct research on ritual social bonding in controlled settings. The second aim is to allow for other researchers to have a paradigm for studying the effects of ritual over time in controlled settings. This is adapted from the submitted article "Bending and Bonding: A randomized controlled trial on the socio-psychobiological effects of spiritual versus secular yoga practice". The co-authors were Dr Miguel Farias, Dr Valerie van Mulukom, Ambikananda Saraswati, Dr Fraser Watts, and Dr Robin Dunbar.

Chapter 6 describes two placebo-controlled, double-blind studies using the μ-opioid antagonist Naltrexone. The first study is a follow-up study to the five-week longitudinal study presented in chapter 5, where Naltrexone (a μ-opioid antagonist) was given to half of the participants and placebo was given to the other half, in a double-blind manner. The second study outlines another placebo-controlled study with Naltrexone, conducted during an Umbanda religious ritual in Brazil, with methods otherwise similar to those described in Chapter 3. This chapter is adapted from the published article "Blocking μ-opioid receptors inhibits social bonding in rituals" (Charles, Farias, van Mulukom, et al., 2020). Co-authors on the original article were Dr Miguel Farias, Dr Valerie van Mulukom, Ambikananda Saraswati, Dr Simon Dean, Dr Fraser Watts, and Dr Robin Dunbar.

The third major section of the thesis, Chapter 7, draws together results from each of the previous chapters and discusses how these contribute to the current literature, assesses the more overarching limitations of the studies described in previous chapters that weren't addressed within the chapters, and presents recommendations for future research. Chapter 7 concludes with a discussion about the wider implications of the findings of the thesis outside of the social bonding literature.

2. Chapter 2. Ritual, Religion and Social Bonding

2.1. Definitions

The three primary aims of this thesis, based on unanswered questions in the scientific study of religion (Dunbar, 2017b), place religious ritual as the main focus of the thesis. Thus, 'religious ritual' needs to be defined so that it can be appropriately studied. I will do this by breaking it down into its component parts: first, defining how the term "religion" is to be used within the thesis, and then how ritual is to be defined. Then, once both terms have been established independently, I will explain how I will be determining what makes a ritual religious in nature for use within this thesis.

Rappaport (1999) suggests that definitions of religion and ritual should have analytic utility. As such, when defining the terms being used, this section aims to determine a *useful* definition of "religion", "ritual" and "religious ritual". What I understand when using the term "analytic utility" is that: (1) the definition is specific to a set of traits such that it does not encompass all/most of human behaviour (i.e., it is actually a useful term to distinguish from other things), and (2) the definition can be broken down into constituent parts, to determine whether something might be more (or less) religious/ritualistic in nature than something else (i.e., it can be analysed in some way).

2.1.1. Definition of religion

The purpose of this section is to provide a working definition of "religion" for use within the thesis. This is by no means an easy a feat. In fact, some have described attempting to define religion and/or religious as a "waste of time" as there is "no 'correct' solution" (Gombrich, 1996, pp. 1-2), while others deem it impossible to adequately define religion such that it is applicable in all contexts (Fitzgerald, 1996, 1997). Similarly, it has been suggested that, from a constructivist perspective, "definitions cannot, by their very nature, be either 'true' or 'false', but only more useful or less so" (Berger, 1967/1981, p. 175). Consequently, it has been suggested to simply adopt a definition that serves the purposes of the context (Gombrich, 1996; Nemec, 2020; Schilbrack, 2013). For me, such a definition should meet the requirement of having the face-level validity of matching the colloquial use of the term "religion" both for what it includes *and* for what it excludes (Martin, 2016). Before being able to provide a useful working definition that is appropriate for the context of this thesis, much groundwork is needed to provide a background understanding of how religion has been defined within the literature up to now.

2.1.1.1. Historic definitions of religion

Historically, definitions of religion have come in two main forms (1) functional definitions – definitions that focus on what religion *does* or the *effect(s)* that it has, and (2) structural definitions – definitions that focus on what religion *is*. Definitions have been provided both explicitly (e.g., Berger, 1967/1981) as well as implicitly (e.g., Boyer & Bergstrom, 2008; Weber et al., 1963). For example, Boyer & Bergstrom (2008) implicitly define religion when they discuss – and provide a list of – a general "collection of behaviors and mental representations that are found in many different human groups" and suggest that "the term 'religion' is to an evolutionary anthropologist what 'tree' is to an evolutionary botanist" (p. 112). This is an implicit definition because they discuss behaviours that might be described as religious (i.e., alluding to a substantive definition) without explicitly providing a definition for religion. For the purposes of providing a working definition of religion, for the remainder of this section only explicit definitions will be discussed for both brevity and because of the clarity these definitions provide.

For functional definitions, the focus is on what religion does, or the effect(s) that it has on those who practice it. Yinger (1957) provides one clear example of a functional definition of religion when he says that religion is "defined as a system of beliefs and practices by means of which a group of people struggles with…ultimate problems of human life" (p. 9) Later in his work, Yinger (1957) focuses on death as the main ultimate human problem. Here, Yinger suggests that religion is any belief system that tackles with the ultimate problems of human life (i.e., death) is religious. So, the focus is on what religion does (tackling ultimate human problems), and not what religion is (i.e., its specific constituent parts). Similar definitions have since been provided by the likes of O'Dea (1966) and Geertz (1966). O'Dea (1966) defined religion as any belief system that *deals with* the concepts of contingency, powerlessness and scarcity and, consequently, with frustration and depression (emphasis mine). The "dealing with" something shows that religion is defined by the effect that it has: it deals with concepts for those who believe. Similar Geertz (1966) defined religion as “a system of symbols which *acts to establish* powerful, pervasive, and long-lasting moods and motivations… *by formulating conceptions* of a general order of existence” (p. 4, emphasis mine). Once again, the definition describes what religion does (it ‘acts to establish’ and ‘formulates conceptions’).

One of the major issues with these definitions is that they often do not clearly distinguish between what is and what is not religious. For example, while Yinger (1957) does state that not every meaning system is religion, the way in which he attempts to distinguish religious belief systems from non-religious belief systems is somewhat opaque: He describes a need for a certain *effort* (e.g., p. 8), without clearly outlining what this effort actually consists of. So, in a Yingerian worldview, that which is called religion is religion, and that which is not called religion is not religion (Dobbelaere, 2011). However, this is circular reasoning that is both tautological and has no analytic utility.

In my opinion, any descriptions and definitions based purely on what religion *does* are not helpful in allowing us understand what is (and is not) religion. If religion is defined only by its function then if something else can serve the same function, even if not as well, is it also religion? Some might be initially inclined to answer ‘yes’ to this question. However, I would argue that in any other context those who answered ‘yes’ would see that this would not hold water. For example, if one needed a screwdriver in order to turn a screw but they did not have a screwdriver to hand, one could instead use a knife to be able to turn the screw (or a coin, for example, depending on the size of the screw). If the definition of a screwdriver is ‘anything that allows you to turn a screw’ (i.e., what it *does*), then knives (or coins, pliers, tweezers, etc.) could all be considered screwdrivers. This would make the definition lose any kind of utility. If the *effect* of a screwdriver is ‘to make the turning of a screw easier’, then you have even more issues in the definition: easier than what? Is there some base level of difficulty for turning a screw? Easier than turning by hand? A knife (or coin) can make turning a screw easier than by hand, too. If, instead, the ‘easier’ part is saying ‘easier than using a different tool’, you now have to define what makes something *different* to a screwdriver. This means you have come back to square one. In fact, you have even more work cut out for you with such a definition: if you have two different screwdrivers, but the first (tool 1) makes turning a screw even easier than the second (tool 2), is the worse of the two (tool 2) still a screwdriver by this definition?. A knife (or coin) makes it easier to turn a screw than a chainsaw, too. In this instance, the knife (or coin) could serve the same *function* as a screwdriver, but this use would not make knives (or coins) also screwdrivers, else the term 'screwdriver' serves no utility. As such, it would not conform to the Rappaportian idea of a useful definition. I believe that the same issues hold for purely functional definitions of religion. It is for this reason that I feel purely functionalist definitions of religion leave something to be desired.

The idea that functionalist definitions of religion currently in use are too broad is far from unique to me: Riesebrodt (2010) suggested that pure functionalist definitions muddy the notion of religion "to the point of futility" where one would consider "barbecues with guitar music, soccer games, shopping in supermarkets, or art exhibitions to be religious phenomena." (Riesebrodt, 2010, p. 73). Schilbrack (2013) has suggested that "the category of religion has become sprawling, overly inclusive, and unwieldly" and that this is because some definitions "are so capacious that the term 'religion' loses its analytic usefulness" (p. 291). As highlighted at the start this chapter, if a definition lacks analytic utility, then it will not be used as a working definition for this thesis. For this reason, the definition I will provide will not be purely functionalist in nature[4]. This leads us to substantive definitions, i.e., those definitions that describe what religion *is*.

Substantive definitions of religion have a long history of use within sociology and anthropology. Schilbrack (2013) provides a comprehensive history of the development of substantive definitions of religion (he calls these 'ontological' definitions). In this history he notes the Christian-colonial roots of substantive definitions[5]. One example of a substantive definition, that broke away from the colonialist approaches that came before it, was provided by Edward Tylor (1924) in his writing about Animism. In his definition, Tylor suggests that religion is simply the *belief in spiritual*

[4] This is not to say that religion serves *no* function. Simply that the function of religion is not an integral part of its definition.
[5] While a very worthy and interesting read, the colonialist origins and other historical aspects of defining religion are beyond the scope of this work. In short, definitions of religion started as explicitly Christian, and these evolved over time to allow for the idea of religion as a 'genus' or 'taxon' to be studied and compared cross-culturally (Schilbrack, 2013, p. 309)

beings. Many substantive definitions have since come from the Tylorian school of thought: these describe specific attributes that religion has. For example, Dobbelaere (2011) defines religion as ‘a system of beliefs and rituals relative to the supernatural” (Dobbelaere, 2011, p. 194). In this definition, the Tylorian ‘spiritual beings’ has been extended to all of the supernatural (i.e., no need for a *being*).

Of course, in a modern context, these Tylorian definitions have the opposite problem to the overly-inclusive functionalist definitions: it would exclude many things that laypeople might describe as religion/religious, such as Buddhism (which has no belief in any spiritual beings, nor the supernatural). That the average person would consider Buddhism a religion, but that the Tylorian definitions focusing on the supernatural would not suggests that such definitions may not be appropriate in a modern context. Others have since tried to extend the Tylorian concept into metaphysical “powers” or “forces” that are beyond the scope of science, while others break away from Tylor’s simplicity altogether to suggest that religion is the belief in an “order of reality beyond or behind the apparent, given order.” (Martin, 1993, p. 385). While the latter of these does include Buddhism, it would also define as ‘religious’ further worldviews not deemed religious by the average person. For example 9/11 “trutherism”[6], or the belief that law-enforcement are monitoring you and inserting thoughts into your head are both beliefs in an order of reality beyond or behind the apparent, given order (Martin, 1993). As such, a purely substantive approach to defining religion also appears to fail at passing the ‘would the average person consider X a religion?’ test (Martin, 2016).

2.1.1.2. Defining religion with analytic utility

At this point, it should now be clear why it is that many have said that defining religion might be impossible (Fitzgerald, 1996, 1997). Whether Buddhism does, or does not, fall within definitions of religion has become somewhat of a litmus test to the quality of a definition of religion in recent years (Turner, 2011). The question is, can one define religion in such a way that it does include things that the average person would deem religious (e.g., Buddhism), while being specific enough that it

[6] the belief that the terrorist attacks that took place in the US in September 2001 was an inside job, covered up by the US government

also excludes things that are generally considered to be not religious, i.e., so that it still retains analytic utility?

In the previous subsection, I mentioned that historic definitions of religion fell within two types: functional, and substantive. While generally true, this is not always the case. There are scholars that have provided definitions that are not *purely* functional, nor *purely* substantive. For example, Durkheim's (1912) definition of religion involves a combination of substantive and functional factors. For Durkheim, the substantive aspects of religion has two clear components: (1) a religion contains a separation between the sacred and the profane, and (2) religion has a 'church' (i.e., a communally agreed upon source of rules, morality and a space in which one can practice). However, Durkheim would also argue that the function of a religion is to create a sense of social bonding. According to this definition, activities or belief systems that do not achieve the sense of bonding or a creation of community would – definitionally – not be religious. By Durkheim's definition, secularism (often deemed to be the antithesis of a religion by the average person) would itself be a religion. In fact, from a Durkheimian standpoint, there are not many activities or beliefs one could perform/hold that would not be deemed religious in some circumstances. Despite the Durkheimian idea of "collective effervescence" having been a major impetus behind starting this thesis, I will not be using a Durkheimian approach to defining religion because of its over-inclusivity leading to a lack of utility.

More recently, Schilbrack (2013) suggests another definition that, in his mind, is neither purely substantive, nor purely functional (he describes it as 'mixed' or 'dithetic'[7]). In his writing, Schilbrack discusses religion in relation to 'realities'. Specifically, realities that take three forms: the empirical, the non-empirical, and the super-empirical. In his writing, empirical realities include everything that can be sensed or otherwise perceived via current or future technological help (p. 312), i.e., mountain ranges, black holes, and protons would all be deemed empirical realities. This is because mountains can be perceived with the naked eye, while black holes and protons can be detected via technological measuring equipment. Non-empirical realities include things such as

[7] Depending on one's interpretation of this definition, it could be viewed as a substantive definition. While I am inclined to agree that it is a substantive definition, for the sake of presenting his definition, I will defer to how Schilbrack views his own definition.

morals and aesthetic judgements (e.g., ‘pretty’ or ‘ugly’): those things which are not perceived, but that are subjective. Non-empirical realities are held by religious and non-religious individuals alike.

Finally, a super-empirical reality is the idea that at least one non-empirical reality exists independent of empirical realities. One example would be that an action is ‘good’ irrespective of any empirical reality. Another, more specific and less loaded, example would be the belief that a certain sea turtle is ‘ugly’ – not because of the way in which its facial features relate to symmetry or some other relation to the empirical (i.e., a measurable thing), but because it just *is* ugly (i.e., the non-empirical reality is ‘true’ without reference to any empirical reality). A super-empirical reality, in this sense, is to answer ‘no’ to the question ‘is this non-empirical reality reliant on some empirical reality?’ According to Schilbrack, what makes a religion is “forms of life predicated upon the reality of the super-empirical” (Schilbrack, 2013, p. 313).

Schilbrack (2013, p. 317) provides an example of how this definition does not overfit nor underfit what might be considered religion by the average person. Within this framework, a ‘nation’ (an imagined community that cannot be measured) is considered to be non-empirical. Simply having some kind of respect, or reverence for the nation (a type of nationalism) would not be deemed religion, so long as this respect or reverence stemmed from a belief that the nation is made up of actual humans and their works (where, under a Durkheimian view, this would be considered religious). However, were someone to have respect or reverence for a nation because it is somehow the embodiment of super-empirical realities (e.g., the will of God), then it would be considered religion and would, in this case, be described as “religious nationalism”. So, Buddhism falls within the definition of religion provided here, but 9/11 trutherism would not. Therefore, Schilbrack’s definition of religion passes the face-validity test outlined at the beginning of this section (in that it does not overfit, nor underfit what the average person might consider to be religious), and also has analytic utility.

To conclude this section on defining religion, I will say that Schilbrack provides a compelling case for the use of his definition when attempting to find a pragmatic definition of religion for the purpose of academic work. As such the definition of 'religion' that will be used throughout the thesis will conform to his:

Acts in accordance with the belief in at least one super-empirical reality.

The phrasing I have used makes this definition not only useful, in that it can be used to distinguish between what *is* and what *is not* religion, but also gives it analytic value. This is because different beliefs can be assessed as 'more' or 'less' religious based on the number of super-empirical realities that are believed. So, Theravada Buddhists might be deemed religious (due to having the belief that selflessness, impermanence, and emptiness are the three marks of existence: a non-empirical reality that is not conditional on an empirical reality). Theravada Buddhism, while undeniably a religion by this metric, might be considered 'less' of a religion than the Church of the Latter Day Saints of Jesus Christ (Mormonism), as Mormonism requires the adoption of a greater number of super-empirical realities (the belief in an all-powerful God with a son named Jesus, that this God has angels that do their bidding, that one such angel spoke to Joseph Smith, that Joseph Smith found and translated 'Seer Stones' via inspiration from God, and that there are still living 'Revelators' who can reveal previously unrevealed spiritual truths to the Mormon community, etc.). Similarly, things that are deemed to be 'spiritual' ('powers', 'forces' etc.) can be viewed in this framework as religious, because these demonstrate a belief that there is some non-empirical reality that does not rely on an empirical reality. Under this definition, 'spiritual but not religious' people (Ammerman, 2013) are simply 'religious' by another label.

Importantly, I want to make it clear that to define religion in relation to super-empirical realities is purely so that religion can be a subject of study. This is not to determine religion's 'naturalness' (cf. Boyer & Bergstrom, 2008), nor to explicitly describe specific expressions of religion, such as 'wild-type' religions (Boyer, 2020, 2021). Actually, the very fact that the definition is general – so it does not only apply to specific religious expressions – and that it makes no reference to the evolutionary history of religion, in my mind, makes it a good definition. The 'naturalness' and specific expressions are aspects that can only be assessed once the boundaries of the subject of study have first been established by defining it.

2.1.2. *Definition of ritual*

So, now that a definition of 'religion' has been established, what of 'ritual'? As with the definition of religion, I will be taking the same position as Rappaport (1999) in that what I believe are more useful definitions of ritual are those that have analytic utility. As in the previous section, to come to a definition of ritual I will first cover some background about past definitions of ritual, and will then discuss what relevance, in my opinion, these previous definitions have to the current thesis. I will then conclude this section by providing the definition of ritual that will be used for the remainder of the thesis. The purpose of providing a definition that will be used for the thesis is twofold: (1) To ensure that there is little ambiguity in what *is* meant when using the term 'ritual' throughout the remainder of the thesis, as it is a term that will feature regularly; and (2) to ensure it is clear what is *not* meant when the term 'ritual' is used. This second point is important because I feel it is vital that the anyone who reads this thesis does not equate the behaviours being examined (nor the conclusions drawn about ritual) with other, non-ritual behaviours. To conflate ritual with other behaviours would mean that the term 'ritual' loses any utility. So, for this reason, the definition that will be provided will address both what ritual is *and* what ritual *is not*.

2.1.2.1. Historic definitions of ritual

To begin this section, it must first be noted that, as with "religion", the discussion around the definition of ritual has a long history that include many mutually exclusive ideas about what ritual is (e.g., Bell, 1997; Boyer & Liénard, 2006; Humphrey & Laidlaw, 1994). Some have used functional definitions: attempting to define ritual based on what ritual *does* and the *effects* that it has. For example, the idea that ritual might be used as a form of communication (Alcorta & Sosis, 2005; Asad, 2017; Wagner, 1984), or that it may have some kind of social function (e.g., Gluckman, 1962). For example, Asad (2017) described ritual as "as a type of routine behavior *that symbolizes or expresses something*" (p. 1, emphasis mine), while Sosis (2005) suggests that ritual serves as a method of communicating a willingness to incur a cost to oneself to the benefit of the wider group (aka. costly signalling). Similarly, Atran & Henrich (2010) suggest that rituals, especially high-intensity rituals, strengthen social emotions and promote prosociality, and that this is what makes what we call rituals a ritual. This is in line with the Durkheimian view of ritual (which almost entirely overlaps with the Durkheimian view of religion), defining ritual by its ability to cause social bonding.

Additionally, Lang and colleagues (Lang et al., 2015) build on the work of Malinowski (Malinowski, 1948/2014), Keinan (1994), and Sosis & Handwerker (2011) to suggest that ritual serves as a way to reduce anxiety, or as a result of anxiety in those who take part. More recently, an example of a functional definition comes from Lan (2018). Lan (2018) defines ritual as a set of behaviours that causes the change of relation between two categories in the mind of the performer(s). Specifically, they define ritual as "acts aiming to change the relationship between the ME1 and ME2." (p. 11) Where ME1 refers to one state of mental existence and ME2 refers to another state of mental existence. In each of these descriptions and definitions of ritual, we find a focus on the effects of ritual, or what it does. As clearly outlined in section 2.1.1.1., I believe that defining anything (including ritual) in a purely functional way is not conducive to a useful definition. I will not labour the point, and so I will simply move to definitions of ritual that are not purely functional in nature.

2.1.2.2. Rappaport and ritual

As noted earlier in this thesis, Rappaport (1999) wrote what he described as a treatise on ritual. In it he provides a long and robust discussion around ritual and comes to a short, but specific, definition of ritual, that he suggests is *universal* to all ritual: "the ***performance*** of ***more-or-less invariant*** sequences of ***formal*** acts and utterances ***not entirely encoded by the performers***" (p. 24, emphasis mine). This might be seen as something akin to a 'substantive' definition of ritual, to borrow the terminology from definitions of religion (Rappaport uses the term 'formal' to describe his definition). This is because, as written, it describes attributes of ritual – what it *is* - with no focus on what it does, nor the effects that it has. Rappaport spends the following ~400 pages of his treatise to help contextualise this definition, to provide clarification, and to explain its constituent parts (the four italicised parts of the definition above). I will do my best to cover this context and clarification in a much swifter manner over the next few paragraphs.

First, Rappaport (1999) attempts to tackle what he means by 'not entirely encoded by the performers'. Here, he simply means that the form the ritual takes (the behaviours that make up rituals) were established by people/entities other than the ones performing them. However, rituals don't *only* contain new behaviours that were established by others, but also contain old, known behaviours. As far as Rappaport is concerned, the mix of old and new behaviours helps establish legitimacy of the new behaviours. Because of the inclusion of both old and new behaviours, the participants of the ritual understand the newer behaviours to be specific to the ritual. In short, this aspect of the definition suggests ritual requires the performance of (at least some) behaviours that were determined by someone/something else.

The second feature Rappaport clarifies is the use of the term 'formal'. Here, he means that rituals have a specific 'form' that adheres to 'decorum', i.e., some kind of agreed upon etiquette. According to Rappaport, it is the fact that rituals have a form that allows us to recognise events as rituals at all. Rappaport uses the five-tier system of formality established by Abrahams (1973)[8]. In short, each tier is considered more formal/ritualistic than the former. A short account of these tiers are as follows: (1) simple stylised words and gestures, (2) "everyday ceremoniousness" (p. 34), (3) more formal procedures where the invariant parts are subservient to the parts allowed to vary (e.g., court procedures, where the behaviours of the judge, jury, and lawyers are ritualised but subservient to the overall goal of understanding the facts about the case, and the differences of the legal arguments between each case), (4) events where the invariant aspects become operative (e.g., the crowning of a member of the royal family, where the ritual form is vital for the purpose to be achieved), and (5) where "almost all aspects of performances consisting of stylized and stereotyped words and acts are rigidly specified" (Rappaport, 1999, p. 35), such as a Christian Mass.

Thirdly Rappaport tackles the 'more-or-less invariant' part of the definition. He simply clarifies that, while rituals tend to be specific in the behaviours that are to be completed, imprecision is unavoidable. In fact, according to Rappaport, ritual must have room for logically necessary or deliberate variation (or both). The logically necessary, because no two bodies are identical: a large person and a small person will move slightly differently when performing the same ritual. Deliberate

[8] Rappaports (1999) spends 3 pages (p. 34-36) discussing the five-tier system of the form that ritual might take. I will not reproduce this full discussion here. If this short characterisation interests you, I recommend reading the full elaboration.

variation is also common, such as the option to either touch or not touch the Torah covering with one's Tzitzit/Tallit when it is taken out of a synagogue's Ark for Shabbat. Finally, Rappaport (1999) clarifies that his definition specifies 'performance'. Here, Rappaport is unambiguous: "Unless there is a performance there is no ritual" (p. 37). While not in the wording of his formal definition, Rappaport also suggests that ritual relies on 'indices' (indicators of meaning) that "are impervious to falsification and resistant to misinterpretation" (p. 56). For example, reading a *maftir* and a *haftarah*[9] at a synagogue at the age of 13 indicates that you are a male who has become Bar Mitzvah (reached the age of 13 and, in the eyes of Jewish law, become accountable for your own actions). This is impervious to falsification, because of the knowledge of ancient Hebrew, and the Torah (and how it is to be recited) required, and it is resistant to misinterpretation because of the specificity of the actions.

Rappaport's (1999) definition provides a holistic account of ritual. For many scholars of ritual, this has served as *the* definition of ritual since it was published. However, more recently, this definition has been elaborated on by Hobson and colleagues (2018), who define ritual as "(a) predefined sequences characterized by rigidity, formality, and repetition that are (b) embedded in a larger system of symbolism and meaning, but (c) contain elements that lack direct instrumental purpose." (p. 261). Part (c) of Hobson et al.'s (2018) definition specifies a lack of direct instrumental purpose, which is not present in the wording of Rappaport's (1999) definition of ritual. This is also a substantive definition, but one that takes influence from Goody (1961), who suggested that ritual has behaviours whose relationship between the means and ends are not intrinsic.

In my mind, the term 'direct' in part (c) is the operative word. By this definition, a ritual *can* contain an instrumental purpose (e.g., washing away one's sins), even if this purpose is not *directly* instrumental. To return to the courtroom analogy used earlier, the banging of the gavel in a US court system signifies to the audience when to stand or sit (i.e., the purpose is to bring the meeting to order). There is no *direct* association with banging wood on wood that should cause people to stand or sit (and would not cause standing/sitting in other settings), nor is there any direct effect on the outcome

[9] The maftir is the final section of the weekly Torah reading, while the haftarah is a passage from elsewhere in the Tanakh selected to be related to the message/ideas presented in this week's Torah reading.

of the trial in having a gavel bang and having attendees stand and sit. We know this is the case because the English and Welsh court system (established close to a millennium ago) do not have – and have never had – need for a gavel. However, the instrumental purpose of banging the gavel in the US system is to bring the meeting to order, and it does this, just via an indirect mechanism.

2.1.2.3. What is not ritual

The Hobson et al. (2018) extension to the take on ritual given by Rappaport (1999) also helps to clarify what is *not* ritual. According to these definitions, ritual is a form (or structure) that contains many elements (performance, invariances, etc.). None of these are *unique* to ritual, but it is the specific combination of them that causes the behaviour to become defined as 'ritual'. Rappaport (1999) attempted to provide comparisons to other behaviours to determine how behaviours not usually conceived of as 'ritual' compare to the definition (as with defining religion, one does not want to make it so that *all* behaviours are considered rituals, making the term useless).

"Theatre" is one comparison he gives. Theatre has many similarities to ritual. However, Rappaport distinguishes theatre from ritual in the following way: being present at a ritual makes you either a performer or part of the congregation (which is simply another role as a minor performer), so participation is always occurring. In comparison, being present at the theatre in the audience does not make you a performer. Audiences are separated from the stage performers. According to Rappaport (1999), the audience at the theatre *watch* and they *listen*, but they do not *perform*.

Rappaport (1999) ends his comparison to theatre at non-participatory audiences, but this leaves open a glaringly unanswered question: what about theatre that includes audience participation? Rappaport was an *American* anthropologist, and so he may have been unaware of the British winter tradition of the pantomime, a specific subtype of theatre during which the audience plays a participatory role. In a pantomime, the audience plays the role of helping the protagonist and hindering the antagonist by interacting with the performers: the audience shout "He's behind you!" when the antagonist appears to the back of the stage while the protagonist is at the front of the stage, thus making the audience 'performers' themselves. By a Rappaportian definition, this would make a pantomime a ritual. However, due to the nature of this type of performance, I would argue that this participation has the *direct* instrumental purpose of moving the performance to its next stage: On-stage pantomime performers will not turn around, or even may not continue with the play at all, without this interaction because they have not been given the 'cue' required to turn around. This is directly instrumental because shouting "He's behind you!" in other contexts would also lead the person you are communicating with to turn around (cf. the gavel example, where the hitting of wood against wood doesn't intrinsically cause people to stand/sit in non-court contexts – showing its indirect nature).

The same logic also means that on-stage performers during a play (what Rappaport described as "Drama") are not taking part in a ritual. There is clearly a *formal performance* that contains behaviours that were *encoded by another* (the playwriter), and these behaviours are *more-or-less invariant*. Rappaport handwaves this apparent issue and goes on a tangent about the knowledge that ritual performers "*might*" be changed as a result of the ritual, and that they "*can*" assume things about others in attendance. The use of "might" and "can" mean that these attributes are not always present, and thus stops his definition from being universal (as he claims his definition is). I also feel that it does not do a good job of adequately distinguishing between performing while acting and performing a ritual.

However, using the Hobson et al. (2018) definition, the behaviours of on-stage performers have a direct instrumental purpose: to please, and/or captivate the audience in some way. The actors performing know that to change the behaviours too far away from what is written or how they were directed will likely lead the audience to lose interest, unsuspend their disbelief, or simply not enjoy it. As such, adhering to the set behaviours has a direct link to the purpose of ensuring the audience enjoys the performance. I would argue this can be extended to dance (e.g., ballet), music performance (e.g., concerts), and even the theatrical nature of 'professional' wrestling (i.e., the scripted performing art involving acrobatics and athleticism, where the 'kayfabe' performance is important for sustaining the suspension of disbelief). Each of these are formal performances that involve behaviours encoded by others that are more-or-less invariant. What makes these not a ritual is their inclusion of behaviours with direct instrumental purpose.

This is where the Hobson et al. (2018) definition shines. The requirement for a lack of direct instrumental purpose allows events such as pantomimes – things that are not deemed to be rituals by the average person – to be excluded from the term where they might otherwise have been included. Another activity that comes close to being 'ritual' but is not, by this definition, is athletics competitions. "Fans" resemble congregations of a ritual more than they do the passive audiences of the Rappaportian theatre. However, as the world saw during the COVID-19 pandemic when competitions occurred in empty stadiums, an athletic competition does not require fan participation at all in order to occur. Even in the event of fans being present and contributing (performing) in some way for the athletes, the fans' singing, cheering, etc. has the *direct* instrumental purpose of supporting or inspiring the athletes on the field (or to distract the opposition) via directly effecting their emotions. Having a large crowd of people shouting/screaming at you will cause an emotional shift in anyone, irrespective of where and when it occurs. Moreover, unlike in ritual, during a sporting event fan behaviour is not set in stone: they can cheer or boo whenever they like, and they can create new cheers/chants at-will, at any time (UK football fans are well-known for this). In short, an athletic competition is not, itself, a ritual. While not intrinsically ritual, there may be elements of athletics performances that *are* ritualistic: 'pre-game' chants/songs (e.g., national anthems) have no direct effect on the outcome of the competition, so it could be argued that performing these might be considered ritualistic. The distinction here is that athletic competitions can *contain* rituals, but are not *themselves* rituals.

Finally, the behaviour that is widely considered to be most like ritual (and by some to be indistinguishable from ritual): ceremony. Researchers that have attempted to disambiguate ritual from ceremony have described ceremony as a subtype of ritual (Firth, 1967/2012; Gluckman & Gluckman, 1977; Huber, 2003; Mitchell, 1979). I would be inclined to agree that a ceremony is a subtype of ritual. For the sake of completeness, I will elaborate on my interpretation of this disambiguation. My perspective is somewhat informed by the ritual form hypothesis (Lawson & McCauley, 1993; McCauley, 1999; McCauley & Lawson, 2002) – the idea that rituals have agents (e.g., a priest), acts (e.g., baptisms) and patients (e.g., babies)[10]. I believe that a ceremony is a specific type of ritual that conveys a state-change on the patient of the ritual that are considered to be long-lasting, whereas a ritual need not have this. For example, when someone receives a Knighthood (or CBE, OBE, or MBE) in the UK, the Queen (agent) knights (act) the person to be knighted (patient). This ceremony-ritual causes a long-term state change that means the person is a knight for the remainder of their life. Similarly, at a wedding, a priest (agent) ordains (act) the marriage between the couple (patients). This conveys a state-change from unmarried to married that cannot be undone without another ceremony-ritual (divorce/annulment). Conversely, a ritual such as the Shabbat (Friday Night) Dinner in Judaism would not be considered a ceremony in my mind, as there is no long-term state change that takes place on any of the patients.

So, incorporating part (c) of Hobson and colleagues' (2018) definition into Rappaport's definition allows for the distinction between what *is* ritual and, importantly, what is *not*. It does this with a precision that conforms to the condition of providing analytic utility that Rappaport (1999) desired, while also having face validity insofar as including behaviours that would be deemed ritual as ritual, while excluding behaviours that are not usually deemed as ritual. It is for this reason that I will be incorporating part (c) of Hobson et al.'s (2018) definition going forward for the rest of this thesis.

Hobson et al. (2018) also suggest, in part (a) of their definition that ritual requires repetition. The requirement for repetition suggests that a behaviour that is formal, encoded by others, and is more-or-less invariant with no direct instrumental purpose would be a ritual even if only ever done a single time. Were such an occasion to occur only a single time, we might describe it as a phenomena, as an event, or even a 'charade' (to use Rappaportian terminology), but not as a ritual. As such, I feel that inclusion of repetition in the definition is warranted. Similarly, in part (b) of their definition, Hobson et al. (2018) state that, for something to be a ritual, the behaviours must be "embedded in a larger system of symbolism and meaning" (p. 261). Were one to interpret Rappaport's use of Abrahams' (1973) five-tier system more liberally, at all five tiers one could suggest that there is a

[10] A deeper understanding of the ritual form hypothesis is not germane to the thesis, so it will not be elaborated on here.

larger system of symbolism and/or meaning at play: Even for the lower tiers, where there are only stylised gestures (e.g., a tipping of the hat, or a nodding of the head, to greet someone). The stylised greeting gestures are embedded in a meaning system that has determined that "visually demonstrating that you are greeting someone is a good thing to do" – it is a form of decorum or etiquette. So, in large part, the additions to the Rappaport (1999) definition that Hobson et al. (2018) make are to do with repetition, and the lack of direct instrumental purpose. To clarify, the definition of ritual being used in this thesis is:

> *the repeated performance of more-or-less invariant sequences of formal acts and utterances not entirely encoded by the performers, and that lack direct instrumental purpose.*

This definition is built upon the Rappaport (1999) definition, with extensions (underlined) taken from the Hobson et al. (2018) definition.

2.1.3. *Definition of a 'religious' ritual*

Over sections 2.1.1. and 2.1.2. I have established working definitions of both religion, and ritual. But how can one determine whether a ritual is religious or not? When defining religion, I focused on Schilbrack's (2013) concept of super-empirical reality. However, the belief in super-empirical realities is only one side of Schilbrack's definition: the substantive side. Schilbrack also says that to be considered religious, one must also act in accordance to the super-empirical beliefs. To believe, but not act in accordance with those super-empirical beliefs is to (for all intents and purposes) not believe them. Though, if one does live their life in a way that is in accordance with super-empirical beliefs does that make all of their acts religious? To answer this, one can use an example provided by Rappaport (1999, p. 24-25). Rappaport asks whether a Christian who avoids committing adultery is engaging in a religious act. He continues: if so, is a Christian engaging in religious acts every moment of their life that they are not actively committing adultery? I.e., would walking to work be a religious act? What about falling asleep? I would argue (as would Rappaport) that these are not religious acts because the acts themselves are not *only* done in relation to religion (one does not *only* walk to work, or fall asleep because of a super-empirical reality). As such, a religious act is one that is any behaviour that is conducted directly in relation to the super-empirical. So:

> *a religious ritual is a ritual that is conducted directly with reference to/in relation to the super-empirical.*

By this definition, religious rituals would include rituals that might otherwise be described as being 'spiritual but not religious'. This is important, because 'spiritual but not religious' is an identity/affiliation/description of behaviour that is increasingly subscribed to (Ammerman, 2013). To be clear, for the purpose of this thesis, something that is 'spiritual' is considered to be religious, as it also relates to the super-empirical. A benefit of this is that it means that there can be a distinction between rituals that are spiritual/religious and those that are not so – i.e., those that are *secular*. In short, secular rituals are those rituals that are not performed in reference or relation to any super-empirical realities. Importantly, under this definition, a secular ritual may be almost identical, behaviourally, to a religious ritual. This provides analytic utility in studying the difference between religious ritual and secular ritual (which is required to address a primary aim in this thesis).

Finally, there has been much written on 'modes' of religious ritual (Whitehouse, 2000, 2002, 2004b). Specifically, the difference between high-intensity, low-frequency (imagistic) rituals and low-intensity, high-frequency (doctrinal) rituals. As will be expanded on in section 2.2.3., when discussing religious rituals in the context of social bonding, it is the low-intensity, high-frequency rituals (e.g., Shabbat Friday Night Dinner, or attending Sunday Mass) that is of interest to me for the purpose of this thesis, and not the high-intensity, low-frequency rituals of the imagistic mode (e.g., pilgrimages)

2.1.4. Definition of social bonding

As outlined in Chapter 1, Durkheim (1912) suggested that religious ritual causes a 'collective effervescence' within those in attendance, an observation that helped spawn this body of work. For the thesis, and much like many scholars of religion and ritual (e.g., Lang, 2019; Stein et al., 2021), I focus only on the social bonding component of the phenomenon that Durkheim described.

Importantly, in this section, I will explain what I mean by the term *social bonding* when used in this way, and for its use within the rest of the thesis.

2.1.4.1. Social Identity, Identity Fusion, and Social Bonding

Within social psychology, a prominent theory of how social processes are governed is Social Identity Theory (SIT; Tajfel & Turner, 1979; Tajfel et al., 1979). SIT is an offshoot of Identity Theory(Boring, 1933; Place, 1990). Identity Theory describes the cognitive processes underlying people's personal identifications of themselves, in which they specify aspects of the self that make them a unique person. SIT extends this idea of identification and categorisation to objects outside of the self. While there is a long and rich history of research around SIT, how it relates to the current thesis can be summed up as follows: SIT is mainly concerned with how one conceives of the self in relation to others, e.g., one's membership of a group, or how one is situated during intra- or inter-group interactions. A major idea within SIT is that "the concept of 'self' is reflexive in that it can take itself as an object and can categorize, classify, or name itself in particular ways in relation to other social categories or classifications" (Stets & Burke, 2000, p. 224). These social categories might include things such as 'Musician', 'football fan', or 'Christian'. This ability to self-categorise (or identify) as being part of a group, deemed to be a cognitive process, is a core aspect of SIT.

Within this framework, social bonding might be described as a person expanding their self-categorised identity to encompass others in some way. For example, they might categorise both themselves and another as 'friends', or as 'family', where they are a member of the 'family' group. This expanding of their self-category allows for their self-identity to overlap with at least one other person. This expansion of the self-identity causes the overlap between the mental representation of the self and the mental representation of others, which has been described as a *self-other-overlap* (Davis et al., 1996; Galinsky et al., 2005; Galinsky & Moskowitz, 2000). Historically, social identity theorists have used measures of self-other overlap to assess their idea of social bonding (e.g., Galinsky et al., 2005). Usually, this is done using the Inclusion of Other in Self Scale (IOS; Aron et al., 1992). The way in which self-other overlap is purported to cause social bonding is that it assumes that the 'group' category overshadows, or envelops the 'self' category, obscuring the distinction between individual group members. This self-other-overlap appears to foster the adoption of prototypical behaviours, such as favouring the in-group members over out-group members (e.g., Turner et al., 1987), which are thought to be behaviours reflective of an underlying social bond.

A competing idea of how social bonds form that is also an offshoot of identity theory is *Identity Fusion* (Swann Jr & Buhrmester, 2015; Swann Jr et al., 2012). Swann and colleagues (Buhrmester et al., 2012; Gómez et al., 2011; Swann Jr & Buhrmester, 2015) argue that the idea that one's self-identity, instead of expanding to encompass others as in SIT, can be changed such that the self-category is *equated* with the group category (i.e., the identity of the self has *fused* with the identity of the group, such that they are now one-and-the-same). Within Identity Fusion Theory, proponents make the argument that identity fusion is not a temporary shift in one's perception of the self, but instead a long-term change. Swann & Buhrmester (2015) describe this as the 'irrevocability principle' (p. 54). They suggest that the state-change lasts at least 18 months for those who have strongly fused (if not more).

Within the identity fusion framework, social bonding occurs via the identity of the self being *conflated* with the group identity. They *are* the group. This is not to be confused with being *a member of* a group. For example, someone who experiences self-other-overlap might feel as though they are a member of the nation, as the nation identity overlaps with their self-identity. In contrast, someone who experiences identity fusion believes that they *are* the nation. For a real-world example of this, someone born in Israel may feel as though they are a member of the country/nation-state that is Israel. However, for many deeply religious Jewish people, even if they are not from Israel (and have never been there), they consider themselves (and other Jewish people) to *be* the nation of Israel (i.e. their self-identity has fused to the identity of 'nation of Israel').

For identity-fused individuals, any positive affect/emotions/mood that occurs that would otherwise be experienced as the self is attributed to the group itself, causing positive opinions of the group. While identity fusion theorists do distinguish between local fusion (i.e., fusion that takes place within the group that you see, touch, and have immediate contact with, such as family and work), and extended fusion (the fusion with a more abstract notion that includes others that one has never met, such as ‘Christian’ or ‘Scottish’), this distinction is purely semantic. Mechanistically, according to identity fusion theorists, the fusion that occurs, and thus the behaviours that one is willing to enact as a result, are functionally equivalent. The main distinction between the two is that extended fusion might be more difficult to initiate: e.g., most people would sacrifice themselves in some way for the benefit of their immediate family, however not nearly as many people would sacrifice themselves in some way for the benefit of ‘Britain’, even if there are those who would.

Presented in this subsection are two theories behind how social bonding might occur that are embedded within identity theory: (1) self-other-overlap and (2) identity fusion. The former purports to cause a sense of bonding in individuals because they feel that the self and others overlap in some way. The latter suggests that one’s perception of the self is not just overlapping with others but, instead, that one’s identity of self becomes indistinguishable from the group identity. The relative importance of these two ideas will be explored within section 2.1.4.2.2., after other interpretations of social bonding are also presented

2.1.4.1.1. Group entitativity

In both social identity theory’s self-other-overlap and identity fusion theory, there is already the assumption that the group with which one is overlapping or fusing with is a distinct entity. Where a single person has a coherent and unified personality, groups usually vary quite wildly in how consistently they are seen as coherent units. A group of people who happen to be in your local supermarket at the moment are likely not considered to be a single, meaningful group. Conversely, a group of sports fans at their local team’s venue might be more likely to be considered as a coherent unit instead of as an aggregate of individuals. The degree to which a collection of individuals are thought to be a single, coherent unit (i.e., an understandable ‘entity’) is described as the group’s entitativity (Campbell, 1958).

I feel it is important to point out that the sense of “group-ness” (for lack of a better term) that one perceives from a collection of people is not the same as the feeling of social bonding to others (be that to individual others, or to groups). To clarify, I think using the example of colour might help. A person might determine that a collection of wavelengths is a single colour, or a set of distinct colours.

This is typified in language differences: the wavelengths spanning about 420nm to 500nm includes the 'light blue' of aquamarine, to the 'dark blue' of sodalite, but both are usually described as being of the single group of colours 'blue' in English; However, in Russian, the same wavelengths in would be described as distinct groups of colours: 'goluboy' (light blue) and 'siniy' (dark blue). Whether someone perceives them as a single colour or as separate colours, this has no bearing on whether or not someone *likes* the colour. Similarly, whether or not someone perceives a group as a single entity, or as a group of individuals, this does not equate to one's level of *social bonding* to the group.

While group entitativity may not be equivalent to social bonding (as outlined in the previous paragraph), entitativity might still play a role in bonding in some fashion: it is difficult to feel bonded to a group that one does not perceive to exist. In Campbell's (1958) original article on group entitativity, one of the main ways in which he felt that entitativity was determined by an individual was the *similarity* of group members to each other (i.e., how much did the members of the group have in common with one another). Other research has supported the idea of similarity being key to perceiving a collection of people as a single group entity (e.g., Brewer & Harasty, 1996; McGarty et al., 1995). As such, one way that one might assess whether a person perceives of themselves as being part of a group would be to assess how much they feel they have in common with the group (i.e., a measure of how similar they are to the group).

To summarise this short subsection, group entitativity is not equivalent to social bonding. However, one can use the theoretical framework underlying group entitativity to assess how much one *feels* they are part of a single group entity via assessing how similar the individual feels they are to the group. Much like self-other-overlap, this might be deemed as one *aspect* of group social bonding, but not the entirety of the social bonding experience. To cover the other aspects of social bonding, it is important to discuss how it has been described as a feeling (rather than in relation to identity) in other parts of the academic literature.

2.1.4.2. Social Bonding as 'feeling'

I ended the previous section, which focused on identity theory perspectives on social bonding, by describing that one might be able to *feel* as part of a single group entity. The idea of social bonding as a ‘feeling’ is not new, though. In fact, there has been much written about social bonding in the context of ‘feeling’ (affect, emotion, and mood). For example, the Durkheimian collective effervescence (in its original incarnation) is fundamentally about positive feelings aimed towards others in the group caused by participation in religious ritual. Similarly, psychobiological research on social bonding has described social bonds as a *feeling* of ‘social warmth’ (Inagaki et al., 2019a), or *feelings* of trust (e.g. Kosfeld et al., 2005), neuroscience research specifically characterises it as a ‘social emotion’ (Hofmann & Doan, 2018), whereas psychological research describes it as a *feeling* of connection with others (Wiltermuth & Heath, 2009), or a *feeling* of liking others (Hove & Risen, 2009).

The main difference between these approaches is the central focus: in psychology it is the *cognition* underlying the feeling, in psychobiology it is the *neurotransmitters* underlying the feeling, while in neuroscience it is the *location of brain activity* underlying the feeling. Despite the difference of foci, in each of these three major approaches to social bonding it is viewed as a *feeling*. To clarify what is meant by the idea of ‘feeling’ (and the terms that fall under the umbrella of feeling, including ‘affect’, ‘emotion’, and ‘mood’), I will quickly tangent to a wider discussion on the use of these terms in the psychological literature.

2.1.4.2.1. Disambiguating ‘affect’, ‘emotion’ and ‘mood’

Historically (in the 1990s and earlier), there was a tendency to use the terms mood, emotion and affect interchangeably. Since the turn of the century there has been much discussion within the science of emotion regarding the use of these terms and how they are distinct constructs (see Ekkekakis, 2012, 2013). In their book discussing the use of the terms affect, emotion, and mood, Ekkekakis (2013) outlines how the three should be considered distinct constructs that all fall under the umbrella of ‘feeling’. In the first few chapters of their book, Ekkekakis (2013) provides some examples of this distinction being made. For example, Gray and Watson (2007) suggest the terms differ with regard to four aspects: (1) duration, (2) frequency, (3) intensity, and (4) pattern of activation. Others distinguish them in other ways. Here I will provide a short overview of what I feel is the strongest disambiguation of the terms provided by Ekkekakis (2013).

In Ekkekakis' model, affect (sometimes also known as 'core affect') is considered to be a nonreflective, noncognitive aspect of feeling. Affect, then, is simply feeling with a valence, and intensity. In the framework presented by Ekkekakis (2013), affect is an *aspect* of emotion, but can exist outside of emotion. Affect is a part of, but not the whole of, emotions and moods (Feldman-Barrett & Bliss-Moreau, 2009; Russell & Feldman-Barrett, 1999). In this way, affect can have a positive or a negative valance, and can be of high or low intensity. It is the very basic starting point on which other aspects of 'feeling' are built upon.

Emotion is therefore not separate from, but builds on, affect. Clore and Ortony (2008) suggests that emotions are cognitively elaborated affective states. Ekkekasis (2013) builds on this and provides five components that emotions require that distinguishes emotion from affect: emotion requires (1) an information-processing (cognitive) component, (2) a neurophysiological component (there needs to be biological changes), (3) an executive component, which prepares and directs actions, (4) an expressive component (the ability to demonstrate the emotion in some fashion, via vocal outbursts, or bodily action – such as facial changes), and (5) an experiential component, which monitors these four prior components in relation to the environment to give rise to subjective feelings named "emotional experiences" (Frijda & Scherer, 2009; Scherer, 2005). Importantly, emotions are *short-lived* due to them requiring the co-ordination and/or alignment of all these different sub-processes. As such, "there is an increasing conceptual clarity regarding emotion, considered… as a fast process focused on a relevant event" (Coppin & Sander, 2021, p. 25).

Emotions, then, (a) are focused on specific events, (b) involve a process of cognitive appraisal (in relation to something specific) as a defining feature, (c) affect most or all bodily subsystems that (d) are subject to rapid changes due to the continuous unfolding of events and reappraisals, and (e) have a strong impact on behaviour due to their inherent linkage to specific action tendencies consonant with each emotion (Frijda & Scherer, 2009; Ekkekakis, 2013). For example, pride can be thought of as feeling good about oneself (possibly because of something). The feeling good is *affect* (the valence aspect), the "about oneself" (i.e., in relation to the self) is an additional, cognitive (reflective) component that makes pride an *emotion,* not an *affect* (Russell & Feldman-Barrett, 1999).

Finally, ‘mood’ is the aspect of feeling that is longer in duration, and of lower valence. Moods are diffuse and global (Morris, 1992). With ‘diffuseness’ being important because it means moods are not related to a specific event or object (Frijda, 2009). Mood, then, is the “designation for affective states that are about nothing specific, or about everything – about the world in general” (Frijda, 2009, p. 258). This doesn’t mean they are not in relation to something. They are just in relation to something vague (e.g., ‘the future’ (if one has an anxious mood)). Moods are temporally remote, and have been described as “existential background” (Lazarus, 1982).

Having clarified the distinction between affect, emotion, and mood, Ekkekasis emphasises that “The uncritical interchange of terms can no longer be considered innocuous or justified on the basis of precedent” (Ekkekasis, 2013, p. 46). Because of this, for the remainder of the thesis, the use of the terms will be used in the specific ways the Ekkekakis model outlines. However, where the terms are used to name pre-made scales, or where I am quoting from authors, the terms might be used incorrectly. In these instances, I will clarify when they first appear.

2.1.4.2.2. Social bonding as emotion

To return to social bonding, based on the disambiguation presented above, when approaching social bonding as a type of feeling, it is clear that it should be deemed an emotion for three reasons. The first reason social bonding should be considered an emotion is because the feeling (be it ‘warmth’, ‘liking’, ‘trust’, or ‘connection’) is short-lived and is directly related to a specific time and action (cf. the Durkheimian ‘collective effervescence’ is caused by the religious ritual, and the feeling is a reaction to it). This makes it not temporally remote (as a mood would be). The second reason it is an emotion is because the feeling is in relation to something specific – others (those who are being bonded with). This makes the feeling more than simple *affect* (which is simply valence and intensity) but specific enough to not be a vague *mood*. The third reason social bonding should be considered an emotion is that it appears to describe an experiential component: the ‘sense’ of warmth toward, closeness to, trust of, or liking of others are experiences relative to the environment.

Importantly, by this understanding the feeling does not last days, or even weeks, as moods can. To tie this back to the identity approach to social bonding, the feeling of self-other-overlap would likely be considered an emotion, as it is a short-lived feeling, that is subject to change. Conversely, identity fusion, which is considered a long-term effect by its proponents (Gómez et al., 2011; Swann Jr & Buhrmester, 2015), might be considered something different from the emotion of social bonding all-together. In fact, identity fusion advocates assert that identity fusion is a completely distinct construct from self-other-overlap (Gómez et al., 2011; Swann Jr & Buhrmester, 2015; Swann Jr et al., 2012). As such, identity fusion likely is not a measure of social bonding at all, but a measure of something else that may be related to social bonding in some way. Also, while group entitativity as a construct is not the same as social bonding (see 2.1.4.1.1.), one's feeling of similarity to others in the group may also be an aspect of social bonding, as one likely cannot bond to a group they do not perceive to exist in the first place.

The 'state vs. trait' terminology (and how to distinguish the two) from psychological literature also highlights why the 'emotion' characterisation of social bonding is appropriate, and why identity fusion is not an aspect of social bonding. Fridhandler (1986), provides a list of four aspects that a construct may have that allow us to determine if it is a trait or a state: (1) duration (short vs. long), (2) manifestation (reactive vs. continuous), (3) concreteness (vs. abstractness), and (4) cause (situational vs. personal). Because of its short duration, its reactive manifestation, its concreteness as an experience and that it seems to be situationally causative, social bonding is a temporary 'state', and not a long-standing 'trait' (Fridhandler, 1986). Conversely, given its long duration, its continuous manifestation, its abstractness as a theoretical construct, and that it appears to have some personal causality, whether or not someone has fused identity with a group would be considered a 'trait', and thus is separate from the emotion of social bonding. This conception of social bonding as emotion is in line with more recent academic work on social bonding from the psychobiological (Gangestad & Grebe, 2017; Inagaki et al., 2019b; Inagaki et al., 2016), and neuroscientific (Hofmann & Doan, 2018) approaches. For this reason, when discussing social bonding for the remainder of the thesis, I will be using it the sense that it is an *emotion* that is able to change in intensity over time.

When discussing the 'state' of social bonding, it is important that we also understand that this state may have multiple different aspects to it. By this, I mean that 'social bonding' may not be a single variable that can be assessed using a single-item measurement tool. Instead, it might be like state anxiety, or state depression, where we can only measure the latent variable of the state via assessing multiple aspects of what the state is made up from. This is true whether the underlying state variable of interest is multidimensional (such as cognitive load; Andersen & Makransky, 2021) or unidimensional (such as happiness; O'Connor et al., 2015; Swami et al., 2009).

Yet another view of social bonding comes from evolutionary psychology. Savage and colleagues (2020) define social bonding from the evolutionary psychology perspective. They define it as "the formation, strengthening and maintenance of affiliative connections ('bonds') with certain conspecifics" (p. 2). Here, they do not view it in the framework of identity theory, nor does it use the framework of 'feeling' (provided one does not interpret their use of the term '*affiliative'* as a feeling). Instead, using the Savage et al. (2020) definition, social bonding might be considered *a process*. Savage and colleagues, however, do not explain how this process occurs, or what parts make up the process. If using this definition, where social bonding is the process of forming, strengthening, and/or maintaining the affiliative connections, then one has to break down what parts make up the whole of the process.

Processes contain behaviours or actions (e.g., to maintain, to strengthen). However, actions have a motivational, emotional component to them (Ekkekakis, 2013). In the context of social bonding, I would argue that the main component underlying the process would be the emotion component (feelings of warmth, liking, trust, self-other-overlap, commonality, and connection), which causes an impact on behaviour consonant with affiliation. This is in line with part (e) of Ekkekakis' (2013) characterisation of emotion outlined in part 2.1.4.2.1.. So, it is the emotion that leads to the outcome of the formation/strengthening/maintenance of the affiliative connections. For this reason, the definition of social bonding being used for the thesis is as follows:

> *social bonding is an emotion that enables the formation, strengthening, and maintenance of affiliative connections to others.*

2.2. Current understanding of social bonding and religious ritual

With a definition of religious ritual determined, and a clearer picture of what is meant by the term 'social bonding', the next step needed before one can attempt to address the three main gaps in knowledge highlighted by Dunbar (2017b) is to provide a background of what we do know. To do so, this section will cover what is currently known about how social bonding may occur outside of religious ritual settings. Then, I will explain how these come together, in the context of religious ritual, to demonstrate where exactly the gaps in knowledge are, and how this thesis will address them. As noted in the Chapter 1, much of the research into social bonding can be broken up into two levels of interest: (1) the neurochemical mechanisms and (2) the psychological mechanisms. As such, I will also break the current understanding of mechanistic causes down into these two major types of mechanisms, before bringing them together and examining them in the context of religious ritual.

2.2.1. Possible neurochemical mechanisms underlying social bonding

Neurotransmitters are chemicals that alter the way neurons and glial cells behave in the central nervous system, peripheral nervous system, or both. These neurotransmitters work by binding to receptors on nervous system cells, which causes change in the post-synaptic cell. Psychobiologists and cognitive neuroscientists often look to neurotransmitters to explain behavioural and cognitive phenomena. In doing so, they seek to explain the onset and maintenance of behaviours, emotional states, and cognitions by citing the necessity and sufficiency of the role of specific neurotransmitters. The motivation for behavioural scientists to explain such phenomena in this way extends to social bonding.

In this context, necessity is when a neurotransmitter is required for social bonding to occur (though bonding is not guaranteed even if the neurotransmitter is present), and sufficiency is when a neurotransmitter's presence alone guarantees social bonding, but the neurotransmitter may not be required for social bonding to occur. To be both necessary and sufficient, the presence of the neurotransmitter would, by itself, lead to social bonding occurring and that social bonding could not occur without it. For a crude example of the difference between necessity and sufficiency we can look at human life/death: water is a necessity for a human to survive – without water, a human would die –

but water alone is not *sufficient*, as humans also need air to breathe and food to eat. Alternatively, decapitation is a sufficient cause of death – if one's head is chopped off, that will cause loss of life – but one can die without decapitation, meaning it is not *necessary* for death.

This section will briefly mention some of the neurotransmitters that have caught the attention of social bonding researchers and explain why μ-opioids are the major focus of this thesis. The three major neurotransmitters of interest within social bonding research are oxytocin, dopamine, and μ-opioids[11]. As this section discusses neurochemical, neuroanatomical, and neurotransmitter receptor names that are both longwinded and often repeated, a table of some of the key terms, what they are, and their abbreviations, as used in the academic literature, is presented in Table 2.1.

Table 2.1.

Table showing some of the main biological terms used in this section, with their abbreviations

Key Term	Abbreviation	What it is
Oxytocin	OT or OXT	A neurotransmitter associated with social bonding
Dopamine	DA	A neurotransmitter associated with social bonding
Endogenous Opioids	EOs	A group on neurotransmitters (opioids) that are naturally occurring in the body (endogenous). This is contrasted with external opioids drugs that are not produced by the body, such as morphine (exogenous).
Mu-opioid receptor	MOR	A neurotransmitter associated with social bonding
Ventral Tegmental Area	VTA	A group of neurons located at the floor of the midbrain
Nucleus Accumbens	NAc	A specialised region of the striatal cortex
Ventral Striatum	VS	A nucleus in the basal ganglia region of the forebrain, made up of the NAc and the olfactory tubercle
Prefrontal Cortex	PFC	The cerebral cortex that covers the front part of the frontal lobe
Ventral Pallidum	VP	A structure within the basal ganglia region of the forebrain
Lateral Septum	LS	A part of the medial olfactory area in the frontal lobe, it has no role in smell, only in reward and reinforcement

[11] While these are the three most prominent neurotransmitters discussed in the social bonding literature, they are by no means the only ones that have been researched. Other neurotransmitters of interest include, but are not limited to, progesterone, arginine vasopressin, and prolactin (see Gangestad and Grebe, 2017 for a comprehensive review)

Mesocorticolimbic Pathway	MCL	A term for a group of brain regions that are to do with reward. Made up of the VTA, and the VS

2.2.1.1. Oxytocin

In the context of social bonding, few neurotransmitters have received as much research focus, and press interest, as oxytocin (abbreviated to OT or OXT in the literature). Oxytocin is a neuropeptide, from the nonapeptide family, produced in the hypothalamus of mammals and stored in the posterior pituitary gland (Standring, 2015, p. 358). It was first discovered by Henry Dale (1906) and was originally thought to only be related to milk production and childbirth (Burbach et al., 2006). It has since been found to be related to other bodily processes, such as feeding behaviour (Atasoy et al., 2012). Outside of these more basic biological functions, research on wider behavioural effects of oxytocin started to surface in the 1970s after it was found that oxytocin may play a role in the onset of maternal behaviours, including parental bonding (see Ross & Young, 2009, p. 534). For example, in their paper looking at knockout mice – mice who have been selectively bred to have certain genes removed – Dölen and colleagues (Dölen et al., 2013) look at the mesocorticolimbic (MCL) pathway, with an emphasis on the nucleus accumbens (NAc). Dölen and colleagues demonstrated that social place preference learning (a proxy measure of social bonding in rodents) in these mice is reliant on the oxytocin receptors in the mouse NAc. Follow-up research demonstrated that oxytocin can be directly used to enhance place-preference in rats (Moaddab et al., 2015).

In their review paper, Ross and Young (2009) provide a strong case for the role of oxytocin in bonding behaviour in multiple mammal species, from rodents to sheep. These findings have also been extended to dogs (Romero et al., 2014) and even some non-human primates (Crockford et al., 2013; Smith et al., 2010). Though, it should be highlighted that Heinrichs and colleagues note that "Specifically, OXT seems both to enable animals to overcome their natural avoidance of proximity and to inhibit defensive behaviour, thereby facilitating approach behaviour" (Heinrichs et al., 2009, p. 548). This role of *facilitating* approach behaviour is distinct from oxytocin being a sufficient neurochemical cause of social bonding, or even a necessary one.

The build-up of literature suggesting oxytocin played a key role in social bonding in animal models gave rise to research on the role of oxytocin on human social bonding. Research studying oxytocin's role on human social behaviour has used three main methodologies, outlined by Nave and colleagues (Nave et al., 2015, p. 773):

1. Using placebo-controlled studies measuring behavioural outcomes of administered intranasal oxytocin (see reviews by Bakermans-Kranenburg & van IJzendoorn, 2013; Bartz et al., 2011; Bos et al., 2012);
2. Correlating plasma/salival (peripheral) oxytocin levels with behaviours (e.g. Feldman, 2012; Zhong et al., 2012); and
3. Correlating oxytocin-related gene polymorphisms with behaviours. (e.g. Donaldson & Young, 2008; Ebstein et al., 2012; Pearce et al., 2017)

The seminal article by Kosfeld and colleagues (Kosfeld et al., 2005) using the intranasal oxytocin method showed that intranasal oxytocin increased feelings of interpersonal trust. This finding was then corroborated by a plasma correlation study suggesting the same effect: oxytocin increases feelings of trust (Zak et al., 2005). These early studies linking oxytocin to trust provided psychobiologists a neurotransmitter to cite as playing a key role in human social bonding. Furthermore, research looking at the facilitation of approach behaviour in humans has been able to replicate the findings of those in animals for both males (Scheele et al., 2012; Striepens et al., 2014) and females (Preckel et al., 2014). Though, this research notes that it did not demonstrate the necessity or sufficiency of oxytocin in human social bonding.

In fact, the literature on the necessity or sufficiency (or *any* key role) of oxytocin on social bonding in humans is far from clear. One reason for this scepticism is that oxytocin may play a more complex role in human social bonding than in animal models. "Indeed, the broader view that nonapeptides [oxytocin, and arginine vasopressin] selectively promote positive social behaviour is challenged by an increasingly large number of studies" (Goodson, 2013, p. 471 clarification mine). Challenging the view that oxytocin promoted positive social behaviour or positive social feelings developed into what is now termed the 'Oxytocin Paradox' (Bethlehem et al., 2014). The Oxytocin Paradox describes the inconsistent findings found in oxytocin research conducted with human participants, such as context dependency (Bartz et al., 2011) and gender differences (Bos et al., 2012). In their initial article on the Oxytocin Paradox, Bethlehem et al. (2014) recommend a shift away from viewing oxytocin as playing a role in social bonding specifically, to having a more generalised effect on anxiety (Eckstein et al., 2015) and reward sensitivity (Feng et al., 2015).

Moreover, whether oxytocin is even necessary for human bonding becomes questionable when the effects of increases in feelings of trust are scrutinised. A critical meta-analysis of the relationship between oxytocin and feelings of trust describes issues with many of these studies (Nave et al., 2015). Three examples of such issues (among many others) include (1) unwarranted *variability* in the trust measures used, (2) lack of *specificity* in the measures of trust used throughout the literature, and (3) methodological issues with *how oxytocin itself was measured*. Moreover, Nave and colleagues (2015) found that, even after ignoring the methodological issues, the overall effect size for the effect of oxytocin on increasing feelings of trust was so small that it was not significantly different from zero (Cohen's d = 0.077, 95% CI [−0.124, 0.278], z = 0.75, p = .45). This indicates that there likely is no real effect of oxytocin on trust.

Furthermore, another meta-analysis reviewing research on oxytocin receptor genotypes and behavioural and health outcomes, including sociability (Bakermans-Kranenburg & van Ijzendoorn, 2014), found that the effect size for the role of oxytocin on social behaviours and emotions did not significantly differ from zero for either of the two oxytocin genes they assessed (SNP: rs53576, R^2 = 0.02, 95% CI [-0.03, 0.07], SNP: rs2254298, R^2 = -0.01, 95% CI [-0.08, 0.06]). This supports previous allegations that the studies that *have* found a significant positive effect of oxytocin on social emotions or behaviours were likely to be false positives in underpowered studies (Benjamin et al., 2012; Hewitt, 2012).

As an aside, Bakermans-Kranenburg & van Ijzendoorn (2014) also note that there was a further serious issue with the oxytocin research that they assessed. Specifically, that that there are known inter-ethnic differences in reported behavioural correlates of oxytocin (e.g. Kim et al., 2011), but that most research is conducted on Caucasians (13,404 of the 17,559 (76.3%) participants in rs53576 studies and 11,296 of the 13,547 (83.4%) participants in the rs2254298 studies were

Caucasian). This raises the question that, even if there is an effect of oxytocin on social bonding (i.e., if effect sizes were significantly different from zero), could the effect be generalised to non-Caucasian humans (i.e. the majority of the human population)?

In addition to this, research in the psychology of emotion has found that oxytocin pathways may translate to the human experience of general positive affect or even ‘spirituality’, and not social bonding (Van Cappellen, Way, et al., 2016). This difference between social bonding in animal models, and positive affect and spirituality in humans raises questions as to the specificity, necessity, and sufficiency of oxytocin in the bonding process. So, it is possible that the view of oxytocin as the ‘cuddle chemical’ (Szalavitz, 2008), as perpetuated in much of the media (and accepted in much of the popular social psychology literature), is one that needs to change. Future research looking at the neurotransmitter basis of social bonding should focus on other neurotransmitters that have also been implicated in the bonding process such as progesterone (Maner & Miller, 2014), prolactin (Gettler et al., 2012), dopamine (Aragona et al., 2006) and opioids (Machin & Dunbar, 2011).

A final nail in the coffin for the idea that oxytocin is a sufficient or necessary neurotransmitter for human social bonding comes from genetics research (Pearce et al., 2017). Pearce et al. (2017) sought to determine how the six main neurotransmitters that have been linked to social interaction (oxytocin, arginine vasopressin, progesterone, prolactin, dopamine and opioids) play a role in social bonding. While previous research was largely interested in romantic, empathetic, parent-child, or other dyadic relationships, this study sought to investigate all social bond types, including non-familial, non-romantic, group bonds. Pearce et al. (2017) recruited 757 participants (423 females) without a history of recreational/medical drug use or psychological disorders. Using the genome analysis tool PLINK (Purcell et al., 2007), they analysed known genes related to the neurotransmitters (e.g. OPRM1 for mu-opioids) and compared this with results from verified self-report measures of various forms of bonding (e.g. they used the Inclusion of Others in Self scale – IOS; Aron et al., 1992, as a measure of self-other-overlap as a measure of group bonding).

Overall, Pearce et al. (2017) found that oxytocin, arginine vasopressin, progesterone and prolactin are each only related to a single domain of bonding. In the case of oxytocin, they found that oxytocin receptor genes seemed to be only related to romantic pair bonding. This is in line with much of the animal model research on social bonding, where many of the studies that found positive effects were focused on mate-pair bonding (e.g., Cho et al., 1999; Insel & Hulihan, 1995; Williams et al., 1994), and also aligns with research that shows that non-monogamous animal models tend to have a lower density of oxytocin receptors in the NAc (Insel & Shapiro, 1992). Furthermore, Pearce et al.'s (2017) findings might also explain the inconsistent results (the Oxytocin Paradox) found in humans. Much of the work on oxytocin and feelings of trust has looked at the role of oxytocin in non-romantic bonds, which would explain the near-zero overall effect size.

Because oxytocin appears to play a role in a specific subtype of social bonding (romantic bonding), but not in social bonding more generally, it likely is not a good candidate for a neurochemical mechanism underlying group social bonding, especially within the non-mating setting of a religious ritual. Conversely, Pearce et al. (2017) noted that dopamine and opioid receptor genes (especially mu-opioid receptor genes) are more generalised in their role in social bonding. As their research suggested dopamine and opioids (especially mu-opioids) are likely to play a key role in all social bonding, it is these two that will become the focus of the next sections.

2.2.1.2. Dopamine

Dopamine (abbreviated to DA in the literature) is a neurotransmitter that is important in multiple parts of the brain and plays a role in a wide array of behaviours and biological processes. Examples of these range from motor control (such as the role of dopamine in Parkinson's Disease; Galvan & Wichmann, 2008), attention (with a role in ADD/ADHD; Blum et al., 2008), hormone release (Ben-Jonathan & Hnasko, 2001), and incentive salience (Schultz, 2015), among others (Webster, 2001). Dopamine has 2 major types of receptors in the central nervous system: (a) DA1-type, which increase the production of cyclic adenosine monophosphate (cAMP, a second-messenger protein) in the post-synaptic cell, and (b) DA2-type, which inhibit the production of cAMP in the post-synaptic cell. There are two DA1-type receptors (DA1 and DA5) and three DA2-type receptors (DA2, DA3 and DA4). As will be explained below, it is the incentive salience (motivation) aspect of dopamine that likely plays a role in social bonding. However, due to the wide-ranging effects, distribution, and types of dopamine receptors in the brain, few studies have looked at dopamine's role specifically in social bonding.

The dopamine system is the name given to a set of brain regions and nuclei that deal with the creation and release of dopamine, as well as where it is most active. The mesocorticolimbic (MCL) pathway is linked to the dopamine system (Ikemoto, 2010), and it plays a role in incentive salience (Berridge, 2012). The MCL pathway is made up of the ventral tegmental area (VTA), the pre-frontal cortex (PFC), the nucleus accumbens (NAc), the ventral pallidum (VP) and the lateral septum (LS). As a major component of the MCL pathway, the NAc has received the most attention when it comes to research on incentive salience. In rodent animal models, dopamine receptors have been shown to play a role in pair-bonding (Aragona et al., 2006). Specifically, Aragona and colleagues found that activation of DA1-type receptors in the NAc of Voles inhibited pair-bonding, whilst activation of DA2-type receptors in the NAc encouraged pair-bonding. These findings were expanded upon in further rodent models showing that DA2-like receptors in the NAc are necessary for pair-bonding (Young et al., 2011) and that DA1-type receptors are up-regulated to promote aggression to other (non-bonded) opposite-sex rodents (Resendez et al., 2013), acting as the onset and maintenance of the pair-bond respectively. Dopamine in the MCL pathway has also been heavily associated with drug addiction (Wise & Koob, 2014), which has lead pair-bonding to be described as "social addictions between mating partners" (Johnson & Young, 2015, p. 39). Much like with oxytocin, rodent models can tell us only so much information about human social bonding, with research on non-human primates being more revealing.

Bales and colleagues (Bales et al., 2007) used MRI-assisted PET scanning in 17 titi monkeys (Callicebus cupreus), a socially monogamous primate, to track glucose uptake in 12 long-term bonded monkeys and five non-bonded monkeys. The five non-bonded monkeys were then reassessed 48 hours later, after pair-bonding had occurred. When comparing glucose uptake differences between the already-bonded and unbonded monkeys, they found greater uptake to be located in the NAc and VP (as well as the medial preoptic area, medial amygdala, and the supraoptic nucleus of the hypothalamus). When comparing the pre- and post-bond formation PET scans, they found that uptake increased in the right side of the NAc and VP only. Citing past research on rodents, Bales and colleagues suggest that this is because of increased dopamine activity. Hostetler and colleagues (Hostetler et al., 2017) later also used PET to monitor labelled DA1 receptor antagonists (blockers) before and after titi monkey bonding (n=13). Counter to the findings of Bales et al. (2007), they found no difference in DA1 receptor binding in the NAc or VP, but did find an increase in the LS. They suggest that this is because of the role of oxytocin receptors: in titi monkeys they are not found in the NAc but in the LS (Freeman et al., 2014; Freeman & Young, 2016). This somewhat undermines the legitimacy of the role of dopamine in social bonding, as it appears to be linked to oxytocin here. As outlined in the previous subsection, oxytocin is not a good candidate for a neurochemical mechanism of human social bonding. Outside of this, I am unaware of further research in non-human primates that studies the role of dopamine specifically focusing on bonding.

When it comes to dopamine's role in bonding between humans, as others have noted, the literature is even more sparse (Atzil et al., 2011; Atzil et al., 2017; Swain et al., 2014). This is, in part, due to the major focus on oxytocin in the social bonding literature. However, it is also because of serious methodological difficulties: dopamine does not pass through the blood-brain barrier, so a direct measure would need cerebral-spinal fluid, which requires an invasive procedure to gather. Also, while major dopamine by-products, such as homovilic acid, can pass through the blood-brain barrier, these by-products are also produced by the breakdown of other neurotransmitters, such as noradrenaline. Thus, measuring homovilic acid is not at all a reliable measure of dopamine release. Moreover, due to the wide-spread nature and varying types of dopamine receptors in the brain, there are no practical behavioural proxy measures that can be used to reliably measure changes in dopamine receptor activation. This is especially the case if one is looking for a specific type of dopamine receptor activation (i.e., DA1-type vs. DA2-type, which have opposite effects on the post-synaptic cells).

Despite these difficulties, some studies on the role of dopamine on social bonding in humans do exist. In their PET-fMRI study, Atzil et al. (2017), sought to better understand the location of bonding networks in the brain. Their reasoning was such that, if they could show it was linked to regions that are believed to have a high concentration of dopamine receptors, aka the dopamine pathway, then it is likely that dopamine plays a role. They did this using [11C]raclopride, a labelled chemical that binds specifically to free (unoccupied) DA2-type receptors, which can be detected via PET scan. This measure works as an inverse proxy for dopamine release (i.e. when the measure is low, the underlying value of interest is actually high and vice-versa). If less dopamine has been released, we presume that there will be a greater number of unoccupied receptors. So, the less dopamine that is released, the more [11C]raclopride can bind. In this experiment, they had human mothers (n = 19) watch videos of either their own child or an unknown child in a counter-balanced design, concurrently assessing for behavioural markers of bonding, such as vocal synchrony (Golinkoff et al., 2015). They found that mothers who had higher levels of behavioural markers of social bonding had a lower level of [11C]raclopride binding in the r-Pallidum and the r-NAc (though, not the left), indicating increased dopamine release in the mothers who were performing greater levels of bonding behaviours. This is the first study to demonstrate a role of dopamine (specifically, DA2 receptors) in the human mother-infant bonding process. However, it is still too early to determine if dopamine is necessary, or even if it is sufficient to create a bonding sensation. Moreover, the low number of participants and current lack of replication of this effect means that this finding could be prone to the same issues that plagued oxytocin research (see, Benjamin et al., 2012; Hewitt, 2012).

In fact, the research linking dopamine to social bonding is largely based on the *location* of dopamine binding or brain activity. However, the regions of interest that are cited as suggesting a role of dopamine in social bonding (e.g. the NAc), are also heavily linked to the endogenous opioid system (Berridge, 2009; Berridge & Kringelbach, 2013; Pecina & Berridge, 2005; Smith & Berridge, 2007). Consequently, it is possible that the research that suggests dopamine plays a key role in social bonding, or that it plays a role at all, could be misattributing the mechanism to dopamine, where it should actually be opioids. It is also possible that, as per the Pearce et al. (2017) hypothesis, dopamine interacts with other neurotransmitters (e.g., opioids) in a way that means it does play a role in social bonding, but it is not sufficient to produce it.

It is widely known that both peripheral (e.g., Vaidya et al., 2021) and central (e.g., Matsumoto & Hikosaka, 2009; Navratilova et al., 2012) mu(μ)-opioid receptor activation leads to dopamine receptor activation. There is also some evidence that drugs that cause increased levels of dopamine activation (e.g., cocaine) lead directly to changes in μ-opioid mRNA expression (Azaryan et al., 1996; Unterwald, 2001; Yoo et al., 2012). As such, the reason for dopamine genes playing an apparent role in social bonding (Pearce et al., 2017) could stem from the feedforward effects that increased dopamine release has on μ-opioid expression. Similarly, the apparent release of dopamine (and activation of DA receptors; Atzil et al., 2017) could be caused by μ-opioid release, where social bonding is related to μ-opioid release, and DA release is simply an after-effect.

To conclude, it is possible that dopamine plays a key role in human social bonding. However, there are a number of reasons that focusing on dopamine in this thesis is ill-advised. Firstly, hypotheses of how dopamine might play a role in social bonding are non-specific in mechanism. By this I mean that hypotheses do not specify what type of dopamine receptors – DA1-type or DA2-type – are expected to be involved in bonding (or how). DA1-type and DA2-type receptors have opposite effects on post-synaptic cells. Without specifying receptor type, it is difficult to know what kind of agonist/antagonist drug one might want to use for an appropriate study. The fact that the different receptor types have opposite effects also means that attempting to use dopamine antagonists as a method of assessing dopamine's necessity for social bonding would not be easily interpretable: if using a general dopamine agonist (i.e., it is not specific to only DA1- or only DA2-type receptors, but binds to both) how should one interpret a null effect of the antagonist on social bonding? The lack of effect could be because the DA1- and DA2-types both being blocked cancel one another out, due to their opposite effects.

Secondly, the hypothesis of how dopamine might play a role on social bonding relies heavily on very generalised understandings of the human reward system. It is simply assumed that, because reward areas of the brain are active, dopamine must play a key role. However, this discounts the fact that opioids (especially mu-opioids) are also released in those same regions of the brain, and that opioids themselves play a fundamental role in the reward system (Berridge & Kringelbach, 2015; Castro & Berridge, 2017).

Finally, the measurement of dopamine levels/activation is not easy to do for the kind of research that allows one to also research religious ritual. As far as I am aware, there are no measurable behavioural proxy measures for those with functioning dopamine systems. As it does not pass through the blood-brain barrier, nor can dopamine be measured via assessment of peripheral levels of dopamine (via blood or saliva, like oxytocin can). Also, those peripheral biomarkers that *are* related to dopamine release (e.g., homovilic acid) are not *only* related to dopamine release. So, without an invasive procedure (e.g., a spinal tap) or equipment that cannot be used during field studies of religious ritual (e.g., PET scanners), dopamine levels cannot be measured either directly or indirectly. If one cannot measure dopamine levels (either directly or indirectly) and also one cannot be sure what kind of agonist/antagonist drugs to use to assess hypotheses of the role of dopamine on social bonding, then attempting to study dopamine is rather a lost cause without better theory proposed by those who are proponents of dopamine's role in social bonding.

In summary, I am writing off dopamine as a viable neurotransmitter of interest for this thesis because there are no current viable methods to measure it in a religious ritual context that also align with dopamine-caused social bonding hypotheses. Because of much more detailed theoretical frameworks around the specific mechanisms around how opioids may play a role in social bonding, and because there are feasible methods to measure opioid release, the focus of this thesis will be on the endogenous opioid system.

2.2.1.3. Endogenous Opioids

Endogenous opioids (EOs) are a type of neurotransmitter that consists of different 'families'. endorphins, enkephalins and dynorphins are the three best-known families (see Benarroch, 2012 2012 for a full review of their chemical precursors, production and release). These families each preferentially bind to one of three types of opioid receptors. The endorphins have a preferential binding specificity for the mu(μ)-opioid receptor, enkephalins have a binding preference for the delta(δ)-opioid receptor and the dynorphins have preferential binding to the kappa(κ)-opioid receptor.

A fourth family, endomorphins, were found only 20 years ago, over two decades after the other EOs were discovered (Horvath, 2000; Zadina et al., 1997) so less is known about their function in comparison to the other three families (Benarroch, 2012) except that they, too, have a binding preference for µ-opioid receptors.

In the 1970s and 80s, Jaak Panksepp noted that opioids may play a role in bonding processes (Panksepp, 1986; Panksepp, Bean, et al., 1980; Panksepp et al., 1978; Panksepp, Herman, et al., 1980). He noted that "brain opioids constitute the brain neurochemical system for which we have the most extensive evidence for a key role in the specific role of social-affective processes" (Panksepp, 1986, p. 20). His work was focused largely on mother-infant bonding, rather than other forms of social bonding. Though, it was suggested that the link between EOs and social bonding can further be seen with the similarity between the behaviour of narcotics addicts and those who form close relationships (Barends, 2014; Burkett & Young, 2012; Insel, 2003; Panksepp, 1999).

The social neuroscience community largely ignored this research in favour of the in-fashion oxytocin at the time (a notable exception being a dedicated issue of the journal Ethos titled 'Shamans and Endorphins'; Prince, 1982). It was only much later that Machin and Dunbar brought the idea that opioids could lead to social bonding back into academic scrutiny, in the `Brain-Opioid Theory of Social Attachment' (BOTSA; Machin & Dunbar, 2011), based on the social brain hypothesis (Barton & Dunbar, 1997; Dunbar, 2009). In BOTSA, Machin and Dunbar suggest that it is EOs that play the largest role in social bonding behaviour (Machin & Dunbar, 2011). Specifically, Dunbar makes the argument that the opioid pathways play as large a role in social bonding, if not larger, than oxytocin (and other nonapeptides like AVP) in humans (Dunbar, 2007).

EOs have been linked to maternal and infant bonding (Barr et al., 2008; Kalin et al., 1995), grooming behaviour (Martel et al., 1995), as well as kin relationships, separation anxiety and play behaviour (Vanderschuren et al., 1995). EOs also seem to play a role in the reduced social behaviour of those with autism spectrum disorder (Pellissier et al., 2018; Tordjman et al., 2009) and borderline personality disorder (Bandelow et al., 2011; Stanley et al., 2010; Stanley & Siever, 2010; Venter, 2018), among other mental health disorders (Charles et al., 2020). While BOTSA suggests that all opioids play a role in bonding, μ-opioid agonists (e.g., β-endorphin) are highlighted as the key neurotransmitters underlying feelings of social bonding (Keverne et al., 1989; Machin & Dunbar, 2011).

Burkett and colleagues (Burkett et al., 2011) were one of the first researchers to look at the role of opioids in adult social bonding, as opposed to mother-infant and kin bonding. They ran two experiments on prairie voles using μ-opioid antagonists. In the first study they found a dose-schedule-dependent decrease in bonding. In the second study they found that a μ-opioid antagonist caused a complete inhibition of bonding. That an antagonism of μ-opioid receptors caused *complete* inhibition of social bonding suggest that μ-opioids play a necessary role in adult prairie vole social bonding. In a further study on prairie voles, Resendez et al. (2013), showed that μ-opioid receptors in the dorsal striatum play a role in pair bonding, and that the bonding was altered when a μ-opioid agonist was administered to shell of the nucleus accumbens (NAc-shell). Both sets of researchers note that that μ-opioid receptors appear to play a *necessary* role in adult social bonding (Burkett et al., 2011, p. 2207), which has been confirmed in other, non-primate, animal models (Garduño-Gutiérrez et al., 2013; Kelm-Nelson et al., 2013; Kobayashi et al., 2013; Parra-Gámez et al., 2013).

Bonding research in non-human primates has also sought to understand the role of EOs in the social bonding process. Across two experiments, Ragen et al. (2015) explored the role of opioids in separation behaviours in monkeys. In the first study, Ragen et al. (2015) found the μ-opioid agonist, morphine, lead to fewer behavioural markers of separation anxiety, and that cortisol (a neurotransmitter indicative of stress; De Kloet & Reul, 1987) release was higher after separation in those administered with a general opioid-antagonist, naloxone. In the second experiment they found a significantly lower level of locomotor separation-response in monkeys administered with a κ-opioid antagonist than control. These results corroborate some of the earlier work on the role of EOs in non-human primate bonding (Fabre-Nys et al., 1982; Keverne et al., 1989; Martel et al., 1995; Meller et al., 1980; Schino & Troisi, 1992). Together, these results suggest that EOs play a significant role on the separation aspect of adult social bonds, suggesting opioids at least play a role in the *maintenance* of bonds.

However, the μ-opioid receptor (MOR) system's role of social motivation seems to have opposite effects in socially isolated rodent animal models than it does in primate models (Loseth et al., 2014, p. 3). BOTSA's focus on μ-opioids did mean that such contradictions in results need to be addressed for a mechanism for how μ-opioids lead to social bonding can be provided. Løseth et al. (2014) explained this discrepancy by showing that the μ-opioid receptor system differentially modulates positive and negative affect in relation to social bonding, where rejection caused activation of μ-opioid receptors in the bilateral amygdala, periaqueductal grey area and the ventral striatum (Hsu et al., 2013), whilst acceptance led to increased μ-opioid receptor activation in the right insula and the left amygdala (Hsu et al., 2013). Therefore, according to Løseth et al. (2014), μ-opioid receptor activation plays a role in social motivation by either alleviating distress (if one has an initial state of distress) or increasing resistance to rejection (if one is initially comfortable). BOTSA (Machin & Dunbar, 2011) provides a likely neurochemical candidate for the cause of social bonding, in the form of μ-opioids. Løseth et al. (2014) – via their model of the differential effects of μ-opioids based on current affect – provide one explanatory mechanism for how μ-opioids may play a role in social bonding in animal models: via lowering distress (i.e., lowering current negative affect) or increasing resistance to rejection (i.e., stopping the onset of negative affect).

Central to BOTSA is the idea that EOs are innate analgesics (Zubieta, Heitzeg, et al., 2003; Zubieta, Ketter, et al., 2003; Zubieta et al., 2001), especially μ-opioid receptor-preferred opioids (Hsu et al., 2013). As the most abundant endogenous μ-opioid receptor agonist, β-endorphin has been the subject of most studies related to EOs and social bonding in humans. However, most EOs (including β-endorphin) cannot readily pass through the blood-brain barrier (Witt & Davis, 2006), and levels in cerebral spinal fluid (in the central nervous system) can sometimes differ widely from those found in plasma serum (in the peripheral nervous system; Furui et al., 1984). Some data suggests 'a distinction between 'central' (spinal fluid) and 'peripheral' (serum) pools" of β-endorphin (Zimmerman et al., 1990, p. 764). Thus, direct measurement of β-endorphin via blood or saliva is not often considered practical. Instead, based on the analgesic effects μ-opioids, a proxy measure of β-endorphin used in many studies has been the experience of pain, pain threshold, or pain tolerance.

Research on measuring a direct link between pain and social bonding in humans is still in its infancy, but early signs are promising: pain tolerance has been positively correlated to social group size (Johnson & Dunbar, 2016), ratings of pain lowered when people see pictures of their romantic partners, i.e., those who they feel most bonded to (Younger et al., 2010), and group participation in exercise also increases pain threshold by double that of lone participation in exercise (Cohen et al., 2010). Whilst a proxy measure, these studies suggests that EOs, especially μ-opioid receptor agonists, are related to group behaviour in some way; Proponents of BOTSA suggest this is because of the role of μ-opioids in social bonding.

Tristen Inakagi and colleagues (Inagaki et al., 2019a, 2019b; Inagaki et al., 2016; Ross et al., 2021) have run a number of studies using Naltrexone, an opioid receptor antagonist with preferential binding to μ-opioid receptors, on humans to assess what they call feelings of 'social warmth' and 'social connection' (which they use interchangeably with social bonding). They have found that, compared to control groups, participants given Naltrexone experience reduced feelings of social connection to close others - friends, family, or romantic partners (Inagaki et al., 2019b) and that this effect was not only seen in laboratory conditions, but also in daily life (measured via writings in a daily journal; Inagaki et al., 2016). Moreover, they note that a positive correlation between ventral striatum (i.e., NAc and olfactory tubercle) activation and feelings of social bonding was blocked by Naltrexone (Inagaki et al., 2019b). These are the first studies that have found a *necessary* role of μ-opioids in human social bonding. Even so, Inagaki (2018) suggests that future research should assess more general group social bonding (as opposed to dyadic bonding), as well as assess bonding longitudinally.

The current evidence suggests that, in animal models, EOs likely play a *necessary* role in social bonding (Burkett et al., 2011), and there is some early work suggesting that this could also be the case for human dyadic adult social bonding (Inagaki et al., 2019a, 2019b; Inagaki et al., 2016; Ross et al., 2021). However, whether opioids – particularly μ-opioids – play a necessary role in *group* social bonding is still not known. To further explore the neurochemical mechanisms underlying social bonding, it is first important to find a set of behaviours that can be used to reliably evoke the social bonding experience in participants, so that the neurotransmitter mechanism can be isolated.

2.2.2. Possible cognitive-behavioural mechanisms underlying social bonding

As the debate about neurochemical mechanisms was ongoing, the last decade has seen various studies which attempted to match behaviours with hormone/neurotransmitter release (e.g. Launay et al., 2016; Tarr et al., 2014). As a result, we are beginning to establish a set of behaviours and cognitions that reliably evoke the social bonding emotional response. Being able to find these behaviours allows researchers to design studies including these behaviours to assess the necessity and sufficiency of specific neurotransmitters. This section will outline some of the behaviours and cognitive-affective processes that have been demonstrated to evoke feelings of social bonding. Links between these behaviours, cognitive-affective processes, and related neurotransmitter release will also be discussed.

2.2.2.1. Positive emotional states

Emotions determine our behaviours; for example, fear leads to defensive behaviours (McNaughton & Corr, 2004) and anger leads to aggressive behaviours (Lochman et al., 2010). In fact, as outlined in part (e) of Ekkekakis' (2013) characterisation of emotion (see section 2.1.4.2.1.), what makes something an emotion is its ability to impact behaviour. So, it is no surprise that emotions and the behaviours they elicit also serve social functions (Shiota et al., 2004). Chief among the emotions linked to social bonding are those that have a positive valence (Fredrickson & Levenson, 1998; Mauss et al., 2011). Fredrickson's 'Broaden and Build theory of positive emotion' (Fredrickson, 2001; 2004, 2013; Fredrickson & Levenson, 1998) suggests that positive emotions lead to an individual behaving in ways that causes a greater amount of exposure to others ('broadening'). This greater exposure means there is a higher likelihood of building relationships ('build'), which have various beneficial psychological and physical effects. Note that Fredrickson uses the term "positive emotions" as an umbrella for any emotions that stem from an affective state that has a positive valence. So, it can also be described as the 'Broaden and Build' theory of positive affect (Fredrickson, 2001, 2004). This section will focus on the proposed link between positive affect and social bonding.

Studies concerning the effect of positive affect on psychological and physical outcomes are numerous. Work on positive affect over the last few decades (e.g. Isen, 2000) has provided the basis for the connection of positive emotions with social bonding (see Fredrickson, 2013, p. 17 for a review of much of this work). The Broaden and Build theory suggests that emotions that have a positive valence increase feelings of the self as being part of a group, via a greater identification with the group. This greater identification with the group (self-other-overlap) has been used as a stand-in for, or even seen as synonymous with, social bonding in some research (e.g., Newson et al., 2018).

So, the mechanism proposed by Fredrickson (2013) is that various emotions that have a positive valence (e.g., feeling happy, proud, inspired, strong, etc.) leads to a change in one's focus: one's focus that is normally on the self, and individuals, shifts to focus being on others, and groups. Once this focus has changed, one is more likely to identify with a wider group, than as a single person. In other words, emotions with a positive valence lead to self-other-overlap, which Fredrickson (2013) and others (e.g., Newson et al., 2018) view as synonymous with group social bonding. Under the definition of social bonding I provided in part 2.1.4.2.2., where social bonding is itself an emotion, it is only logical that emotions that rely on a positive affective state would co-occur with social bonding. This is because social bonding, and other positive emotions such as happiness or pride, all rely on having an underlying positive affective state. Under my definition of social bonding, and to borrow terminology from Fredrickson (2013), social bonding *is* a 'positive emotion', and so it is likely to co-occur with other positive emotions.

The neurochemistry underlying how other positive emotional states give rise to increased social bonding could stem from the role of opioids in inducing positive feelings. Berridge and colleagues (Berridge, 2003; Berridge, 2009; Berridge & Kringelbach, 2013; Berridge & Kringelbach, 2015; Berridge et al., 2009; Castro & Berridge, 2014) have argued that positive affect is split into two distinct 'modules'. The dopamine 'wanting' module, and the opioid 'liking' module. These are the two neurotransmitters that have been linked with general social bonding (Pearce et al., 2017), and were discussed at length in section 2.2.1. As opioids, especially μ-opioids, elicit positive affect in the form of the 'liking' reward pathway (Berridge & Kringelbach, 2013; Berridge & Kringelbach, 2015;

Castro & Berridge, 2014), and positive emotions are linked to increased levels of empathy and sociable behaviour (Fredrickson, 2013; Isen, 2000), it is possible that the mechanism underlying the link between other positive emotions (e.g., happiness) and social bonding is via the release of μ-opioids – the 'liking' neurotransmitter (Berridge & Kringelbach, 2013).

While μ-opioid release is a plausible explanation from a neurochemical perspective, Fredrickson (2013) provides a cognitive mechanistic explanation instead. Fredrickson (2013) suggests that positive affect may cause social bonding via increasing the scope of an individual (i.e., the person pays attention to more things around them, that are outside of the self; Fredrickson & Branigan, 2005). This allows them to share attention with others more easily. This idea fits well with Berridge and colleagues' dopamine ('wanting') side of the reward pathway, which controls the incentive salience (e.g. Berridge & Kringelbach, 2015). In other words, the focus of one's attention (salience) is moved away from the self and onto a wider goal (incentive). In the Broaden and Build model, positive affect would not be directly leading to social bonding (i.e., positive affect does not always lead to social bonding), but positive affect would lead to social bonding via changing behaviours to encourage a person to pay attention outside of the self, and to share attention and goals with others. So, according to Broaden and Build, it is joint attention and shared goals that might be considered the *direct* cognitive causes of social bonding, with positive affect only indirectly related.

2.2.2.2. Joint Attention and shared goals

Even though Fredrickson proposed the connection between positive emotions and social bonding via joint attention close to two decades ago (Fredrickson & Branigan, 2005), little research has been conducted to test the specific role of joint attention, as opposed to other behaviours, on social bonding (Wolf et al., 2016). One reason for so little research being conducted is that isolating only joint attention in a task is difficult – most manipulations that remove join attention will likely alter some other aspect of the behaviour being used as the independent variable, thus making the measure less valid. For example, Reddish, Fischer & Bulbulia (2013) found that actions with intentional shared goals was significantly better at eliciting feelings of social bondedness than accidental/incidental synchrony. However, having shared goals is a cognitive process over and above just having shared attention. Despite these difficulties, using a Bayesian analysis technique, Wolf and colleagues (2016) tried to test whether joint attention, by itself, was enough to influence social bonding. In their experiment, Wolf et al. (2016) used a two-by-two experimental paradigm where they were able to manipulate joint attention and shared goals separately to try and establish a causal relationship between joint attention and bonding compared with shared goals. They manipulated shared attention by altering where participants were looking during the task. Those in the joint attention group were looking at the same side of a computer screen, whereas those in the no joint attention group were looking at different sides of a computer screen. They demonstrated a small, but consistent effect of joint attention on measures of social bonding but did not find an effect of shared goals when there was no joint attention. This provides a strong starting point for further research which uses joint attention as a base mechanism for social bonding. However, due to the methodological difficulties of isolating joint attention, more complex but easier to manipulate behaviours that incorporate shared attention have been researched: behaviours that require joint action, such as synchronous movement.

2.2.2.3. *Music making and synchronous movement*

The two major joint action behaviours that have been studied within the context of social bonding across the last two decades are music making and synchronous movement, such as dance (e.g. Freeman III, 1998; Kirschner & Tomasello, 2010; Kreutz, 2014; Pearce et al., 2015; Tarr et al., 2014). Given that group music making also involves synchronous activity (i.e., it is a behaviour over-and-above just synchronous movement), synchronous movements have been the focus of more recent studies (Hu et al., 2017; Launay et al., 2016; Rennung & Göritz, 2016; Tarr et al., 2015). For example, Tarr and colleagues (2015), by studying dance and synchrony, sought to find how music *listening* might encourage social bonding. Tarr et al. (2015) used five items to measure social bonding: (1) self-other-overlap, (2) how much the participant liked others in the group, (3) how similar the participant felt to others in the group, (4) how connected the participant was feeling to others in the group, and (5) how much the participant felt that they trusted the group. Using a two-by-two design (high- and low-, exertion and synchrony), Tarr and colleagues (2015) found a positive role of both exertion and synchrony on the social bonding measures, providing evidence that synchronised movement increases feelings of social bonding.

Rennung and Görtiz (2016) conducted a meta-analysis of 60 studies investigating the role of interpersonal synchrony on social bonding and pro-social behaviours. One of the major findings was that attitudes (subjective feelings of social bonding) did not directly influence behaviours (pro-social actions), but that there is a strong positive relationship between the two. They also found that the effect of synchrony on either attitudes or behaviours was not moderated by having a musical stimulus, suggesting that it is behavioural synchrony, and not music, that leads to social bonding. Though, there were only limited studies to try to test this effect (Harmon-Jones, 2011; Rennung & Göritz, 2016).

A major issue that Rennung and Görtiz (2016) point out in the literature is that most experiments take place in a lab with student samples, meaning generalisation is difficult. Therefore, they recommend more field studies to both corroborate their findings, and to allow them to be generalised. Moreover, they note that the body of research is still small, that their findings are only a rough estimate, and that further studies in the area are both warranted and needed. Similar calls to contextualise findings from lab-based studies come from those who study neurochemical mechanisms of social bonding: researchers have been urged to produce field studies to help link actual bonding behaviour in naturalistic settings to hormone/neurotransmitter response (Gangestad & Grebe, 2017).

There are various contexts where a mix of the above mechanisms – positive emotional states, joint attention, shared goals, synchronous movement and music making – can occur, such as at sporting events, music festivals, or weddings. However, religious rituals, such as Christian Mass, also include all these behaviours, and they tend to be far more controlled than sporting or familial events. By this I mean that at the non-religious ritual events, there are many more extraneous variables that are harder to account for: fans at a sports event might be influenced by the result of the event (if their team loses vs. if they win may cause differences in measurements); attendees at a music festival might see different artists, may like the artists' music more or less than those around them, or may be more likely to dance or mosh[12] than other attendees (moshing vs. not moshing would likely cause major differences in outcome); attendees at a wedding might have differing emotional reactions depending on their degree of relationship to the couple – the parents or siblings of the couple may have a greater reaction than a 2nd cousin. These issues with extraneous variables don't even include potential differences between attendees in the amount of alcohol (or other psychoactive substances) consumed, which is common at all sporting and musical, as well as weddings.

In comparison, religious ritual, given its highly regimented form (according to Rappaport (1999), religious ritual tends to fall into the top tier of the Abrahams (1973) five-tier system), tends to have specific sets of behaviours that all members of the congregation are expected to do. At a Christian Mass, almost all attendees will sing the hymns, almost all attendees will stand and sit at about the same time (having roughly the same amount of exertion), almost all attendees will imbibe the same amount of psychoactive chemical (if any), via holy communion wine. This level of control over possible extraneous variables makes religious ritual an important subject of study for those interested in studying social bonding in naturalistic settings, even if they have no prior interest in religion or ritual in and of themselves.

However, given that the main aims of this thesis are specific to understanding religious ritual, the benefit of better controlling extraneous variables outlined in the previous paragraph is simply a nice bonus when studying social bonding in a religious ritual context. Given this, it is now time to reflect on what is currently known about what might cause social bonding within religious rituals.

2.2.3. Causes of bonding in religious rituals

With an understanding of how social bonding occurs outside of religious ritual, I can now ask the question: What exactly is it about religious rituals, in particular, that would cause sociologists and anthropologists to comment on how it appears to create social cohesion?

[12] Moshing, sometimes called 'slam-dancing', is an activity that takes place during music concerts. It started within the punk rock scene, but has since become popular at performances in other genres, including hard rock, metal, and even rap. It is a hyper-physical improvised 'dance' where people engage in uninhibited activities such as deliberately colliding with, pushing, kicking, or hitting others (see Barker, 2019; Frazier, 2020 for more information).

Shared attention, goals and synchronised actions are strongly linked to an increase in feelings of social attachment (Fischer et al., 2013; Reddish et al., 2013; Wolf et al., 2016). Religious rituals appear to confer upon the adherents a distinct, unified sense of purpose, as well as often demanding synchronised behaviours. Anthropologists often cite shared actions and intentions as the key factor for an increase in social cohesion found from religious rituals (Ehrenreich, 2007; Levitin, 2008). Similarly, Van Cappellen & Rimé (2013) have argued that it is the shared actions and a unified sense of purpose found within religious rituals that also elicits positive emotions. They argue that these positive emotions then go on to increase feelings of social bonding.

Music making, while not any more effective in fostering social bonding than other synchronised behaviour (Rennung & Göritz, 2016), is a vital part of most religious ritual. We find music in all modern religious rituals (Chaves et al., 1999) as well as in other ritually constrained religions (Atran, 2002). This is to the point where music is said to be inseparable from religious rituals (Alcorta & Sosis, 2005). This can go so far in some cultures, such as the African Igbo tribe, that music and religion share the same word (Becker, 2001). Alcorta & Sosis's (2005) suggest that the use of music within religious ritual leads to the increased levels of social bonding in religious rituals.

Some have stated that the religious beliefs alone (in the context of this thesis – the belief in the super-empirical) lack both emotional salience and motivational force without the collective behaviours conducted in rituals (Sosis, 2003). If this were true, it is not clear whether the religious component of a ritual plays a role in social bonding that takes place, or if it is superfluous (re: social bonding). From an evolutionary perspective, if the religious component was not an important cognitive mechanism in some way, then behaviourally similar non-religious rituals should be universal, and the religious beliefs would not be universal. However, religious rituals *are* universal (Brown, 2000). It could be the case that the structure of the religious component(s) within a given ritual framework provides a strong reason for congregation members to return to the rituals on a regular enough basis to 're-up' on their social bonding hit (to utilise addiction terminology, cf., Burkett & Young, 2012). Alternatively, it could be the case that religious rituals themselves are innately better able to create a sense of connection than non-religious rituals. A third possibility is that religious rituals are better able to create a connection to the object of worship, such as their deity, which itself leads to a feeling of social bonding.

Whitehouse, in his theory of ‘modes of religiosity’ (Whitehouse, 2000, 2002, 2004b), leans towards the first of these possibilities (the religious aspect provides a *reason* to return to perform rituals, and religion provides the framework on why the rituals should be performed and passed on at all). Whitehouse (2000, 2002, 2004b) suggests that the ‘modes of religiosity’ model expands on categorisations of religion from prior anthropological and sociological work, which suggests that religion comes in two distinct forms (Gellner, 1970; Goody, 1975; Weber et al., 1963; Weber & Kalberg, 1930/2013). Likewise, Whitehouse (2000, 2002) discusses two major ‘modes’ of religious practice: the doctrinal, and the imagistic. This distinction is made to describe the difference between highly stimulating, emotionally intense expressions of religion (imagistic) and those expressions that are more sedate, with the purpose of transmitting theology (doctrinal). Specifically, Whitehouse characterises these two ‘modes’ of religious expression as effectively falling into two types of religious ritual, where the imagistic expressions have high-arousal, low-frequency rituals, and doctrinal expressions have low-arousal, high-frequency rituals. The critical thing noted by Whitehouse (2000, 2002) is that these two types of religious expression can occur within the same religious tradition, and even interact with one another. For example, Muslims are expected to pray (a low intensity activity) five times per day (with high frequency), but they are also encouraged to take a pilgrimage (the Hajj; a highly-emotionally intense experience) once in their lives (with low frequency).

Under the modes of religiosity framework, both high- and low-intensity rituals are important for allowing religion to propagate and, therefore, for religious ritual to have become universal. The consistent repetition of low-intensity rituals are designed to teach the doctrine: with enough repetition, even the difficult-to-remember concepts, dogmas, and stories of the religion can be remembered. Whereas, the high-intensity rituals are designed to create a long-lasting sense of connection to the group, ensuring that there is a continued motivation to continue doing the low-intensity rituals. Those who subscribe to the modes of religion theory also conform to the ideas laid out in section 2.1.4. that group identification (i.e., self-other-overlap) and identity fusion are distinct constructs (Whitehouse & Lanman, 2014). In fact, Whitehouse and Lanman (2014) suggest that the doctrinal (low-intensity) mode of religious ritual produces group identification, whereas the imagistic (high-intensity) mode produces identity fusion. This distinction, in my mind, is of great importance. All three primary aims and both secondary aims of this thesis centre around social bonding (which I have defined as an emotion – i.e., a short-term feeling). Because of this, a focus on high-intensity, low-frequency, imagistic modes of religious ritual that lead to identity fusion – a long-term change – is not relevant for the aims of the thesis, and it will be the doctrinal modes of religious ritual that will be the subject of research.

So, the purpose of doctrinal modes of religious ritual is to provide the concepts, dogmas, doctrines, and stories of the religion in a manner that they are more easily remembered, but also to encourage group identification (self-other-overlap). I believe these two are intrinsically linked, too. My thoughts are that doctrinal rituals are designed to espouse *concepts* that cause an increase in positive affect, which will *broaden* attendees' focus outside of the self (Fredrickson, 2013), allowing for the use of *stories* to create a combination of joint attention (e.g., jointly attending to a pastor/rabbi/imam/etc. telling the story), where the stories contain specific *doctrines* (e.g., spiritual enlightenment is something to strive for) creating a shared goal, and the *dogmas* (e.g., deities can hear prayer, and see acts) leading to repetition of synchronised behaviour (singing of hymns, repeated standing and sitting, rocking back and forth, prostrating, etc.) to cause a greater level of social bonding with others in the group (the *build* component of the Broaden and Build hypothesis). Importantly, my interpretation of the doctrinal mode of religious ritual means that the *broadening* caused by positive emotions also leads to a greater perception of group entitativity for the religious group.

To clarify, the approach to religious ritual I have here is that doctrinal religious rituals (henceforth, religious rituals, for ease of writing) create a greater level of group entitativity and sense of social bonding. However, while it is plausible that this is the case, it is not known whether the religious aspect of religious ritual (i.e., the stories of the super-empirical, the super-empirical concepts, and the dogmas about the super-empirical) actually contribute to social bonding. It is still an unanswered question in the scientific study of religion (Dunbar, 2017b). As such, one of the major aims of this thesis is to determine if the religious aspect of a ritual plays a key role in the social bonding that takes place. Importantly, the behaviours that make up religious rituals provide some explanation of the behavioural mechanisms underlying the social bonding taking place during religious ritual, and could apply to behaviourally identical non-religious ritual just the same. This may mean that the religious component is superfluous, in terms of social bonding.

One method that has been used to assess whether religion plays a specific role in social bonding is to assess how religious primes alter prosociality (as prosociality is highly correlated with social bonding; Rennung & Göritz, 2016). There is now a large body of research that has shown that priming participants with religious imagery leads to prosocial behaviour (e.g., Xygalatas, 2013). In fact, meta-analyses on the role of religious priming across 93 studies with 11,653 participants found that religious priming shows robust effects on prosocial behaviour (Shariff et al., 2016). However, the effect of religious priming does not seem to be reliable in those who are not religious (Shariff et al., 2016).

To extend this from religious primes to religious ritual, in participants without a belief in the super-empirical, it may be that the stories, concepts, and dogmas of a religious ritual do not work in encouraging social bonding. Returning to primes, in work that assessed whether religious primes were particularly special in their ability to generate prosocial behaviour, Johnson and colleagues assessed prosocial behaviour after either religious prime *or* secular prime, as well as having a non-prime control condition (Johnson et al., 2015). They found that those in either the religious or secular prosocial priming conditions had increased levels of prosocial behaviour over the control condition (Johnson et al., 2015). As prosociality (religious or secular) was explicitly primed in the Johnson et al. (2015) study, whereas simply "religion" was primed in prior studies (where prosociality is only implied by the idea of religion; e.g., Xygalatas, 2013), it is not clear whether the religious aspect is important for prosocial behaviour (or social bonding, re: ritual).

In some similar work on religious vs. secular priming, and in contrast to previous results about behavioural synchrony, Cohen and colleagues (Cohen et al., 2014) found that synchronised movement alone was not enough to lead to increased feelings of social bonding (measured via 3 questions: (1) “How connected did you feel to other participants”, (2) How much did you trust the other participants, and (3) “How similar are you to the other 3 participants?”). Cohen et al. (Cohen et al., 2014) found that synchronised drumming only lead to increases in social bonding when a religious prime was used, but not when a secular prime was used.

I think it is important to highlight here that conducting a study with a religious prime does not make the activities undertaken in the remainder of the study to be religious, nor make them rituals. As defined in section 2.1.2., for something to be a ritual, the act must include the repeated performance of more-or-less invariant sequences of formal acts and utterances not entirely encoded by the performers, and that lack direct instrumental purpose. In that section, I specifically outline what would not necessarily be included as a ritual, music performance being one of them. Importantly, the drumming that the participants were asked to perform did not lack a direct instrumental purpose. Similarly, while half the participants were religiously primed (i.e., the importance of the drums within certain religions were made aware to them), the participants were not told that they were playing the drums with direct reference to the super-empirical. In this way, the participants were not only not performing ritualised behaviour, but they were also not conducting religious acts. To clarify, being shown religious iconography, or to have a story about the importance of tools to some religions is to be religiously primed. However, for an act to be religious, it must be conducted directly with reference to the super-empirical. Thus, religious vs. secular priming studies, while interesting, are not to be confused with studies on actual religious acts, such as religious ritual.

In summary, there are known behaviours that appear to lead to social bonding. Religious ritual contains many of these behaviours. Similarly, studies on the neurochemical mechanisms of dyadic social bonding in settings outside of religious ritual suggest that μ-opioids play a necessary role. However, in the context of group religious ritual, the importance of the religious component of ritual, and the importance of μ-opioids in group ritual social bonding, are still yet to be established.

Religious priming studies have attempted to assess whether the religious component is important, but have found inconsistent results. Moreover, such priming studies are not necessarily reflective of actual religious acts, such as religious ritual. So, the studies within this thesis seek to address these gaps in knowledge.

2.2.3.1. Theoretical model

Having elaborated in writing on how religious ritual may lead to increases in feelings of social bonding, I think having a visual representation of the theorised mechanism of action would be useful to help clarify things. Figure 2.1. shows the proposed neurochemical mechanism by which ritual (be it religious or secular) might lead to increases in feelings of social bonding.

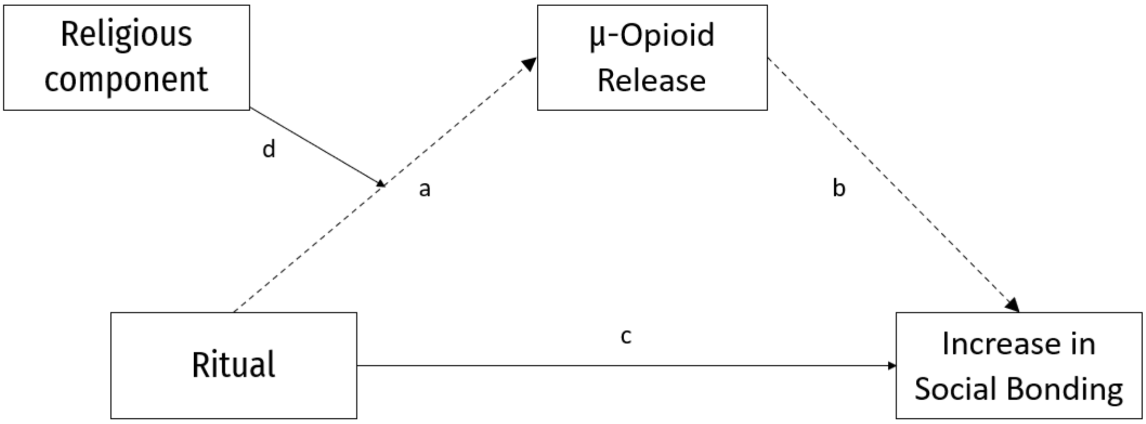


Figure 2.1. The theorised mechanism of action laid out in the thesis. Here, the dotted arrows are the theorised pathway of action for how ritual (religious or secular) might lead to increases in social bonding. This thesis plans to assess, through a series of studies, whether each of pathways shown by arrows in the diagram do exist. Effect ‘a’ is that ritual leads to an increase in levels of μ-opioid receptor activation. Effect ‘b’ is that it is the of increase in levels of μ-opioid receptor activation leads to an increase in social bonding. Effect ‘c’ is simply that ritual (be it religious or secular) leads to an increase in social bonding. In this model, effect ‘c’ is only observed because of effects ‘a’ and ‘b’. Effect ‘d’ is a possible effect that may or may not be present. Effect ‘d’ would be that the religious component of a ritual modulates the effect ritual has on social bonding, via a difference in the levels of μ-opioid receptor activation.

2.3. On Measuring Social Bonding

Before conducting any studies that seek to assess social bonding, however, there is an elephant in the room. One needs to be able to reliably measure social bonding across settings. In their meta-analysis of the effects of social bonding on health, Holt-Lunstad and colleagues (2010) note that very few studies that assess social bonding provide consistent measures of social bonding, nor do most provide a measure of *quality* of the social bond - instead many simply state whether a bond of any kind is present or not. Merely accounting for the binary existence or non-existence of a bond is an opaque measure of social bonding, and does not allow for much nuance for experimental research.

Some measures do exist to measure the 'quality' of a social bond. However, these often only measure a single aspect of what might be considered a social bond. As outlined in section 2.1.4., the inclusion of others in self scale (IOS; Aron et al., 1992), a seven-point scale that uses visual cues for participants to respond to the question of how much they identify with a group (see Figure 2.2.), is a measure of self-other-overlap. There are those who view self-other-overlap, or group identification, as synonymous with the concept of social bonding (e.g., Newson et al., 2018). However, this only measures a specific aspect of the bonding experience: the level of identification one has with the group you are bonded with. Consequently, many researchers, who are interested in different aspects of social bonding, use other measures to assess the level of social bonding, either alongside self-other-overlap (e.g. Tarr et al., 2018) or without it entirely (e.g. Inagaki et al., 2019a). This often leads to researchers each creating their own, new question or measure to assess social bonding (e.g. Hove &

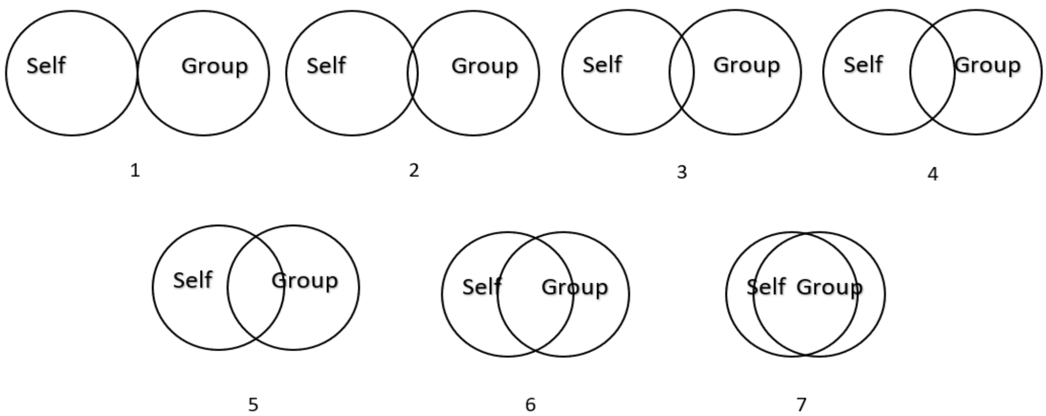


Figure 2.2. The inclusion of others in self (IOS; adapted from Aron et al., 1992)

Risen, 2009; Valdesolo & DeSteno, 2011; Wiltermuth & Heath, 2009), making comparisons of social bonding across studies very difficult (Holt-Lunstad et al., 2010).

In previous research, social bonding has been measured in numerous ways. It is been measured as a feeling of connection to others (Wiltermuth & Heath, 2009), how much one liked the others in the group (Hove & Risen, 2009), how much participants had in common with others (Valdesolo & DeSteno, 2011), among other measures. While each of these articles state that they assessed the same effect (social bonding), each of them asks a different question. Thus, claiming that these studies corroborate one another, or attempting to make comparisons between each of the studies becomes much more difficult. Moreover, in each of these articles a novel measure has been created but not compared with any previously validated measures of social bonding, such as the IOS (Aron et al., 1992).

Here, I see a major issue: social bonding appears to be conceived of as subtly different (identification with the group, having things in common with others, liking one another, feeling connected to one another, etc.), depending on the researchers conducting the study. While the concern with differences in ways of measuring social bonding was highlighted a decade ago (Holt-Lunstad et al., 2010), the issue still persists. There is still not a widely used, comprehensive measure of social bonding to account for the various approaches to assessing social bonding as a short-term emotion. To address the multiple possible interpretations of 'social bonding', we must acknowledge that social bonding likely cannot be measured using only a single question, and that a multi-item social bonding measure needs to be devised.

Across the research literature cited earlier in this chapter, and in the previous chapter, six main themes underlie researchers' conceptions of social bonding: (1) Trust (e.g. Kosfeld et al., 2005), (2) Identification with the group via self-other-overlap (e.g. Aron et al., 1992), (3) Commonality (e.g. Valdesolo & DeSteno, 2011), (4) Liking (e.g. Hove & Risen, 2009), (5) Connection (e.g. Wiltermuth & Heath, 2009), and (6) Emotional Closeness (e.g. Inagaki & Eisenberger, 2013; Inagaki et al., 2019b). As such, for any measure of social bonding to meet a basic level of face validity, it should measure each of these components.

As I view social bonding as an emotion, much like other emotions (such as happiness; O'Connor et al., 2015; Swami et al., 2009), I believe that these different components make up a single, unidimensional latent variable of 'social bonding'. When creating any measure, it is important to validate it by comparing it with pre-validated measures of social bonding. As the IOS (Aron et al.,

1992) appears to be the validated measure of choice in a wide variety of research, I plan to first assess the dimensionality and reliability of the measure without the IOS. I will then correlate the five-question version of the measure (SB5) to the IOS. If correlation between the SB5 and IOS is above .6 (i.e., is moderate-to-high), they are likely measuring the same construct. If this is the case, the IOS will be integrated into the social bonding measure to bring it closer to face-validity and create the six-item social bonding measure (SB6). For more information on the social bonding measure created for this thesis, and how the dimensionality will be assessed, see Appendix 1.

3. Chapter 3. Social Bonding During Religious Rituals

Table 3.1.

Table showing the CRediT allocation for Study 1. Initials are provided for each author for each role they contributed towards. The order of the initials for each role denotes the level of contribution (i.e., appearing first on a contributor role means this co-author contributed most for this role unless otherwise specific)

Role	Author(s)	Role	Author(s)
Conceptualisation	SC*, MF*, VvM*, FW†, JW†, RIMD† , LT	Resources	FW
Data Curation	SC	Software	
Formal Analysis	SC	Supervision	MF, VvM, RIMD
Funding Acquisition	RIMD, FW, MF, LT, JW,	Validation	VvM
Investigation	SC, JB, VvM, RD, EM,	Visualisation	SC, VvM
Methodology	SC, MF*, VvM*, RIMD*, FW, JW	Writing – Original Draft	SC
Project Administration	SC*, VvM*, MF*, RIMD†, FW†	Writing – Review and Editing	SC, VvM, MF, RIMD, FW, JB, EM, LT, JW

* Equal primary contribution

† Equal supporting contribution

As covered in Chapter 2, the brain-opioid theory of social attachment (BOTSA) proposed that opioids provide the neurobiological underpinnings of social bonding. Opioids appear to be activated in the brain by a variety of social activities, including social touch, laughter, singing, dancing and feasting. Several of these seem to be involved in the processes of bonding whole communities by allowing large numbers of individuals to be bonded simultaneously. It has been suggested that religious rituals may also be part of this 'bonding toolkit'. This chapter describes a largescale, multi-national field study that was conducted, in which religious ritual attendees' opioid-release was measured via a behavioural proxy, alongside measuring cognitive-affective processes before and after religious ritual. This chapter is adapted from the article "Religious Rituals Increase Social Bonding and Pain Threshold". The other co-authors were Dr Valerie van Mulukom, Dr Miguel Farias, Revd. Jennifer Brown, Romara Delmonte, Dr Everton Maraldi, Dr Leon Turner, Dr Fraser Watts, Dr Joseph Watts, and Dr Robin I. M. Dunbar. The contribution of each co-author is listed in Table 3.1.

3.1. Background to Study 1

Religious rituals have been of interest to social scientists for over 100 years (Cnaan & Heist, 2018; Durkheim, 1912; Freud, 1927/1961; Weber, 2013), in part because of their ubiquity across the globe (Norenzayan, 2010). The first study that makes up this thesis sought to explore some of the reasons behind why religious rituals are universal. Dunbar (Dunbar, 2017b) suggests that one key reason for religious ritual to be so prominent is its ability to cause the formation and maintenance of social bonds, which occur during religious rituals in a way that is more effective and efficient than other mechanisms. His argument is presented as an extension of the BOTSA (Machin & Dunbar, 2011; Panksepp et al., 1978) and of the social brain hypothesis (Dunbar, 1998). While BOTSA was briefly summarised in chapter 2 (2..2.1.3.), the social brain hypothesis was only briefly mentioned but not explained. Consequently, here I will briefly summarise the social brain hypothesis, and then proceed to apply it and BOTSA to religious rituals, and then describe how these were tested in a field study across religious groups in both the UK and Brazil.

The social brain hypothesis (Dunbar, 1998; Dunbar & Shultz, 2007), posits that primates' larger than average brains is both caused by socialisation and contributes to their ability to socialise. Because brain activity is energy intensive, maintaining a larger brain is a barrier to evolutionary fitness. Thus, this increase in size, especially that of the neocortex (Dunbar & Shultz, 2007), must confer an evolutionary advantage to be worth the cost of upkeep. The social brain hypothesis proposes that it allowed primates to improve their ability to bond socially and manage these bonds by helping keep track of larger social networks and adapting an understanding of group members' social interactions (Dunbar, 1998; Dunbar & Shultz, 2007).

Over the years, this hypothesis has been the subject of much scrutiny (see Powell et al., 2017 for an overview), and there is a large evidence base providing strong support for it (Oesch, 2018;

Powell et al., 2012). In humans, Powell et al. (Powell et al., 2012) demonstrated that orbito-frontal cortex volume predicts social network size, serving as a within-species example of how neocortex size relates to social behaviour. More generally, Oesch (Oesch, 2018) conducted a wide-ranging literature review, covering primatology, social psychology, comparative animal behaviour, evolutionary anthropology, behavioural endocrinology, social cognitive neuroscience, developmental psychology, and psychopathology, and showed that in each field there was substantive evidence in support of the social brain hypothesis. Due to the energy costs that come with increasing brain size, this body of evidence suggests that sociality is, in some way, evolutionarily adaptive.

One example of evolutionary benefits of sociality includes the capacity for communal living, which has a range of advantages, such as improving the efficiency of child-rearing and food collection. In addition, there is now considerable evidence to suggest that the size of one's friendship circle has a significant positive impact on health, survival and general wellbeing (Dunbar, 2018). While social bonds provide a benefit, maintaining bonds over time is difficult due to the necessity to invest time, energy, and other resources into ensuring that the bond continues. Because of this difficulty, primates have developed behaviours to foster and maintain these bonds, such as one-to-one grooming (Matheson & Bernstein, 2000). BOTSA expanded on this and proposed that more advanced behaviours (such as group synchronised behaviour, group laughter, and music making) act as an extension of the one-to-one grooming behaviour. These behaviours have an advantage over grooming behaviours as they can affect larger groups (one-to-many) as opposed to being one-to-one, making it a far more time-efficient way of encouraging bond formation and maintenance.

3.1.1. Religious Rituals

To answer the question of why religious rituals are ubiquitous, it has been suggested that religious rituals reliably encourage the release of endogenous opioids, specifically μ-opioids, to foster the expansion and maintenance of larger social groups in humans (Dunbar, 2013). This has been proposed to occur via two processes: (1) by including overtly painful experiences, such as fire walking (Konvalinka et al., 2011; Xygalatas et al., 2011) or body piercing (Xygalatas et al., 2013), which encourages the release of μ-opioids via the natural pain response; and (2) by engaging in specific group behaviours, such as group synchronised movement (Bamford et al., 2016; Cross et al., 2019; Tarr et al., 2015; Wiltermuth & Heath, 2009) and music making (Pearce et al., 2016).

There are many varied Religious rituals both within and between religious traditions. They can be a simple ritualised meal or a short prayer, such as the Passover Seder or the Shema from the Jewish tradition (i.e., doctrinal modes of ritual), to complex, painful acts such as fire-walking as in the Sawau clan, self-flagellation as seen in the procession of Ashura, or extreme body piercing, as seen in the Thaipusam festival (i.e., imagistic modes of ritual). When it comes to the imagistic modes of ritual, both participants and attendees often claim to feel a connection with others in attendance (Fischer & Xygalatas, 2014; Fischer et al., 2014; Frecska & Kulcsar, 1989; Power, 2018; Xygalatas et al., 2011). However, these studies have largely been conducted during imagistic rituals. As outlined in Chapter 2 (2.1.4.), the imagistic rituals likely cause identity fusion, which is distinct from social bonding in key ways.

But what of lower-intensity rituals (i.e., those more akin to doctrinal modes)? In-group ritual bonding has been demonstrated in children who took part in a novel, structured, and synchronised ritual compared to a non-ritual, unstructured control activity (Wen et al., 2016). Wen et al. (2016) had children (matched for ethnic diversity, sex, age, socioeconomic status, as well as school curricula) take part in afterschool activities. One set of children were assigned to the ritual condition, the other to the non-ritual condition. Each condition was split into two groups, “Yellow” and “Green”, which came with appropriately coloured wristbands. Children were explicitly told that neither group was better than the other. In both conditions, children were tasked with making necklaces. In the control condition, children simply made necklaces. In the ritual condition, each colour was giving a specific set of instructions on how to make the necklace in a ritualised way “the special [colour] way”, e.g., 3 hand claps, string a piece on, touch the next piece to their forehead, string that piece, 3 more claps, string a piece on, touch the next piece to their forehead… etc., all of which was synchronised. Children in the ritualised condition showed greater preference for the in-group than those in the control condition.

The feeling of bonding that leads to greater favourability of the in-group during the necklace making ritual may be the result of behaviours taking place during the rituals, which have been shown to encourage feelings of bonding independently, such as shared attention (Wolf et al., 2016), or synchronised movement (Bamford, 2017; Jackson et al., 2018; Lang et al., 2017; Wiltermuth & Heath, 2009). In short, religious rituals may capitalise on the ability for these behaviours to encourage social bonding by integrating them into the rituals to promote social bonding within a meaningful context of joint goals (Reddish et al., 2013).

3.1.2. Measuring mu-opioid release in field research

This is the first study, to my knowledge, to directly test the hypothesis that religious rituals foster social bonding via μ-opioid release. Field research in the understanding of μ-opioids remains rare (Gangestad & Grebe, 2017), as there is great difficulty in directly measuring their levels in the field. This is because β-endorphin, the body's main μ-opioid agonist, does not readily pass through the blood-brain barrier (Witt & Davis, 2006). This means that invasive procedures, such as a spinal tap, are thought to be needed to measure β-endorphin levels in the central nervous system directly, something that is clearly not possible in fieldwork. However, since μ-opioids act as a natural analgesic (Zubieta, Heitzeg, et al., 2003; Zubieta, Ketter, et al., 2003; Zubieta et al., 2001), one solution has been to use pain threshold and/or pain tolerance as proxy measures for μ-opioid release in experimental research (Cohen et al., 2010; Pearce et al., 2017; Tarr et al., 2014; Tarr et al., 2016). As was pointed out by peer reviewers of the article that this study eventually formed, opioid receptor activation is only one aspect that contributes toward the totality of pain sensitivity. Pain sensitivity, while altered by opioid receptor activation, can be modified by other ascending or descending pathways. As such, pain threshold is only an approximate proxy tool by which we can measure central nervous system opioid activation. Because of this, none of the conclusions being made from this study can be causal in nature.

3.1.3. Research that is worldwide, in-situ, local, and diverse

In this study, I lead a research team to conduct a field study that took place at 24 religious rituals across the United Kingdom and Brazil. At these sites, levels of social bonding and pain threshold – as a proxy for opioid release – were measured both before and after the rituals. As research also suggests that emotional state is related to both pain perception (Edwards et al., 2016; Rhudy & Meagher, 2001) and changes in opioid tone (Koepp et al., 2009; Nummenmaa & Tuominen, 2018), and that positive affect plays a role in social bonding (Fredrickson, 2013), I also measured affect before and after the rituals.

The reasons I opted to study rituals in both the UK and in Brazil were two-fold. The first reason to include rituals from a Brazilian religion meant that I was meeting calls not only to move beyond the usual biases associated with historic sampling in psychology. Psychology has a history of only studying individuals from Western Educated Industrialized Rich Democratic (WEIRD) populations (Henrich et al., 2010; Rad et al., 2018), specifically white, middle-class university students. This is especially true in the psychobiology of social bonding (see Bakermans-Kranenburg & van Ijzendoorn, 2014 for one such criticism). While the psychology of religion (especially the cognitive science of religion) has made a clear improvement (see Newson et al., 2019 figure 1), from conversations I have had with other academics, there are some who suggest that conducting research in non-Western populations is simply serving as a ‘tick-box’ exercise, or even as an attempt to jump on the “non-WEIRD” terminology to promote otherwise-uninteresting research.

However, I believe that specifically assessing a religion that is native to Brazil also allowed us (me, and others in the research team) to measure not only worldwide (i.e., non-WEIRD) populations, but also ensures that the research conforms to more recent suggestions that psychology of religion research is conducted in-situ (to help with ecological validity (Cole et al., 1994), and to avoid the ‘white room’ effect (Cicourel, 1996)), that it accounts for local understandings of religion, and to ensure a more diverse sample (Newson et al., 2019). The idea of conducting research that is worldwide, in-situ, local, and diverse in nature (WILD; Newson et al., 2019) allows one to study both non-WEIRD *and* WEIRD populations simultaneously, and in a way that is not simply serving as a ‘tick-box’ as an attempt to win over otherwise-uninterested readers. Instead, I see it as a way to address concerns about the generalisability of lab-based social bonding findings (Gangestad & Grebe, 2017), especially those that have been highlighted from a psychobiological perspective (Bakermans-Kranenburg & van Ijzendoorn, 2014; Gangestad & Grebe, 2017).

The second reason that research in these countries (as opposed to other countries with other native religions) is simply that members of the research team had access to religious groups in both the UK and Brazil. Being open and upfront with this second reason, i.e., the opportunity bias, is important in understanding that even those who attempt to provide research that is WILD, and that seeks to address the concerns of bias in participant recruitment fall subject to other issues, such as opportunity bias and availability bias.

Despite significant differences in the belief systems of the UK and Brazilian rituals, some clear similarities are present (see Table 3.2. in the Method section): the presence of prayer, communal singing, time spent focusing on an individual speaker directing their attention to the congregation, and ritualised standing and sitting. It is these ritual common behaviours that are hypothesised to lead to social bonding (Dunbar, 2013).

3.1.4. Aims and hypotheses

There were four purposes for conducting this first study. The first goal was to provide evidence that feelings of group social bonding increase from before to after participation in religious ritual (to help address the first primary aim of the thesis, as laid out in Chapter 1), The second main goal of this study was to provide evidence that μ-opioid activation (as measured via pain threshold proxy) is related to group social bonding within religious ritual (to help address the second primary aim of the thesis, as laid out in Chapter 1). The third goal of this study was to demonstrate that the social bonding measure created for this thesis is both valid and reliable (addressing the first secondary aim of the thesis, as laid out in Chapter 1). And, finally, the fourth goal was to conduct analyses to help find other cognitive-behavioural that have a relationship with increasing feelings of group social boding during religious ritual.

In the original plan for this study, as well as measuring pain threshold as a proxy of mu-opioid release, it was planned that a measure of behavioural synchrony would be used to assess the effect of synchronised behaviour on group social bonding (Lang et al., 2017). However, due to various issues outlined both in section 3.1.5. (below) and in Appendix 2 (section S8), such a measure could not be created. Because of this, the experimental hypotheses brought forward from the pre-registration were limited to the following:

(1) The measure of social bonding will be higher after the religious ritual than before the religious ritual (see effect 'a' in Figure 3.1.)

(2) The measure of pain threshold will be higher after the religious ritual than before the religious ritual (see effect 'b' in Figure 3.1.)

(3) Participants' change in feelings of social bonding will be related to their change in pain threshold from before to after the ritual. (see effect 'c' in Figure 3.1.)

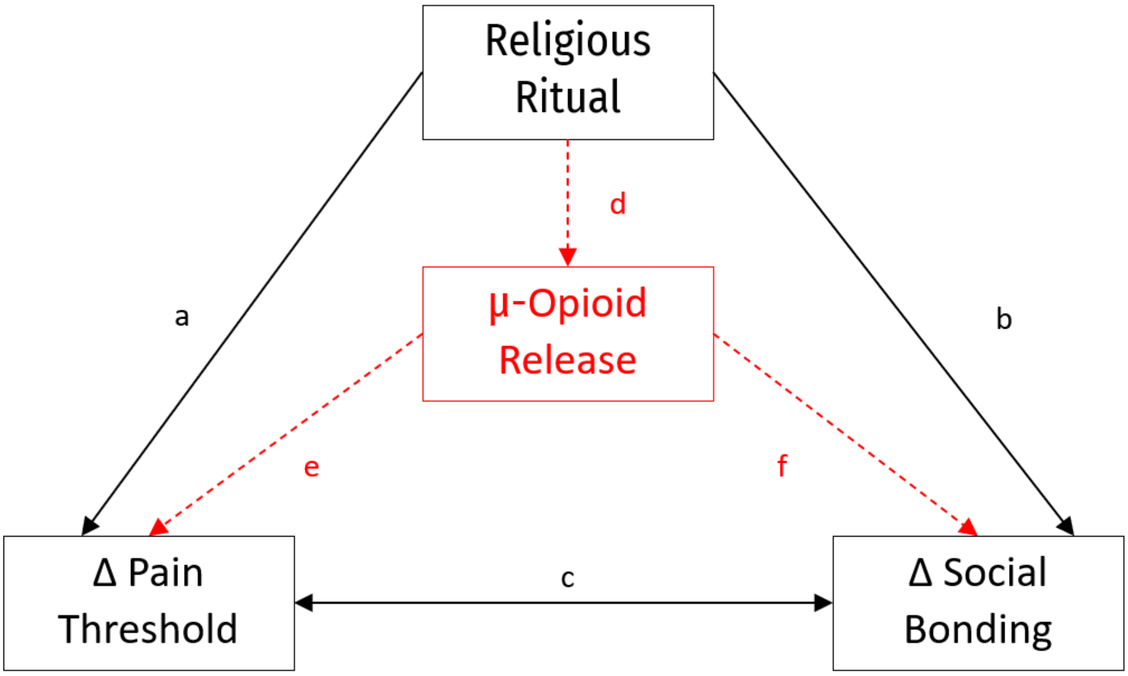


Figure 3.1.. An adapted version of the theorised mechanism of action laid out in the thesis in chapter 2 (2.2.3.1.). This version of the model is for clarity in what the current study is attempting to assess. Here, the dotted arrows are the theorised pathways of action. However, they are not measured, as we have no direct measure of µ-opioid release in these studies. Effect 'a' (which, I propose, acts via 'd' and 'e') is assessed when testing the first hypothesis using the Wilcoxon Signed Rank test (pain threshold increasing from pre- to post- ritual). Likewise, effect 'b' (which, I propose, acts via 'd' and 'f') is also measured via Wilcoxon Signed Rank test (social bonding increasing from pre- to post-ritual). Relationship 'c' (which only exists because of 'e' and 'f') is assessed using the regression/mixed-effects models .

3.1.5. Changes from the pre-registration

This study was also pre-registered on the Open Science Foundation (https://osf.io/tgfkm/, see Appendix 3). Due to some difficulties experienced during the study, there were some changes to the pre-registered plan. The first of the changes to the pre-registered plan is that there is no inclusion of an assessment of behavioural synchrony in the final analyses. This was due to the difference in recording quality between rituals as well as other, more technical issues. Regarding the technical issues, video files for three of the 13 UK rituals (23.1% of UK rituals) and two of the 11 Brazilian rituals (18.% of Brazilian rituals) were completely corrupted due to issues with the SD card in the camera. Video files for a further two UK rituals (15.4% of UK rituals) and four Brazilian rituals (36.4% of Brazil) suffered from intermittent cutting out, followed by the recording finishing before the end of the ritual. The cause of the intermittent cutting out is unknown, but it was likely a battery issue that was solved with a combination of a new battery and constant use of a portable charger. This meant that 38.5% of all UK rituals and 55.5% of the Brazilian Rituals had at least some technical issues that hindered or completely stopped the ability to assess behavioural synchrony. The difference in recording quality was caused by various factors including the different angles and fields of view caused by the vast differences in ritual spaces. This issue was particularly prevalent in the Brazilian rituals, where space was at a premium, and the view from the camera was often obscured entirely by attendees. Because of these issues, no systematic assessment of level of behavioural synchrony could be applied to all ritual sites.

The second change from the pre-registration is that the role of affect was not included in the pre-registered analysis plan, despite being a large component of the theoretical background. My initial focus was to assess the role of μ-opioids, and synchronised behaviour, on social bonding in a religious ritual context, and so I did not consider the role of affect at that time to be a major part of the analysis. I only realised the importance of affect to my own work after the pre-registration was uploaded. In hindsight, I uploaded this pre-registration earlier than I should have. While this may be a weakness of the first study, I believe that a PhD is a learning process. At the time of uploading the pre-registration (still during the first year of my PhD), I had only been newly introduced to the concept of a pre-registration, and I thought that only the most important measures of interest were to be included in the analysis plan, not all planned analyses. I have since learned that this is not the case, and having now read various guides for how to prepare and produce pre-registrations (e.g., Bosnjak et al., 2021; Krypotos et al., 2019; Reich, 2021), I hope not to make such errors again in the future.

The third major change from the pre-registration was made after suggestions from peer reviewers once the article that came from this study was submitted for publication. Due to the data's hierarchical structure (measurement occasion – level 1 – within participants – level 2 – within ritual site – level 3, see Figure 3.2.), I have opted to use linear mixed-effects models (multi-level modelling) to analyse my data. For transparency, I have also included the initial analyses that were planned.

Figure 3.2. A visual representation of the multi-level nature of the data. The measurement occasion (before or after the ritual) is level 1, which is nested within each participant (considered level 2), which are themselves nested within their ritual site (level 3).

3.2. Method

3.2.1. Participants

Participants were recruited from 13 Christian churches of different denominations in the UK (London, Coventry, Oxfordshire) and 11 Afro-Brazilian (Umbanda) religious groups in Brazil (São Paulo and Porto Alegre). All participants were aged 18 and over. In total 359 (M_{age} = 44.3 years, SD_{age} = 17.3, 246 women) participants were recruited across the UK (N = 113, M_{age} = 58.6 years, SD_{age} = 17.2, 77 women) and Brazil (N = 246, M_{age} = 38.0 years, SD_{age} = 13.4, 169 women). Of these, 91 participants met at least one exclusion criteria (see below), which left 265 total participants (M_{age} = 42.3 years, SD_{age} = 15.5, 180 women), 70 UK participants (M_{age} = 54.6 years, SD_{age} = 17.2, 47 women) and 195 Brazilian participants (M_{age} = 37.9 years, SD_{age} = 12.1, 133 women).

Pain threshold data were not collected for participants with a diagnosis of arthritis (Lee et al., 2011; Wessel, 1995), diabetes (Lee & McCarty, 1992; Themistocleous et al., 2016), and/or ADD/ADHD (Stickley et al., 2016; Treister et al., 2015), due to differences in pain perception. Given natural fluctuations that alter the release of μ-opioids during pregnancy (Genazzani et al., 1981; Goland et al., 1981; McMurray et al., 1990), pregnant participants were also excluded. I also controlled for recent alcohol intake (Horn-Hofmann et al., 2015; Thompson et al., 2017) and pain medication as additional exclusion criteria after data collection, given the effects of alcohol and pain medications on pain perception. Finally, a pre-session pain threshold measurement of the upper-limit value of 300mmHg was used as an exclusion criterion, as no upward change can be detected.

In the pre-registration, I conducted a power analysis that suggested the need to recruit 226 participants for the original analysis plan. However, this value was no longer appropriate as synchronised movement was no longer a variable that was used in the analyses. Consequently, to determine the number of participants required to reach an effect size appropriate for this study, I examined effect sizes of similar studies that assessed pain threshold. The only effect size specifically linking pain threshold and a measure of social bonding was provided by Dunbar et al. (Dunbar et al., 2016) at R^2 = 0.08. Using G*Power (Faul et al., 2007), I determined that conducting an "Exact" linear, two-tailed regression test to find this effect, with H_1 ρ^2 = .08 and H_0 ρ^2 = 0, α = 0.05, Power (1-β) = 0.8 with a single predictor, 115 participants would be sufficient.

I also conducted a multi-level model analysis. The calculation of power for a multi-level model, while possible (Snijders, 2005), is not simple for three-level data. I have expanded on this in Appendix 2 (also available online: https://osf.io/2hp6q/). In short, there are instances where 17 top-level objects would be appropriately powered. The data collected for this study likely conforms to these instances, and so 24 ritual sites would be enough for the multilevel modelling analyses to be appropriately powered.

3.2.2. Rituals

3.2.2.1. UK Christian Mass

The UK religious rituals were all Christian, but from varying denominations, including Roman Catholic, Methodist, Church of England, Baptist, and those that self-described as 'Evangelical'. While the exact nature of the content of the rituals differed, all of the UK church rituals included: (1) time spent praying, (2) communal singing while both seated and standing (3) periods of time where a leader (e.g. priest or minister) spoke from a lectern, pedestal or pulpit, (4) a moment of silence, and (5) a period of time where congregants were encouraged to communicate with one another (often via wishes for peace to be brought upon one another). Importantly, Christian Sunday Mass conforms to my definition of ritual (see 2.1.3.) as it contains repeated performance of more-or-less invariant behaviours that were encoded by others, and they contain behaviours which lack direct instrumental purpose (e.g., it is not clear why one should stand or sit when praying/singing, nor is there a direct instrumental purpose to pray out loud instead of in one's head, given the Christian belief that God knows one's thoughts). These acts are performed directly in relation to the super-empirical (in relation to the existence of Jesus, as the son of God, and to the belief in a God), which makes it a religious ritual.

3.2.2.2. Brazilian Umbanda

Umbanda is an Afro-Brazilian religion that seems to have appeared in the early 20th century (Espírito Santo, 2017). It blends spiritualism, Afro-Brazilian traditions (mainly Candomblé), indigenous American beliefs, and Roman Catholic prayers and images. Umbanda literally means "white magic". It exists mainly in South Brazil, but has spread to other parts of the country, as well as into parts of Argentina and Uruguay. While there are many branches of the Umbanda religion (due to there not being a centralisation of power, like there is in Catholicism), there are many commonalities between all branches, such as the belief in a supreme creator, and the syncretisation of sub-deities with Christian saints. Other beliefs common among almost all branches is the ability to contact spirits via psychics or mediums. It is not clear how many people in Brazil attend or identify as believers in Umbanda, because of a continuing and growing prejudice against Afro-Brazilian religions (Engler, 2017), especially from neo-Pentecostal Churches (Gonçalves da Silva, 2007), and because millions of Brazilians appear to attend such rituals without openly disclosing any affiliation with Umbanda (Engler, 2009).

More specific Umbanda beliefs are that a single God created all spirits in existence. Some spirits are incarnate in this world as humans, while others are incarnate in other forms (i.e., express themselves as external forces). For an Umbanda believer, it is natural for spirits to progress through many incarnations. Some of the "more evolved spirits incorporate in mediums as an act of charity" (Engler, 2017, p. 205).

Umbanda rituals include: (1) time spent praying, (2) time spent communal singing, (3) dancing or clapping, (4) time spent with a ritual leader speaking to the congregation, (5) time spent in silence waiting for a spirit to possess a medium, and (6) time spent communicating with the spirits in some way (for more detailed descriptions and ethnographies of Umbanda rituals, see Engler, 2017; Espírito Santo, 2017). See Table 3.2. for a comparison of elements that might be included in each of the ritual types to see the similarities and, importantly, the *contrasts* between the two religious rituals. As with differences between the rituals of separate sects of Christianity (e.g., Roman Catholicism compared to evangelical Protestantism), different Umbanda branches may contain aspects of ritual that are unique to their own branch. For example, in one of the 11 Umbanda rituals we went to, a medium possessed by a spirit used a sword held up in the air to signify they had been possessed. This sword was then swung in a dance-like routine throughout the possession. As this only occurred in a single Umbanda ritual, this type of expression (especially one so extreme) is not something that can be generalised across all Umbanda. The point to be made here is simply that Umbanda has many variances across ritual sites, due to the lack of centralisation. The six key components that were present at all Umbanda rituals are those listed above.

As with Christian Mass, Umbanda conforms to the definition of religious ritual because it is in relation to the super-empirical (spirits that can possess the mediums), and involves the repeated performance of more-or-less invariant behaviours (dances, singing Umbanda songs, standing and sitting) that were encoded by others, and they contain behaviours which lack direct instrumental purpose (there is no direct relationship between the standing/sitting, dancing, or singing and the spirits incorporating into the medium).

Table 3.2.

Traits that appear in each ritual site. This list is to show both similarities, and differences between the two ritual types. Behaviours that were specific to only some types of Christian Mass (e.g., use of an incense thurible) or Umbanda ritual (e.g., use of a sword) are not included.

Trait	**UK Christian MASS**	**Brazilian Umbanda**
Communal Praying	Yes	Yes
Moment of silent prayer	Yes	Yes
Communal singing	Yes	Yes
High-intensity dancing	No	Rarely
Low-intensity dancing	Rarely	Yes
Live instrument performance	Common	Common
Clapping	Rarely	Common
Spiritual possession	No	Yes
Intake of food/drink (e.g., holy communion)	Yes	Common
Ritual greeting (e.g., “peace be upon you”)	Yes	No
Spiritual leader/speaker (e.g., priest, head medium) being the focal point of the ritual	Yes	Yes
Changing from standing to sitting multiple times	Yes	Yes

Specialised role for some members of the congregation (e.g., church choir, supporting medium)	Yes	Yes
Specialised ritual space (e.g., a purpose-built church with a pulpit and religious iconography)	Very common	Rarely

3.2.3. Materials

3.2.3.1. Social Bonding

The social bonding scale created for this thesis described in chapter 2 (section 2.4) was used for this study. Five of these were measured on a seven-point Likert scale, from ‘1’ “not at all” to ‘7’ “extremely”: (1) “At this moment, how connected do you feel to the people in your congregation?” (adapted from Wiltermuth & Heath, 2009); (2) “At this moment, how emotionally close do you feel to the other members of your congregation as a whole” (adapted from Inagaki & Eisenberger, 2013); (3) “Thinking about everyone in your congregation now, how much do you trust the others in this group?”; (4) “How much do you like the people in your congregation overall?” (adapted from Hove & Risen, 2009); and (5) “Thinking about everyone in your congregation now, do you feel you have a lot in common with others in this congregation?” (adapted from Valdesolo & DeSteno, 2011). The last question was the pictorial Inclusions of Others in Self scale (IOS; Aron et al., 1992), which is a seven-point scale that uses Venn-diagrams to illustrate how closely one identifies with others, where ‘1’ signifies mostly separate identity and ‘7’ signifies extremely close identity. Answers to these questions were averaged into a single social bonding score (see results). A full version of the questionnaire can be found in the supplementary material on the OSF (https://osf.io/gnkp9/, see Appendix 5).

One key aim of this thesis was to create a valid and reliable multi-item measure of social bonding. As such, reliability was measured only after factor analysis assessment of the conditions underlying the dependable use of alpha was conducted. Cronbach’s alpha has been largely criticised in recent psychometric work because of alpha’s over-reliance on assumptions that are often violated in psychological research, especially Tau-equivalence (Peters, 2014). However, these assumptions can be actively tested for within a study (Charles, 2020). When the conditions for the dependable use of alpha are not met, the congeneric reliability measure McDonald's total omega (Dunn et al., 2014; McDonald, 2009) is used instead. Total omega (ω_t) is a reliability statistic that can be interpreted in much the same way as alpha, in that a value of at least .8 is considered fairly reliable and of at least .9 is highly reliable.

3.2.3.2. Pain threshold

This was measured using the 'pressure cuff method'. This is where a sphygmomanometer (typically used to measure blood pressure) is slowly inflated on the participant's upper, non-dominant arm at 10mmHg intervals each second until the participant indicates that they are 'very uncomfortable'. The measurement was recorded out of sight of the participant. The 'score' on this test is the pressure (in mmHg) which is listed on the sphygmomanometer when a participant signalled to the experimenter that they were very uncomfortable. For this, I used the ICE Medical Aneroid Sphygmomanometer with three cuffs (Item No: IM-AS3) with a measurement range of 0mmHg to 300mmHg (1mmHg = 133.32Pa, such that an equivalent upper bound of 300mmHg is 39,996.7Pa, or ~40kPa). This measure of pain threshold has previously been used in similar field and experimental studies (e.g. Cohen et al., 2010; Dunbar, Baron, et al., 2012; Dunbar, Kaskatis, et al., 2012). The pressure is taken before and after the ritual, with the difference in pressure taken as the change in threshold (ΔPT). This method of testing has been chosen because other common methods (such as the cold-pressor test or the wall-sit test) have been deemed biased or unsafe in non-lab conditions where the elderly may be involved, such as in churches (for more information, see Appendix 6). Due to the possibility of a ceiling effect (where participants reach 300mmHG), participants who reach the upper limit in the pre-service measure were excluded from data analysis related to pain threshold. For the full cuff measure protocol please see the protocol (Appendix 7, also available online on the OSF https://osf.io/ndv3h/)

3.2.3.3. Affect

We used the Positive And Negative Affect Scale (PANAS, Watson et al., 1988) to collect data on emotional state of participants both before and after the ritual. The PANAS asks participants to say how much they are feeling 20 emotions "at this moment" (10 with a positive valence, 10 with a negative valence) measured on a six-point Likert scale, from zero to five, where zero is "not at all" and five is "very much". Examples of positive emotions include 'Enthusiastic', 'Strong', and 'Inspired'. Examples of negative emotions include 'Distressed', 'Upset' and 'Ashamed'. The values for the 10 emotions for both positive and negative are summed to provide two scores: the sum of the scores for positive emotions, PANAS+, and the sum of scores for the negative emotions, PANAS–. Higher scores indicate greater levels of positive or negative affective state, respectively.

While this measure was not included in the pre-registration (see 3.1.5.), the inclusion of a measure of affect was included because of the theoretical implications of the Broaden and Build theory of positive affect (Fredrickson, 2013). Specifically, Broaden and Build theory suggests that positive affect should lead to an increased likelihood of social bonding. As such, analyses will be conducted to determine whether levels of positive affect predict levels of social bonding.

Ekkekasis (2008, 2012, 2013) suggests a three step process to determining how to measure feelings. Step one is to determine which of the constructs that come under feeling (affect, emotion, or mood), that you wish to assess. In this instance, affect is the primary construct of interest. Step two is to understand what kind of theoretical framework you wish to utilise. Here, there is more difficulty, as affect has been characterised in two ways. One theory of affect is that it is a single unidimensional construct with two poles, where a "low" score would mean negative affect and a "high" score would mean positive affect (cf. Pleasantness-Unpleasantness; Russel, 1980). Others suggest affect is two independent factors (positive affect as being independent from negative affect), where each can have a high- or low- intensity and that these do not necessarily effect one another (e.g., Watson, 1988; Watson et al., 1988; Zevon & Tellegen, 1982). Given real-world evidence of the independence of positive and negative(Watson, 1988), the two-factor model of affect was used. The third step recommended by Ekkekakis (2008, 2012, 2013) is to decide on a psychometrically robust measure. The PANAS has been repeatedly shown to be a robust psychometric measure (DePaoli & Sweeney, 2000), which has been validated in both British and, importantly, Brazilian populations (Carvalho et al., 2013). For this reason, the PANAS was used to measure affect.

3.2.3.4. Religiosity

Given the findings of religious priming research discussed in Chapter 2 (2.2.3.) that religious priming lead to different outcomes based on the religiosity of the participants (Shariff et al., 2016), we felt that it was important to determine religiosity of participants, as it may play a role in the effects of religious ritual. Given my definition of religiosity (the belief in the super-empirical), measures of religiosity should be concerned with belief. However, based on advice from an academic advisory board, including co-investigators FW and LT, the former of whom was the then-president of the International Society for Science and Religion, religiosity was measured with the Duke University Religion Index (DUREL; Koenig & Büssing, 2010). As conceived, the DUREL is a measure of religiosity that splits into three factors: organised religious activity (ORA), non-organised religious activity (NORA), and intrinsic religiosity (IR). However, most empirical assessments of DUREL, in both English and other languages, tend to find a single-factor solution is most appropriate (Chen et al., 2014; Dobrowolska et al., 2016; Hafizi et al., 2013; Lucchetti et al., 2012; Saffari et al., 2013), including in Brazilian populations (de Paula, 2015). Because of this, a single 'religiosity' score was used.

On top of the questions within the DUREL about religiosity (which focus on frequency of religious behaviour and relative importance of/commitment to their religion), participants were asked to rate their own level of religiosity on a single seven-point Likert scale. The purpose of this was to provide a rough approximation of their self-determined belief in the super-empirical. A more direct question about the super-empirical was not asked because of the complexity and abstractness of the concept of super-empirical realities. In an ideal world, to truly assess the level of religiosity participants would provide how many super-empirical realities they believe in, and this continuous measure could be compared. However, given that the average attendee at any religious ritual has likely never heard the term 'super-empirical reality' before (let alone be able to quantify how many super-empirical realities they believe in off-hand), I opted for a more easily-understandable measure. Measures of religiosity were used in follow-up analyses, and not to directly test pre-registered hypotheses.

Because of historic reports of religious ritual attendees describing not just feeling closer to other participants, but also to their object of worship, participants were asked after the ritual "During today's ritual, did you feel connected to God, Jesus and/or the Holy Spirit?". In Brazil 'spirit guides' was added to the question, such that an English translation would read "During today's ritual, did you feel connected to God, Jesus, the Holy Spirit and/or spirit guides". This was considered a measure of 'connectedness to God/a higher power' during the ritual. This question was measured on a seven-point Likert scale, with one being the lowest and seven being the highest value. This was included for use in follow-up analyses.

3.2.3.5. *Behavioural Synchrony*

There were multiple ways in which the behavioural synchrony variable attained from video data could be measured. As the variable did not end up being used, (see 3.1.5.) I will relegate discussion of the thought process behind how to measure behavioural synchrony to the appendices (Appendix 4).

3.2.3.6. *Demographics and other variables*

Age was recorded, as age may cause a change in how opioids are released in the body (Zhao et al., 2012), where older animals tend to be more sensitive to increased levels of μ-opioids (Paul, Gueven & Dietis, 2018). Similarly, gender was recorded as gender may also affect the way in which μ-opioids bind to receptors in the central nervous system (Kieffer, 1999; Sarton et al., 2000; Zubieta et al., 1999). Level of education was also asked for. I also collected information such as size of the ritual group (number of non-clergy in attendance), length of ritual (in minutes) and religious denomination (for Christians).

3.2.3.7. *Translation of survey for use in Brazil.*

Some versions of measures used in this study already had Portuguese versions of the measure that had been validated in a Brazilian population, such as the DUREL (de Paula, 2015) or the PANAS (Carvalho et al., 2013). For measures that had not been pre-validated, or for those that were created for this thesis (e.g., the social bonding measure), measures were translated into Portuguese. Co-investigators Miguel Farias (Portuguese), Romara Delmonte (Brazilian), and Everton Maraldi (Brazilian) are all fluent speakers of Portuguese. To translate measures, first Miguel Farias translated into Portuguese. Romara Delmonte then checked and made any changes they thought were necessary for colloquial/local differences from Portuguese spoken in Portugal to Portuguese spoken in Brazil. Finally Everton Maraldi observed the final version and confirmed that the wording would be understandable to those in Brazil.

3.2.4. Ethics

Conducting field research comes with many ethical issues that go above-and-beyond those of a traditional psychology experiment that takes place in controlled conditions. For one, access to sites where field research can be conducted must be gained in a way that ensures the wellbeing of all stakeholders involved. Moreover, once access is granted to each site, the safety of both the researchers and all those on-site needs to be accounted for. As well as these issues, when dealing with religious rituals, it is important that the research does not impact upon the worship service in any way that would undermine the attendees' experience, be they participating in the study or not. This is because religion is incredibly personal, and to violate an attendee's experience in anyway may do some form of undue spiritual harm, or mental anguish which should be avoided at all costs.

Participants were told about my and other research assistants' arrival at least two weeks in advance of our attendance, so that they would not be surprised by our attendance, to ensure they were not under any undue stress that an unannounced presence may have caused. On the day. Participants were provided with information sheets (see Appendix 8) explaining the overall aim of the experiment, what is needed from them if they chose to take part in the experiment, as well as listing all of their rights as a participant – including the right to withdraw, their right to anonymity, and who they can contact for more information. Explicit consent was then gained via a consent form (Appendix 9). As the ritual was video-recorded, all attendees were made aware of the field-of-view of the camera so that they could choose to not be in the view of the camera if they did not want to be.

To ensure anonymity for the data, all participants were given a two-part participant ID code. The first part is a two-letter code based on their ritual site and the second part a unique number for that site. For example, two participants from the same ritual site would have codes such as AA01 and AA12, whereas participants from different ritual sites would have codes such as MB01 and ZC01.

All audio and video data that was recorded was uploaded to Coventry University's encrypted, password-protected servers, with access only granted to researchers on the research team. This is to ensure that audio/video of participants was not made available for viewing by the general public to protect their privacy and anonymity. Similarly, all physical data was inputted into data-processing software and the files were then saved in password protected form. This is important as, despite each participant only being referred to by a unique code, I did record some demographic information which may be used to identify the participant.

The project went through an ethics approval process where discussions about what is and is not possible was discussed with Coventry University Ethics board. The project was then approved by the Coventry University Ethics board (P53423).

3.2.5. Procedure

3.2.5.1. Ritual site recruitment

The first stage of the research project involved getting access to ritual sites (churches/Umbanda sites), so that I could conduct data collection there. First, lists of churches around where the researchers on the research teams were based (Warwickshire, Oxfordshire, London, Sao Paulo, Porto Alegre) were created. A subset of these were visited by me in the UK and by Miguel Farias and Romara Delmonte in Brazil, to scope out suitability (size of congregation, ability to accommodate the research team etc.). Once this was done, a list of 154 UK sites, and a further list of 80 Brazilian sites, were identified. Relevant information (name of site, contact information, days and times of services, date of last attempted contact, follow-up actions needed) about each potential site was kept in an excel document. Each site was contacted via phone initially using a script approved by Coventry University Ethics Board (see Appendix 10.1). If the ritual site did not answer after 2 call attempts, a message was left with some information and the researcher's contact details. If there was no response after two weeks, a second attempt was made following the same procedure. This was repeated until there were four separate attempts made to contact a site. After this, it was considered a rejection.

If a ritual site in the UK did answer the call, the script (Appendix 10.1) was followed (written by my, in collaboration with Miguel Farias and Valerie van Mulukom). Miguel Farias spoke to Brazilian ritual sites in Portuguese. At this stage, if the person on the phone was a 'decision maker' (DM), such as a minister, head medium, or committee member, then the conversation would continue. If it was a 'gatekeeper' (GK), a short description of the project was provided. If they asked for more information via email to give to a DM, this was provided. Otherwise, a request for DM contact information was requested. If this was not given, this was considered a rejection. Once a DM was successfully contacted, further information was provided, and an offer of a meeting was provided (if the church/Umbanda site thought it was necessary). If the DM had not reconducted us within 2 weeks, without suggesting a date for follow-up (e.g. "we have a committee meeting in 4 weeks, I will have more information for you then"), they were re-contacted. If, after 3 attempts, they still provided no further interest in the project, this was considered a rejection. If a decision was made, either by the DM or a group of DMs (e.g. church committee), then this determined whether the ritual site accepted or rejected us conducting research with them. Some churches (but no Umbanda sites) asked us to send more information via email or letter If so, we sent them a pre-written email/letter (see Appendix 10.2). This letter or email may have been subject to small changes based on the contents of the calls made. For a visual representation of this process please see Appendix 11.

Due to the nature of this recruitment, I acknowledge that the ritual sites that did accept to take part in the study may not be fully representative of all religious rituals in their respective religious traditions. This is a selection bias that could not be solved. However, as we collected data from ritual sites from more than a single religious tradition, and in more than a single country, the results can likely be generalised to the wider population, with the caveat that selection bias may mean the results could be skewed in some way. Finally, I feel it important to note that, as differences between many different religious traditions can mean large changes in the contents of a ritual, generalisations to more imagistic expressions of religion should be conducted with caution.

3.2.5.2. On the day of the ritual

Ahead of my and other researchers' attendance, participants were made aware of our field study via newsletters and announcements at their respective religious groups. On the day of service, we arrived early to set up video and audio recording devices as well as sphygmomanometers (see Appendix 12 for the set-up protocol, or https://osf.io/9ebvr/ for a digital copy). As congregation members arrived for the service, they were reminded of our attendance and asked if they would like to take part in this project. A full outline of this procedure can be found in Appendix 13 (or https://osf.io/6ndf7/ for a digital copy).

Once the congregant has agreed to take part and signed the consent form (Appendix 9), they take part in the study. By the nature of this study design, some form of nonresponse bias is likely. However, in many of the rituals attended, the number of participants recruited included more than 10% of all attendees at the rituals, and in some cases over 20%. This is a significant proportion of all the potential attendees and, while nonresponse may lead to some bias in the outcome, this should be considered a representative sample.

Participants were first shown a list of questions denoting exclusion criteria from the pressure cuff test (Appendix 14, or https://osf.io/vdhpq/ for a digital copy). If they said yes to any of the exclusion criteria, they did not take part in the pressure cuff measure, but still took part in the questionnaire, due to a parallel project being conducted another researcher on the team (Jennifer Brown, interested in religious ritual participation and morality). If they were not excluded, the participant took part in the pressure cuff measure, where the sphygmomanometer was attached to the participant's upper non-dominant arm, with the pump line falling above the elbow. The researcher double-checked that the participant understood what to expect after having read about the measure in the participant information sheet. The researcher then said "I will inflate the cuff slowly. Please, indicate when it becomes very uncomfortable by saying 'now'." Once the participant has confirmed they understand, the cuff was inflated by 10mmHgs-1. Once the participant said 'now', the measurement was recorded, out of sight of the participant, and the participant then filled out the pre-service section of the questionnaire. For the full cuff measure protocol please see Appendix 7 (or https://osf.io/ndv3h/ for a digital copy). The service then took place as normal but was recorded. After the service, the recordings are stopped.

After the service, the participant had the pressure cuff measure retaken by the same researcher who took it before the service and filled out the post-service section of the questionnaire. Participants then were partly debriefed about the experiment. Due to the interconnected nature of church and Umbanda congregations, I could not fully reveal the specific research questions of the experiment to participants in case the aims were leaked to other congregations I intended to work with in future. The researchers then packed away the research materials and left the ritual site in a clean condition.

All pain threshold measures were taken as soon as possible; but all within 15 minutes of a participant's arrival to the ritual site, and within 15 minutes after the end of a service. The majority were taken within five minutes of arrival, but some did have to wait longer than this. The difference in timings depended on the number of congregants who had chosen to take part at that specific ritual site: At one of the larger ritual sites in Brazil, there were upwards of 20 participants waiting to be measured for pain threshold simultaneously. Despite having multiple members in a research team at each ritual site (between three and five researchers depending on the size of the ritual site), and the cuff measure only lasting about two minutes, there were a handful of instances where participants did have to wait between 10 and 15 minutes. Participants who were waiting to have their pressure cuff measure taken spent the waiting time completing the relevant half of the of the survey (first half for pre-service, second half for post-service), such that about 50% of participants completed the survey before the pressure cuff measure and 50% completed it after the pressure cuff measure. If a participant completed the survey first (i.e., before the pressure cuff measure) before the service, this was kept consistent after the service (and vice-versa), to ensure that changes in order of measurement were not the reason for any changes in the outcome measures.

3.2.6. *Data Analysis*

As part of data analysis, non-parametric tests were required. There is more than one effect size that can be used for a non-parametric paired-samples test (Wilcoxon Signed Ranks). The effect size I used, r_R, was calculated in the following way:

$$r_R = \frac{Z}{\sqrt{N}}, \text{where } N \text{ is Total number of pairs multiplied by 2}$$

This version of a Wilcoxon signed-ranks effect size is called the normal-approximation of Z to r (Rosenthal, 1986; Wuensch, 2015). The normal-approximation of Z to r, initially provided by Rosenthal (Rosenthal, 1986) provides a more conservative measure of effect size than the matched-pairs rank-biserial correlation measure, also called the 'simple difference' effect size provided by Kerby (Kerby, 2014). As the Kerby (Kerby, 2014) effect size also uses the character r, I have used the subscript

'R' to denote the Rosenthal (Rosenthal, 1986; Wuensch, 2015) version of the effect size that I have used[13].

Further details on statistical methods used within this study are given in Appendix 2 (and online, https://osf.io/2hp6q/).

3.3. Results

The R (R Core Team, 2020) analysis script is provided in Appendix 15 (and online, https://osf.io/4ke58/). All anonymised data can also found on the open science foundation online repository (https://osf.io/pmdra/). For clarity please see which analyses were conducted, and why in Table 3.3.

Table 3.3.

Analyses conducted, and reason for conducting them

Analysis	Measures	Reason for inclusion
PCFA	Social Bonding	To determine the dimensionality of the latent social bonding variable
Wilcoxon, Pre-Post	Social Bonding	To test hypothesis 1, outlined in section 3.1.3.
	Pain Threshold	To test hypothesis 1, outlined in section 3.1.3.
	Affect	To monitor changes in affect, because of the Broaden and Build theory
	Country Split	Follow-up analysis to determine if there were country-level differences in the effects.
Regression	Pain Threshold on Social Bonding	To test hypothesis 2, outlined in section 3.1.3.
	Affect & Pain Threshold on Social Bonding (Table 3.6)	Follow-up analysis to determine whether including affect into the regression equation accounts for the variance explained by pain threshold.
	As above, with demographic and	Follow-up analysis to determine whether including potential confounding variables into the regression equation accounts for the variance explained by pain threshold.

[13] In Table 3.5, I also present Kerby's Kerby, D. S. (2014). The simple difference formula: An approach to teaching nonparametric correlation. *Comprehensive Psychology*, *3*, 11. IT. 13.11. effect size, with the subscript 'K', for completeness.

	religiosity variables (Table 3.7)	
	Predictors of Pain Threshold	Conducted at the request of peer-reviewers to determine if pain threshold was predicted by other variables, particularly affect. This is important to assess as a significant relationship between affect and pain threshold would provide support for a neurochemical mechanism behind how positive affect might lead to social bonding.
Multilevel Model	Most parsimonious model to explain change in social bonding from before to after the ritual	Follow-up analysis conducted based on recommendations from peer-reviewers to better-account for the type of data structure that the study contained.
	Most parsimonious model of pain threshold	Follow-up analysis conducted based on recommendations from peer-reviewers to better-account for the type of data structure that the study contained. The rationale is the same as for the inclusion of the regular multiple regression analysis.

3.3.1. *Social bonding Measure Reliability*

To create the average score of social bonding, first an exploratory factor analysis was conducted on the five non-IOS questions (i.e., excluding the pictorial IOS question) separately for pre- and post-ritual. Using an oblique rotation and a principal-axis method for extraction, the pre-ritual responses yielded a 1-factor solution that accounted for 62.15% of the variance. An oblique rotation was used because, in social sciences, different behaviours are rarely entirely uncorrelated. So, oblique rotations are more likely to lead to more useful solutions (Osborne, 2015). A scree test and an Eigenvalue of 1.0 were used to select the number of factors. Only items with factor loadings of .40 or higher were allowed to be considered as part of a factor. No items had an Eigenvalue greater than one, and a scree plot showed that the items all loaded on a singe factor. Using the same method, an oblique rotation and principal axis method for extraction of the post-ritual responses also yielded a 1-factor solution that accounted for 71.48% of the variance. No items had an eigenvalue greater than one, and a scree plot showed that the items all loaded on a single factor.

As part of the recommendations suggested by Gignac (2009), a ‘partial confirmatory factor analysis’ was conducted to determine whether the results of the exploratory analyses would be likely to be confirmed upon follow-up. This method, proposed by Gignac (2009), provides the goodness-of-fit measures of NFI, FLI, CFI, RMSEA and SRMR. The higher NFI, FLI and CFI and the lower RMSEA and SRMR, the better the fit. See Table 3.4 for these values for the pre- and post- service values for the goodness of fit values produced using the partial CFA.

Table 3.4.

Partial confirmatory factor analysis (PCFA) metrics for the social bonding measure.

Measurement Occasion	IOS	NFI	TLI	CFI	RMSEA	SRMR
Pre-service	Not included	.928	.873	.937	.159	.046
	Included	.922	.888	.933	.142	.051
Post-service	Not included	.970	.952	.976	.119	.029
	Included	.968	.962	.977	.095	.030

Note. Values were calculated using the formulae provided in Gignac (2009, p.41).

Based on the EFA and PCFA output, there is strong early evidence that the social bondedness questions fit into a single dimension, suggesting the questions all measure the same latent variable of social bonding. The pre-ritual questions had a McDonald’s omega value of ω_t = .85, 95% CI [.81, .87] and the post-ritual questions had a ω_t = .90, 95% CI [.87, .92] providing evidence for moderate-to-high internal reliability. An average of these five questions was used to create an initial social bonding score. This was then correlated with the IOS score to check for construct validity, given its past pre-validated use as a measure of social bonding. The pre-ritual correlation was r = .69, 95% CI [.62, .75], and the post-ritual correlation was r = .67, 95% CI [.59, .73]. This moderate-to-high level of correlation suggests that this social bonding score was measuring a similar construct to the IOS. As IOS is considered a valid measure of social bonding, I felt justified that the other five questions combined were also measuring the same latent social bonding variable.

Given the rationale from Chapter 2 (section 2.3.), the IOS was also added to the list of questions to create an average of all six questions, and then, following the same factor analysis process as above, a check was made that the items measured a single dimension. EFA found that all six items loaded onto a single factor. Partial CFA also showed strong evidence that a single-factor model was appropriate (see table 3.3). Internal reliability was checked on this six question score for both pre- and post-ritual measures, with a pre-ritual McDonald's ω_t = .87 95% CI [.85, .90] and a post-ritual McDonald's ω_t = .90 95% CI [.87, .92], suggesting high levels of internal consistency.

3.3.2. Effects of Religious Ritual

A Shapiro-Wilk test was conducted to check whether data met the assumptions for parametric testing. The pre-ritual (W = .965) and post-ritual (W = .932) social bonding score and pre-ritual (W = .973) and post-ritual (W = .974) pressure cuff scores were all significantly different from normally distributed (all $p < .001$). As a result, non-parametric tests were used.

To test the hypothesis that there would be a change in social bonding from before to after a ritual, a two-tailed, non-parametric Wilcoxon signed-rank test was conducted. As predicted, post-ritual social bonding scores (M = 5.70, SD = .922, Mdn = 6.0) were significantly higher than at pre-ritual (M = 5.41, SD = .942, Mdn = 5.5, Z = 6.89, p < .001, r_R = .30). There was a small-to-moderate positive effect of attending a religious ritual on social bonding

To test the hypothesis that there would be a change in pain threshold from before to after the ritual, a two-tailed non-parametric Wilcoxon signed-rank test was conducted. As predicted, post-ritual pain threshold scores (M = 178.63, SD = 60.35, Mdn = 170.00) were significantly higher than at pre-ritual (M = 157.90, SD =54.45, Mdn = 150.00, Z = 6.30, p < .001, r_R = .27). There was a small-to-moderate positive effect of attending a religious ritual on pain threshold.

The PANAS is split into two factors, PANAS+ and PANAS-, for positively and negatively valanced emotions respectively. Both PANAS+ (W = .962, .967) and PANAS- (W = .930, .863) pre- and post-ritual scores were tested for normality using a Shapiro-Wilk test, and all were significantly different from normal (all $p < .001$). Two-tailed, non-parametric Wilcoxon signed-ranks tests were conducted. There was a significant increase in positive affect as measured on the PANAS+ from pre-ritual ($M = 38.71$, $SD = 11.90$, $Mdn = 41.5$) to post-ritual ($M = 39.78$, $SD = 12.12$, $Mdn = 42$, $Z = 2.81$, $p = .02$, $r_R = .12$). There was also a significant decrease in negative affect from pre-ritual ($M = 11.24$, $SD = 7.34$, $Mdn = 11$) to post-ritual ($M = 8.87$, $SD = 5.57$, $Mdn = 10$, $Z = 7.51$, $p < .001$, $r_R = .33$). These results suggest that there was a small effect of taking part in religious ritual on positive affect and a moderate effect on negative affect. All pre-to-post changes, except for PANAS+, remain significant when correcting for multiple comparisons using the Benjamini-Hochberg correction (Benjamini & Hochberg, 1995).

Given that data were collected across two culturally distinct countries, I further examined whether the participant's country played a role by analysing the data for each country separately (see Table 3.5). After correction for multiple comparisons, all but two changes reported above were found in both countries. I did not find a change in PANAS+ from pre-ritual to post-ritual in the Brazil data, possibly because of a ceiling effect at the pre-ritual scores. There was also no significant change in pressure cuff measure from before to after in the UK rituals after multiple comparisons correction (although the effect was in the hypothesised direction).

Table 3.5.

Wilcoxon Signed Rank Test outputs across the UK and Brazil comparing scores from pre-ritual to post-ritual

Participant Group		Measure			
		Social bonding	Pain threshold	PANAS+	PANAS-
All participants	Z	6.89	6.30	2.81	7.51
	r_R	0.30	0.27	0.12	0.33
	r_K	0.52	0.47	0.20	0.63
	p	< .001	< .001	.020	< .001
UK participants	Z	4.01	1.89	2.81	4.72
	r_R	0.34	0.16	0.24	0.40
	r_K	0.62	0.27	0.76	0.81
	p	< .001	.058	< .001	< .001
Brazil participants	Z	5.67	6.12	0.41	6.29
	r_R	0.29	0.31	0.02	0.32
	r_K	0.52	0.53	0.03	0.60
	p	< .001	< .001	.684	< .001

p-values using a Benjamini-Hochberg correction (Benjamini & Hochberg, 1995)

r_R = The normal approximation of Z to r effect size (Rosenthal, 1986; Wuensch, 2015)

r_K = The 'simple difference' effect size (Kerby, 2014)

3.3.3. Relationship between social bonding and pain threshold

Figure 3.3. plots change in social bonding against change in pain threshold. Data were first tested for multivariate normality, autocorrelation and homoscedasticity. These assumptions were met. Variables were mean-centred and standardised to create Z-scores as appropriate for the purpose of the

regression analysis. As I did not specify in the pre-registration what would constitute a multivariate outlier, no outliers were excluded in this analysis.

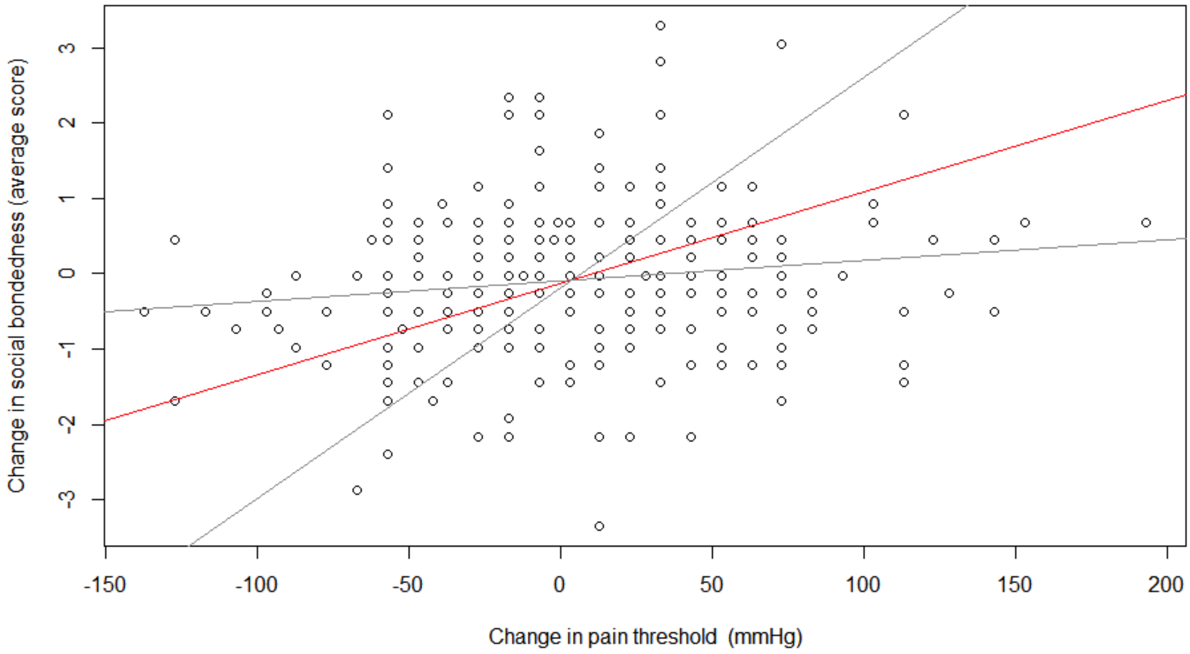


Figure 3.3. Scatterplot with change in pain threshold against change in social bonding. The light grey lines represent the 95% confidence interval of the RMA regression line (shown in red). Produced using R (R Core Team, 2020). The effect size of the model is R^2 = .018.

A simple linear regression was performed to determine whether change in pain threshold (ΔPT) predicted change in social bonding score. It was found that ΔPT significantly predicted change in social bonding score ($F(1,264) = 4.846$, $p = .029$, $R^2 = .018$, $R_{adj}^2 = .014$), where ΔPT accounted for 1.8% of the variance in the change in (Δ) social bonding score.

To examine whether change in affect also predicted change in social bonding, a multiple regression was conducted. We found a significant model ($F(3,262) = 9.167$, $p < .001$, $R^2 = .095$, $R_{adj}^2 = .085$), where ΔPT and ΔPANAS+ were significant positive predictors of Δ social bonding, and ΔPANAS- was a significant negative predictor of Δ social bonding score (see Table 3.6).

As a follow-up analysis, a multiple regression was conducted to control for age, country, gender, religiosity, connectedness to god, and the number of years they had attended the service for. This model was significant ($F(9,233) = 4.47$, $p < .001$, $R^2 = .147$. (see Table 3.7). Δ social bonding was significantly positively predicted by ΔPT, ΔPANAS+, and feelings of connection to God, and it was significantly negatively predicted by ΔPANAS- .

Table 3.6.

Multiple linear regression predicting change in social bonding with change in pain threshold and change in PANAS subscale scores.

Variable	**B**	**95% CI**	***β***	***t***	***Sig. (p)***
(Constant)	- .081	[-.192, .030]		-1.43	.151
ΔPT	.003*	[.001, .005]	.14	2.45	.015
ΔPANAS+	.211***	[.098, .324]	.22	3.69	<.001
ΔPANAS-	- .170**	[-.280, -.060]	- .18	- 3.05	.003

** significant at p < .05; ** significant at p < .01; *** significant at p < .001*

Note: R^2 = .095**, 95% CI = [.03, .16]

Table 3.7.

Multiple linear regression predicting change in social bonding using change in pain threshold and change in PANAS subscale scores.

Variable	**B**	**95% CI**	***β***	***t***	***Sig. (p)***
(Constant)	- .553	[-1.204, .098]		-1.68	.095
ΔPT	.002*	[.000, .005]	.13	2.23	.026
ΔPANAS+	.235***	[.121, .350]	.25	4.05	<.001
ΔPANAS-	- .188**	[-.300, -.076]	- .20	- 3.31	.001
Country	- .150	[-.451, .150]	- .07	-0.98	.326

Connected to God	.111*	[.004, .218]	.15	2.05	.042
Age	- .003	[-.011, .006]	-.04	-0.60	.550
Service Attendance	- .005	[-.020, .010]	-.04	-0.66	.510
Gender	- .102	[-.335, .131]	-.05	-0.87	.388
Religiosity	- .067	[-.269, .135]	-.04	-0.66	.512

** significant at p < .05; ** significant at p < .01; *** significant at p < .001*

Note: R^2 = .148***, 95% CI = [.05, .20]

To determine what may have predicted pain threshold change, a multiple regression was conducted. PANAS+, PANAS-, gender and age were included as predictors, as affect, age and gender have been known to influence pain perception (Fillingim, 2017; Lumley et al., 2011; Mogil & Bailey, 2010; Rhudy & Meagher, 2001). This model was not significant ($F(4,260) = 0.62$, $p = .646$, $R^2 = .01$. This suggests that, in our sample, pain threshold change was not predicted by change in affect or by the variables age or gender.

3.3.4. Multi-Level models

As the data in this study have a hierarchical structure (measurement occasions, within participants, within ritual sites), a series of follow-up analyses were conducted. I followed suggestions provided by Aho et al. (2014) and Luke (2017) in how to conduct the multi-level models. For a detailed rationale and method of how this was implemented, see Appendix 2.

In short, I ran a series of models and used the corrected Akaike Information Criterion (AICc; Akaike, 1973; 2002, 2004) to select the best-fit model. These models were compared with one another to find the most parsimonious model (the one with the lowest AICc value) and then determine significance of fixed effects. The best way to get a more reliable *p*-value is to fit the model using a "reduced maximum likelihood" (REML) instead of a maximum likelihood (ML) method, along with the Satterthwaite approximation or Kenward-Roger approximation (Luke, 2017). In the appendix of his article, Luke (2017) provides the R code for how to run the approximations to get a *p*-value for fixed effects in the model. However, this step can only be done once random effects structures (effects that vary across participants) have been confirmed using model comparisons (i.e. comparing AIC/AICc). The steps have been conducted in the analysis script, and a full report of these can be found in Appendix 2 (available online at https://osf.io/2hp6q/).

After a series of multi-level models were compared, the most parsimonious model included an interaction effect between country and positive affect in addition to the following variables: pain threshold, PANAS+, PANAS-, country, connection to God, age, service attendance, gender, and religiosity. I then used Luke's (Luke, 2017) method to find the significant fixed effects, the results of which are presented in Table 3.8. There were significant fixed effects of measurement occasion (pre- versus post-ritual), pain threshold, positive and negative affect, a feeling of a connection to God, religiosity, and I found a significant interaction effect between positive affect and country, where social bonding was predicted by positive affect more strongly in the UK than in Brazil.

Using the same multi-level modelling analysis method, I also found predictors of pain threshold (see lines 1,311 – 1,422 of the analysis script). The most parsimonious model included measurement occasion, social bonding, gender, country, religiosity interactions between measurement occasion and social bonding, and measurement occasion and gender. Inclusion of PANAS+, PANAS-, age and/or connection to god led to a worse model fit. In the final model, measurement occasion, ($t(238.9) = 3.28$, $p = .001$, default as pre-ritual) was a significant positive predictor of pain threshold while gender ($t(330.2) = -2.25$, $p = .025$, default as male) and religiosity ($t(245.5) = -2.99$, $p = .003$) were significant negative predictors of pain threshold. No interaction effects were significant. Here, post-ritual pain threshold was significantly higher than pre-ritual pain threshold, those who identified as women had significantly lower average pain thresholds than those who identified as men (though there was no interaction with time), and a higher religiosity score was significantly predictive of a lower pain threshold (though there was no interaction with time).

Table 3.8.
Table showing the fixed-effects output, as given by the Luke (Luke, 2017) method, from the most parsimonious multi-level model predicting social bonding.

Variable	**Estimate**	**S.E.**	**95% CI**	***t***	***Sig. (p)***
(Constant)	-1.245***	.363	[-1.608, -.882]	-3.43	< .001
Pre v.s. Post Ritual	.143**	.046	[.097, .190]	3.09	.002
Pain Threshold	.002**	.001	[.001, .002]	2.90	.004
Country	.350	.191	[.160, .541]	1.84	.070
PANAS+	.450***	.102	[.348, .553]	4.41	< .001
PANAS-	- .198***	.046	[-.244, -.152]	-4.32	< .001
Connection to God	.140**	.049	[.091, .188]	2.87	.004
Gender	.082	.099	[-.017, .182]	0.83	.408
Age	.003	.004	[-.000, .007]	0.96	.340
Religiosity	.188***	.053	[.135, .241]	3.55	< .001
*Country * PANAS+*	-.239*	.110	[-.350, -.129]	-2.17	.031

* $p < .05$; ** $p < .01$; *** $p < .001$
Note: All final output results were calculated using the Satterthwaite (1941) correction (see Luke, 2017).

3.4. Study 1 Discussion

The aims of the first study within this thesis were to demonstrate that the social bonding measure created for this thesis was valid and reliable, provide evidence that social bonding increases from before to after participation in religious ritual, to provide evidence that μ-opioid activation (as measured via pain threshold proxy) is related to group social bonding within religious ritual , and to find other cognitive-behavioural predictors of ritual social boding.

This study provides the first evidence that feelings of social bonding and pain threshold, a proxy measure of μ-opioid release, increase after taking part in a religious ritual. This corroborates early sociological literature (e.g. Durkheim, 1912) as well as more recent experimental work on the prosocial effects of religious rituals (Fischer & Xygalatas, 2014; Fischer et al., 2014). It also provides evidence for the BOTSA model about the role of μ-opioids in social bonding during religious rituals (Dunbar, 2013). Specifically, I and my colleagues found that taking part in religious rituals was associated with an increase in feelings of social bonding among the participants, as well as an increase in pain threshold, and that the change in social bonding was related to the change in pain threshold. These findings together demonstrate that the measurable effects presented in Figure 3.1. (effects a, b, and c) do appear to exist. That an increase in social bonding (effect a), pain threshold (effect b), and a relationship between the two (effect c) were shown to be present means that one potential interpretation is that the unmeasurable, underlying effects: that religious ritual causes μ-opioid release (d), that this release leads to pain threshold changes (e), and to changes in social bonding (f) from Figure 3.1. are present.

We also found that the increase in social bonding feelings was associated with a concurrent increase in positive affect, and a decrease in negative affect. Affect has previously been hypothesised to play a role in social bonding (Fredrickson, 2013), and past research suggests that affect may influence pain perception or opioid tone (Nummenmaa & Tuominen, 2018; Rhudy & Meagher, 2001). Follow-up analyses did find support for the Broaden and Build theory (Fredrickson, 2013), that positive affect was related to social bonding, but did not replicate findings of a relationship between affect and pain perception. Moreover, we initially did not find that participants' level of religiosity, or length of time they had attended the ritual, had an added effect in predicting an increase in social bonding. However, follow-up analysis using multi-level modelling revealed that a higher religiosity score increased the level of overall social bonding (both before and after the service), and that the role of positive affect on social bonding was different between the UK and Brazil, where higher positive affect in Brazil was not predictive of social bonding, where it was in the UK participants.

We also found that, when conducting country-specific follow-up analyses, the change of pain threshold from before to after the ritual was no longer statistically significant in the UK population after correction for multiple tests. One reason for this could be the lower sample size for the UK lead to a lower statistical power to be able to detect a true effect: the power analysis presented in section 3.2.1. suggested that to be appropriately powered (i.e., to have a good chance of detecting an effect that is actually present) 115 participants would be able to detect the association between social bonding and pain threshold, but there were only 70 UK participants. In addition, the change in positive affect from before to after the ritual, as measured by the PANAS+, was not statistically significant in Brazil after correcting for multiple tests. As the number of Brazilian participants was quite high, power issues are not as likely here. Instead, a more likely reason for this is a pre-ritual ceiling effect on positive affect in the Brazilian participants, as a large number of Brazilian participants marked their positive affect as being close to the maximum even before the religious ritual.

One limitation of the current study is that participants were recruited from the two countries in uneven numbers. One of the reasons for the uneven number of participants is that the average number of participants which met at least one exclusion criterion was higher in the UK than in Brazil, probably due to a higher average age: 38% of British participants had to be excluded, in contrast with only 21% of Brazilian participants. This difference in participant numbers meant that further exploratory tests comparing UK to Brazilian data were not conducted, as there were not enough participants recruited in the UK to have a well-powered enough analyses. Another limitation is that, while we do have a naturalistic design with high levels of ecological validity, we do not have a control condition in this study. Because of the design of this study, none of the conclusions in this chapter should be interpreted formally as causal relationships. However, based on analogous studies examining other types of supposed bonding behaviours where a control group has been included (e.g., Tarr et al., 2017; Tarr et al., 2015; Tarr et al., 2016; Tarr et al., 2018), it is probable that these relationships have some kind of causal pathway.

To expand on the lack of control condition, one limitation of this study is that I am not able to demonstrate that talking part in a group religious ritual is related to social bonding any more than a *lone* religious ritual (i.e., is the group aspect of ritual important, one potential control), a group activity that is *not* a religious ritual (i.e., is the fact that it is a religious ritual import, another potential control), or even having people *imagining* taking part in a group religious ritual (i.e., not actually taking part in the physical acts, yet another potential control). While it is possible that similar effects might have been found in such scenarios, previous research comparing group to behaviourally identical lone behaviour has found significant differences in levels of pain threshold (Cohen et al., 2010), which suggests that lone religious ritual may not have as strong of an effect, if it has the same effect at all. Similarly comparisons between group ritual behaviour and group non-ritual behaviour have found that those taking part in group ritual had a greater preference for the in-group, which was interpreted as greater social bonding (Wen et al., 2016). To my knowledge, there are very few studies on the role of imagined participation in *group* activity and its effect on social bonding. In the one study that I am aware of, Atherton and Cross (2020) showed that imagining walking with others was related to greater levels of empathy and positive attitudes for out-groups (specifically, those of a different ethnicity and religion), but not those of the in-group. This suggests that imagined group activity is likely to find results more in line with the imagined-contact hypothesis (Crisp & Turner, 2012; Miles & Crisp, 2014), which is more focused on improving attitudes toward out-group members, than it is with social bonding with those in your own group. Even so, future research on group religious ritual bonding should include some kind of control, to serve as a comparison and to allow for more causal conclusions.

At the time it was conducted, this study was the first study that tested whether religious ritual increases μ-opioid activation, as measured through pain threshold (though, since we conducted this study, Fischer and Kruekaew (2020) have also assessed pain and social bonding in the context of religious ritual. However, they looked at an imagistic expression of religious ritual, not doctrinal). In doing so, this is the first study that provides evidence to support the hypothesis that doctrinal modes of religious ritual expression leads to social bonding via the activation of μ-opioid receptors. I have repeatedly acknowledged that this study only provided a proxy for μ-opioid activation. Such a limitation could be combatted by the inclusion of drugs inhibiting μ-opioid activation, such as Naltrexone (e.g. Inagaki et al., 2016). However, using such a drug during religious rituals in the field does not come without ethical concerns that would need to be addressed (see. 6.3.2.). One such possible concern would be that the use of a psychoactive drug, such as Naltrexone, may inhibit the connection with a higher power that is often sought out as part of religious ritual.

I also acknowledge that one of the analyses that had been planned at the pre-registration stage – measurement of movement synchrony during the ritual - could not be conducted due to the varying quality of the video recordings, among other technical issues. There were further hypotheses which I wished to test: (1) the hypothesis that level of behavioural synchrony, which is believed to release μ-opioids (Cohen et al., 2010; Launay et al., 2016; Pearce et al., 2017), would predict changes in social bonding (see also, Lang et al., 2017) and (2) the hypothesis that the effect of behavioural synchrony would be mediated by the change in pain threshold.

In conclusion, this field study has demonstrated evidence for the role of religious rituals in the increase in feelings of social bonding amongst its participants, possibly induced by an increase in μ-opioid release. This finding is supportive of the 'brain-opioid theory of social attachment' (BOTSA; Machin & Dunbar, 2011; Panksepp et al., 1978), and suggests that religious rituals may be an effective way to foster feelings of social bonding among larger groups of people. Increases in positive affect, and a decrease in negative affect may also play a role in the relationship between religious ritual participation and increases in social bonding. This is also in line with the Broaden and Build theory of positive affect (Fredrickson, 2004, 2013; Fredrickson & Branigan, 2005).

Using analyses that account for the multilevel structure of data is recommended because it lowers the likelihood of Type I errors (Aarts et al., 2014; Meteyard & Davies, 2020) - i.e., false positives. However, in the mixed-effect models output, religiosity is significant, whereas it was not in the multiple regression output. This leads to some confusion in how to interpret the results. Due to the inconsistent findings of the role of the religiosity of participants on social bonding – there was no significant effect of religiosity in the multiple regression analyses but there was a significant effect in the multilevel modelling analyses – it is unclear what the specific role of *religious* components of a ritual may contribute to the social bonding that appears to be linked to participation in religious rituals. Consequently, in the next chapter, I outline a follow-up study that was conducted to study the role of the religious component of ritual on social bonding outcomes.

4. Chapter 4. Social Bonding During Secular Rituals

As shown in the previous chapter, participation in religious rituals is related to an increase in feelings of social bonding. But is this effect driven by the religious (super-empirical) context of these rituals, or can they be extended to non-religious rituals? To address this question, I conducted a field study with individuals who participate in secular rituals at UK Sunday Assemblies and compared them with participants attending four matching UK Christian rituals. The content of this chapter is adapted from the published article "United on Sunday: The effects of secular rituals on social bonding and affect", on which I was the lead author (Charles, van Mulukom, et al., 2021). The contribution of each co-author is listed in Table 4.1.

Table 4.1.

Table showing the CRediT allocation for Study 2. Initials are provided for each author for each role they contributed towards. The order of the initials for each role denotes the level of contribution (i.e., appearing first on a contributor role means this co-author contributed most for this role unless otherwise specific)

Role	Author(s)	Role	Author(s)
Conceptualisation	SC*, MF*, VvM*, FW†, RIMD†	Resources	FW
Data Curation	SC, JB	Software	
Formal Analysis	SC	Supervision	MF, VvM, RIMD
Funding Acquisition	RIMD, FW, MF	Validation	VvM
Investigation	SC*, JB*, VvM	Visualisation	SC, VvM
Methodology	SC*, MF*, VvM*, RIMD, JB, FW	Writing – Original Draft	SC
Project Administration	SC, VvM, JB, MF, RIMD†, FW†	Writing – Review and Editing	SC, VvM, MF, RIMD, FW, JB

* Equal primary contribution

† Equal supporting contribution

4.1. Background to Study 2

There is a significant body of research that demonstrates positive health and wellbeing effects that stem from the attendance of religious rituals (for an overview, see VanderWeele, 2017a). The current literature indicates that the benefits of religious ritual attendance include improved wellbeing (Koenig et al., 2012), as well as protection against all-cause mortality (Chida et al., 2009; Gillum et al., 2008; Hummer et al., 1999; Musick et al., 2004), depression (Balbuena et al., 2013; Barton et al., 2013; Li et al., 2016), suicidality (Rasic et al., 2011) and immune dysfunction (Suh et al., 2019). Moreover, VanderWeele (2017a) notes that many of these positive effects appear to be best maintained when ritual attendance is at least once per month. Much of this literature was conducted in western, democratic nations, and within Christian settings, though there are some notable exceptions to this (Chang, 2009; Loewenthal & Dein, 2016; Roemer, 2010).

As noted throughout the thesis, a common assumption of sociological and anthropological sciences is that that one of the primary functions of religion is to promote group solidarity (e.g. Sosis & Ruffle, 2003). Dunbar (2013) has suggested that religious rituals developed as a mechanism to help form and maintain social bonds in groups of humans in a particularly effective manner, hence its ubiquity (Brown, 2000). Evidence does support the idea that, at the very least, *ritual* might cause bonding in a manner more effective than other group behaviour (Wen et al., 2016). This might be because of the many of the behaviours that tend to be incorporated into even doctrinal modes of ritual expression, which have been shown to lead to feelings of social bonding (see Chapter 2, section 2.2. for an overview). Accordingly, religious rituals that incorporate a multitude of these behaviours should, according to Dunbar, foster bonds efficiently (Dunbar, 2013). In Chapter 3, I reported a study conducted with colleagues that provided the first evidence that doctrinal modes of religious rituals (both Christian and Afro-Brazilian) are significantly related to an increase in feelings of social bonding with other attendees. We showed that taking part in the religious rituals that we attended was related to a significant increase in social bonding towards the group, and that the increase in social bonding was itself significantly related to a theorised increase in opioid activation (as reflected by increases in pain threshold), an increase in positive affect, a decrease in negative affect, and by feelings of connection to God during the ritual, but not by age or gender. The relationship between religiosity and the change in social bonding found in the prior study was ambiguous, as it appeared significant in one type of analysis but not in another.

Study 1 not only demonstrated that rituals were related to social bonding, but also provided support for the hypothesis that affective state – more specifically positive affect – is related to feelings of social connectedness (Fredrickson, 2013; Mauss et al., 2011; Waugh & Fredrickson, 2006), i.e. the 'Broaden and Build' hypothesis (Fredrickson, 2004, 2013; 2005; Waugh & Fredrickson, 2006). This hypothesis also serves as the basis for the proposal that the link between religion and wellbeing stems from changes in positive affect (Fredrickson, 2002; Van Cappellen, Toth-Gauthier, et al., 2016), which in turn can lead to improved social bonding, and wellbeing (Diener et al., 2011). Therefore, the mechanism by which religious rituals might lead to social bonding may be just by incorporating behaviours that lead to increases in positive affect, which then contributes to social bonding.

In a separate branch of research than that of the religion and health literature, there is a vast amount of evidence outlining the beneficial health benefits provided by social bonding (For meta-analyses, see Holt-Lunstad et al., 2015; Holt-Lunstad et al., 2010). In short, having strong social bonds has been shown to lead to improved health outcomes compared to those who lack them (Lakey & Orehek, 2011; Zaki & Williams, 2013), in the form of reduced mortality (Holt-Lunstad & Smith, 2012; Holt-Lunstad et al., 2010) and lowering levels of depression, suicidality, and immune dysfunction (Charles, Farias, & Dunbar, 2020; Lutz et al., 2020). These health benefits overlap with those that religious rituals are purported to provide (VanderWeele, 2017a). Consequently, the Broaden and Build hypothesis links religious ritual to wellbeing via positive emotions' role in broadening social bonding (2002; Van Cappellen, Toth-Gauthier, et al., 2016). Given the similarity between the benefits from participation in religious rituals (VanderWeele, 2017a) and those from social bonding (Charles, Farias, & Dunbar, 2020; Lutz et al., 2020), I believe that the link between religious ritual and wellbeing is actually mediated via social bonding. I will return to this idea in section 4.1.1..

In Chapter 3, my colleagues and I also showed that the feeling of connection to God during ritual positively predicted changes in social bonding, albeit to a lower level than affect. However, the mechanism underlying how a connection to a higher power is related to increased social bonding is unclear. It could be that a feeling of connection to a higher power directly leads to further feelings of bonding with others in the group, or it could be that connection to a higher power could first lead to affect changes, which in turn would promote bonding with others (Broaden and Build). Either way, wellbeing improvements that are reported to come with being religious could stem from a connection to a higher power (Pirutinsky et al., 2019; Tung et al., 2018). Though, Pirutinsky et al. (2019) also showed that, in addition to attachment to God, social support significantly predicted the protective effects of religion against mental health problems.

To bring this back to the aims of this thesis – to understand the role of *religious* ritual on social bonding – the above information leads, in my opinion, to a key question: "What about rituals that are not religious in nature?" The reason this is important is that Dunbar (Dunbar, 2013, 2017b) specifically suggests that religious ritual likely leads to social bonding because of its inclusion of multiple behaviours that each, independently, have been shown to increase feelings of social bonding (e.g., Pearce et al., 2015; Tarr et al., 2018). If it were simply the incorporation of each of these individual behaviours into a single activity that leads to increases in feelings of social bonding, then a secular ritual that included the same combination of behaviours, for the same amount of time should, theoretically, be just as effective at causing a change in social bonding as a religious ritual. The only reason that this would not be the case would be that the religious component contributed, in some way, to the change in feeling of social bonding. It is for this reason that finding an appropriate secular ritual to compare to religious rituals is important when attempting to address one of the primary aims of this thesis: to determine if the religious component of religious ritual is related to social bonding.

4.1.1. Secular Rituals

As we progress further into the 21st century, growing numbers of individuals are identifying as non-religious. In 2012, 16% of the world population reported no religious affiliation (Pew Research Forum, 2012) and these numbers are growing in several countries, such as the UK (Bullivant, 2016; Clements, 2017), the USA (Twenge et al., 2016), and other Western countries (Brenner, 2016). Given the positive health effects associated with religious ritual attendance (VanderWeele, 2017a), leaving religion – or not having one in the first place, and thus not attending religious rituals – may mean the positive effects of such rituals can no longer be reaped.

Yet, there have been efforts to counteract the loss/lack of religious rituals by secular groups and individuals. For over two centuries there have been attempts to establish secular rituals that mirror religious rituals, such as Comte's Church of Positivism, founded in the 1800s (Mill, 2015). While it was a 'church' (having a communal space of worship that brought the community together), the beliefs held by those within the Church of Positivism were all based on empirical realities: For example, their belief that wellbeing was the centre of morality meant that their beliefs of what was morally 'good' or morally 'bad' (non-empirical realities) were based on the empirical reality of pleasure and pain experienced by living beings, and not on any super-empirical realities. Hence, by the definition of 'religion' used in this thesis, the Church of Positivism was a secular organisation. The Church of Positivism, held regular services (rituals) at their own temples in the UK, France, and Brazil. However, with time they were unsuccessful in recruiting new members and have, for the most part, closed down (the last remaining active church is located in the south of Brazil; for a recent documentary, see Porto, 2019).

A more contemporary, and flourishing (COVID notwithstanding), attempt to develop such a secular ritual is that of the Sunday Assembly. This movement was started in London, England in 2013 by Sanderson Jones and Pippa Evans, as a way of "doing church without god" (Pigott, 2013). This regular Sunday ritual intentionally mimics Christian Evangelical services, behaviourally. Traditional hymns are substituted with famous popular songs with positive messages, such as U2's '*Beautiful Day*' (U2, 2000). The sermon, a cornerstone of Christian Sunday Mass rituals, is replaced by an inspirational lecture-style informative talk. The topics of these talks vary in nature, from the importance of local flora on the community's sense of identity to talks on gender equality in modern society. Were one to see footage of a Sunday Assembly taking place without audio, it would be largely indistinguishable from many evangelical churches.

Sunday Assemblies, like the Church of Positivism, are considered secular by the definition of this thesis because they do not base any of their stances in relation to any super-empirical realities. Sunday Assembly does appear to have a 'creed' or motto of some kind (a non-empirical reality of what is 'good'), which is "live better, help often, wonder more". This is based not in relation to the existence of some super-empirical reality, but instead in relation to how living by these principles appears to provide tangible benefits to people in the real world (i.e., these are 'good' because of their effect on empirical reality, not because they are intrinsically 'good' separate from empirical reality). If it was found that living by this motto were to not improve people's lives, Sunday Assembly would change its motto in accordance with empirical reality. Because of its specific relationship with empirical reality (and not super-empirical realities), Sunday Assembly is not religious, i.e., secular.

Similarly, due to Sunday Assembly being based on Christian Sunday Mass, it fits the definition of ritual because of the inclusion of repetitive behaviours that lack direct instrumental purpose, such as standing and sitting at seemingly random intervals. Since its inception, the Sunday Assembly has grown to become an international brand of secular ritual, with 22 Assemblies in Europe, another 22 in North America, and five across Australia and New Zealand at the time of writing (see https://sundayassembly.online/find-an-assembly/ for a full list).

Price and Launay (2018) recently conducted a longitudinal study with the flagship Sunday Assembly in Central London to improve understanding of some of the effects on wellbeing that being part of a specifically secular group can offer. Their results suggest that attending the Sunday Assembly services was related to a significantly improved score on a composite measure of wellbeing. In the discussion section of their paper, Price and Launay (2018) hypothesise that the improved wellbeing they found may stem from the social connections made at Sunday Assembly, much like what is found in religion and health literature (e.g. Holt et al., 2018).

Some researchers believe that religion provides health benefits in ways that secular means cannot, such as through the sense of meaning that religion provides (e.g. Hood Jr et al., 2018). However, Galen (2018) has suggested that the link between religiosity/spirituality and factors that lead to wellbeing stems from a congruence fallacy, i.e. Galen notes that religiosity/spirituality is not satisfactorily compared to appropriate secular counterparts and that the link between religion/spirituality and wellbeing could be caused by a factor outside of the ostensibly religious/spiritual beliefs (note: Galen (2018) uses the term 'religiosity/spirituality' or 'R/S', hence my use of it here, even if they are definitionally the same according to this thesis).

Price and Launay's (2018) findings, alongside Galen's (2018) criticism of the conflation of Religiosity/Spirituality with the participation in rituals allows me to return to the idea raised in the previous section: that the link between religious ritual attendance and wellbeing is mediated via social bonding. Price and Launay (2018) explicitly hypothesise that the secular ritual-wellbeing link is mediated by social bonding in their discussion, while VanderWeele (2017b) notes that it is specifically social religious rituals (and not the religious/spiritual beliefs or lone religious ritual) that to lead to the wellbeing benefits and VanderWeele (2017b) also cites the social bonds that were formed as playing an operative role in wellbeing. As such, I believe that it is important to follow this up by assessing whether feelings of social bonding can be found from ritual, be it secular or religious, and to determine if the religious component appears to play a role in the effect that is thought to cause the wellbeing benefits.

4.1.2. Aims and Hypotheses

In the study outlined in the remainder of this chapter, I sought to test whether a secular ritual was related to increased feelings of social bonding with others in a similar way to a behaviourally similar religious ritual. To do so, I, and a group of co-investigators, recruited participants from Sunday Assembly services, and matched these to Christian churches, taken from the study presented in Chapter 3. We then measured levels of social bonding before and after the rituals.

Unlike the first study presented in this thesis, this study was not pre-registered. In part, this was because of my realisation of the mistakes I had made with the former study's pre-registration, but I had not yet learned how to correct for them. The hypotheses that were provided in the original academic article based on the study presented in this chapter were as follows: (1) as the Sunday Assembly ritual mimics Sunday church ritual, social bonding will significantly increase from before Sunday Assembly to after the Sunday Assembly ritual; (2) as it is believed that it is the incorporation of various behaviours that leads to social bonding from ritual (Dunbar, 2013), and that Sunday Assembly rituals mimic Christian Sunday Mass rituals, the change in social bonding would not be significantly different between participants attending Sunday Assembly services and those attending church services; and (3) as there is research suggesting that emotional state/affect is related to feelings of social connectedness (Fredrickson, 2013; Mauss et al., 2011; Waugh & Fredrickson, 2006; see also chapter 3), we expected that changes in affect would predict change in social bonding, where increased positive affect and decreased negative affect would lead to an increase in social bonding.

Note: during discussions with co-investigators Miguel Farias and Valerie van Mulukom, as well as the PhD examiners during the viva voce process, I realised that using a hypothesis the predicts *no difference* between two groups cannot be assessed using the statistical analysis that was provided in the original academic article. To assess whether there is *no* difference between the effects, a two-one-sided test (TOST) procedure is required. As such, a TOST has been conducted and added to the results subsection 4.3.2.

4.2. Method

4.2.1. Participants

Adult (≥18 years) participants were recruited from four Sunday Assemblies in the UK; (a) Central London, (b) Reading, (c) Bristol and (d) London, East End. Four churches from the data collected for study 1 (presented in Chapter 3) were chosen as close matches (see below for matching procedure). For consistency, exclusion criteria that we applied to participants in this study were the same as those applied to the previous study.

49 (M_{age} = 39.6, SD_{age} = 12.24) participants were recruited from Sunday Assemblies, of which 16 identified as male, 32 as female and one identified as non-binary, and these were matched with 50 (M_{age} = 57.8, SD_{age} = 18.08) participants from churches that were in study 1, of which 16 identified as male and 34 identified as female. A total of 99 participants (M_{age} = 48.2, SD_{age} = 18.21) were included in the study.

4.2.1.1. Matching churches to Sunday Assemblies

To reduce the amount of variance between the religious ritual, and the Sunday Assembly, close matches were sought for each Sunday Assembly, to act in a similar way as a matched pairs design. This was done in order to make it as likely as possible that any difference found between the secular and religious rituals were due to the independent variable of ritual type (secular vs. religious) as opposed to other systematic factors, such as gender balance of participants. The following were considered when looking for an appropriate match:

- Congregation size (and approximate gender ratio)
- Location of Ritual, where whether the church was urban or rural was considered, and the size of the city it was based within were considered.
    - e.g. the Central London Sunday Assembly was matched with a Christian church from Central London, while the Bristol (population ~450,000, ~75% employment rate; Bristol City Council, 2020) Sunday Assembly was matched with a Church from Coventry (population ~400,000, ~72% employment rate; Coventry City Council, 2020)
- Length of the ritual, in minutes.
- The amount of behavioural synchrony as measured via the inverse-proxy described in Appendix 4.

The four Sunday Assemblies and their matching churches are shown in Table 4.2.

Table 4.2.

Table showing the pairs of churches (code beginning A) and Sunday Assemblies (code beginning Z)

Pair	Ritual Site Code	Inverse-Synchrony rating (% time stationary)	Length of service (mins)	Number of Attendees [of which female]
1	AC	62	67	54 [28]
	ZA	65	69	48 [29]
2	AG	68	64	187 [104]

	ZB	56	70	188 [125]
3	AN	60	79	39 [25]
	ZC	65	61	35 [17]
4	AK	64	90	64 [33]
	ZD	56	93	55 [36]

4.2.2. Materials

4.2.2.1. Social Bonding Measure

This is the same social bonding scale discussed in Chapter 2 (2.3.) and outlined in Chapter 3 (3.2.3.1.), with some specific differences. For the Sunday Assembly participants, these questions were phrased such that it made sense for their group: e.g. "At this moment, how emotionally close do you feel to the other members of this *Sunday Assembly* as a whole?" or "Thinking about everyone in this *Sunday Assembly* now, how much do you trust the others in this group" (emphasis mine). Answers to these questions were averaged into a single social bonding score. As this measure is a six-item social bonding measure, it has been abbreviated to SB6.

Raykov and Marcoulides (2019) and Savalei & Reise (2019) suggest conducting a factor analysis on any data that is being used to create an average or summed score to check for which measure of reliability should be used. Similarly, Charles (2020) provides specific criteria that can be tested for, to ensure the dependability of Cronbach's alpha. Consequently, I conducted the appropriate tests, such as a factor analysis, and found that all items loaded onto a single factor, with mean factor loadings above

0.7 and a range of less than 2, suggesting that the assumptions of unidimensionality and of essential tau-equivalence were not violated. Errors were also not significantly correlated. As such, both the alpha and omega reliability estimates should be essentially equal. Here I present only the alpha values, but the analysis script (Appendix 16, also available online at: https://osf.io/5rhz4/) also provides omega values for those sceptical of alpha due to recent critical articles (e.g. Dunn et al., 2014; McNeish, 2018; Peters, 2014). Internal reliability for the social bonding measure in the Sunday Assembly participants was $\alpha = .93$, 95% CI [.90, .96] before the ritual and $\alpha = .93$, 95% CI [.90, .96] for the post-ritual measure, providing evidence of high reliability. For the matched church participants, these scores were $\alpha = .94$, 95% CI [.91, .96] and $\alpha = .89$, 95% CI [.84, .93] for the pre- and post-ritual measures, respectively. The reliability estimates for all participants when pooled together are $\alpha = .93$, 95% CI [.91, .95] and $\alpha = .91$, 95% CI [.88, .94] for the pre- and post-ritual measures, respectively, also providing evidence of high internal reliability. As with the study presented in Chapter 3, this shows that the novel social bonding measure is reliable to use and can be used across different ritual settings in the field.

4.2.2.2. Pain Threshold

Pain threshold measures were assessed, as in the previous study, however too few participants were recruited to provide an appropriately powered analysis: as shown in the power analysis presented in 3.2.1. at least 115 participants would be required to have an analysis that had at least 80% power. This is because analyses that suffer from low statistical power are prone to Type II errors (false negatives), where the lower the power one has the greater the chance one has of making a Type II error. Analyses conducted in situations with low power are often uninformative, because null results become highly likely, even if there is a true effect. So, significant results in analyses with low power are ambiguous, as they can be interpreted as a false positive (because you were not likely to actually detect a true effect; cf. Oxytocin research (Benjamin et al., 2012; Hewitt, 2012)), whereas a null result in analyses with low power are also ambiguous, as you might have simply failed to detect a true effect.

To assess whether the power was too low, a post-hoc power analysis was conducted to determine what the power to detect a true effect of pain threshold on social bonding would be given only 49 participants. Based on same power analysis inputs used in study 1 (R^2 = 0.08, see section 3.2.1.), analyses to find an effect of pain threshold on social bonding would only have 40% power. Moreover, to use the more conservative effect size actually found in the results of study 1 (R^2 = 0.018, see Figure 3.3.), a post-hoc power analysis suggests that analyses attempting to find an effect of pain threshold on social bonding with 49 participants would only have 11% power. Given the issues with conducting analyses withy low power highlighted above, having power that is likely somewhere between 11% and 40% - much lower than the recommended 80% (McDonald, 2009) - is too low to warrant conducting analyses using pain threshold.

4.2.2.3. Affect

As with the previous study. We used the Positive And Negative Affect Scale (PANAS; Watson et al., 1988) to collect data on the affective state of participants both before and after ritual participation. The rationale for choosing the PANAS to measure affect was outlined in Chapter 3 (3.2.3.3.). To avoid duplication I will not restate this rationale here. The PANAS asks participants to say how much they are feeling 20 emotions (10 positive, 10 negative) "at this moment" measured on a 6-point Likert scale, from zero to five, where zero is "not at all" and five is "very much". Examples of positive emotions include 'Interested', 'Proud', and 'Inspired', examples of negative emotions include 'Nervous', 'Upset' and 'Irritable'. Watson and colleagues (1988) sum the values for the 10 emotions for both positive and negative to provide two scores: the sum of the scores for positive emotions, PANAS+, and the sum of scores for the negative emotions, PANAS–. A check of the conditions for dependability of alpha showed that the conditions were not met for either PANAS+ or PANAS– for any of the population types (Sunday Assembly, churches or pooled), at any time point. As such, Omega was used to determine reliability of the PANAS subscales, which can be seen in Table 4.3.

Table 4.3.
Reliability (as given by total omega), of the PANAS subscales both before and after the ritual

Population	Time	PANAS+ ω_t	95% CI	PANAS– ω_t	95% CI

Sunday Assembly only	Pre	.90	[.85, .95]	.81	[.70, .93]
	Post	.96	[.94, .98]	.79	[.59, .99]
Churches only	Pre	.90	[.86, .95]	.88	[.82, .94]
	Post	.94	[.91, .96]	.94	[.85, .99]
All Participants	Pre	.90	[.86, .93]	.85	[.80, .90]
	Post	.94	[.93, .96]	.86	[.77, .96]

4.2.2.4. Religion and Spirituality

Sunday Assembly participants were asked to self-rate both how religious and how spiritual they considered themselves to be, each on a scale of one to seven, where one meant “Not at all” and seven was “Extremely so”. Church participants in the previous study had only been asked to self-rate how religious they considered themselves to be. Given the definition of ‘religion’ I provided in Chapter 2, the term ‘spiritual’ can be considered equivalent to ‘religious’, given both require at least one belief in the super-empirical. But, the term ‘spiritual’ does not carry the same connotations, or societal weight/baggage, as the term ‘religious’ does to laypeople (the kind of person who does not use the term “super-empirical”). This is especially the case in the context of an explicitly secular ritual, such as the Sunday Assembly. For me, that many people are now identifying as ‘spiritual but not religious’ is simply a shift in identification, but not away from the belief in the super-empirical. After consultation with co-investigators, and an advisory board, it was felt that asking members of the Sunday Assembly how spiritual they were would be an appropriate measure of their belief in the super-empirical. These were included because there is evidence from religious vs. secular priming studies that religiosity of participants may alter the effects observed in psychology of religion research (Shariff et al., 2016). These variables were included for follow-up analyses to see if the results that were found were influenced by ratings of religiosity, in line with priming research.

We also asked a question about the feeling of connectedness to something bigger that the self. Sunday Assembly participants were asked after their ritual: "During today's Sunday Assembly, did you feel connected to something bigger than yourself, like the universe, and/or feel a sense of awe or wonder?" Based on conversations with a co-investigator who is a Christian minister, as well as two theologians on the advisory board, 'something bigger than the self' was considered a secular parallel to 'God' in the Christian religion. The reason it is deemed a *secular* analogue is that it makes no direct reference to any specific super-empirical reality (one may feel connected to Earth, to the Universe, etc. – empirical realities) and the part about awe or wonder was included because I (as a non-religious person, who has never been religious) was informed that there is a sense of awe or wonder that is felt when connected to the divine in a religious ritual. I interpreted this to mean that a feeling of connection to God, Jesus and/or the Holy Spirit automatically pre-supposes a sense of awe or wonder. Conversely, a feeling of connection to something bigger than the self does not (in my mind) intrinsically imply a sense of awe and wonder. For this reason, I specifically ask about a sense of awe and/or wonder in the Sunday Assembly question. To be clear, the question about a connection to something bigger than the self was considered analogous to the question the church participants were asked after their service: "During today's service, did you feel connected to God, Jesus, and/or the Holy Spirit?". Both questions were measured on a seven-point Likert scale with "Not at all" (1) being the lowest and "Extremely" (7) being the highest value. Each intermediate value also had a prompt: Very slightly (2), A little (3), Moderately (4), Quite a bit (5), and Very much (6).

As a non-religious person, to me, these two questions appear to be both semantically and functionally equivalent. Semantically so because God/Jesus/The Holy Spirit are, doctrinally, larger than the self. Functionally so because, if a feeling of connection to God/Jesus/The Holy Spirit provides a sense of awe or wonder, then asking about these feelings is targeting the same underlying construct. However, I am aware that those with a religious background may feel that this equivocation is not only misguided, but also false. It is here that I must admit that, as with any research using a post-positivist approach, the bias of the researcher will be present in at least some way. Given my background as an Atheist-Jewish person, I am limited in my ability to understand how Christians may conceive of, or experience, a feeling of connection to their higher power. It is for this reason that I use the "something bigger than the self" and "awe and/or wonder" terminology/constructs recommended to me by a Christian minister and academic theologians. Determining whether the two questions *do* target the exact same underlying construct is outside the remit of this study (and may be worthy of a thesis in its own right).

4.2.2.5. Demographics

Age, gender identity, and level of education were recorded to allow for inclusion in follow-up analyses.

4.2.3. Procedure

4.2.3.1. Assembly Recruitment

Initial contact was made at the flagship Central London Sunday Assembly. Calls were made to Sanderson Jones, the co-founder of the Sunday Assembly movement, wherein they wanted to confirm data privacy laws, appropriate ethics, etc. would be adhered to before the flagship Assembly confirmed their participation. After this, contact was made with other Assemblies. A total of four Sunday Assemblies, including the Central London flagship Assembly, agreed to take part. The procedure for attempting to recruit Sunday Assemblies followed the multiple-contact procedure outlined for the religious ritual sites in study 1 (see 3.2.5.1.)

4.2.3.2. Participant Recruitment

Ahead of our attendance, the Assembly alerted attendees that research would be taking place via newsletter communications, Facebook posts, and announcements at the previous month's ritual. On the day, researchers arrived 1 hour before the start of the Assembly. Attendees who arrived anytime between 45 minutes to 5 minutes before the Assembly began were provided with information sheets. Those who opted to take part and met the inclusion criteria were provided with a consent form before taking part.

4.2.3.3. *Study procedure*

Participants who took part were provided with a questionnaire, which had an ID code on the front unique to each participant, to ensure anonymity. The pre-Assembly section of the questionnaire contained the PANAS, social bonding questions, and their self-reported level of religiosity and level of spirituality. Halfway through the questionnaire, there was a two-page break which alerted participants that this was the end of the pre-Assembly section. Participants' names were then noted on a post-it note and attached to the questionnaire to match it with the same participant after the Assembly.

After the Assembly, participants returned to the researchers and filled in the post-Assembly half of the questionnaire, which asked for demographic information, connection to something bigger than the self, and re-measured both PANAS and social bonding. The post-it notes were collected and destroyed to ensure anonymity of the data.

All data was collected within 30 minutes before the start of the assembly (with the majority occurring within 10 minutes before the start of the Sunday Assembly ritual), and within 15 minutes of the end of the Sunday Assembly rituals to make it most likely that the responses were due to the Sunday Assembly ritual, and not because of events occurring after the ritual.

4.2.4. *Data Analysis*

A power analysis was conducted to determine the appropriate number of participants. Based on the data from study 1, in chapter 3, the effect size of change in social bonding from before to after a religious ritual was given by both the conservative r_R , (Pallant & Manual, 2007; Rosenthal, 1986) and the 'simple difference' effect size r_K (Kerby, 2014). The UK religious ritual effects had an effect size of r_R = .34 and r_K = .62, which converts to a d of 0.72 or 1.58, respectively. Using G*Power (Faul et al., 2007), and a one-tailed Wilcoxon-Signed-Rank test (non-parametric, within-participant design) in the *t*-test family with the distribution assumed to be the minimum asymptotic relative efficiency (the most conservative distribution assumption; Buchner et al., 2017), α = 0.05, Power (1-β) = 0.80, and an effect size of d = .72 (the more conservative effect size), I calculated that 16 participants would be needed to have an appropriately powered study for testing the first hypothesis that social bonding would increase from before to after the Sunday Assembly ritual. This study had 49 Sunday Assembly participants, suggesting this study is appropriately powered to test this hypothesis.

A similar power analysis for hypothesis two (the comparison between churches and Sunday Assemblies) was also conducted. To detect an interaction effect (before/after ritual interacting with ritual type) using an ANOVA, an effect size of $f = .36$ (converted from $r_R = .34$), $\alpha = 0.05$, Power ($1-\beta$) = 0.80, 2 groups, 2 measurements, nonsphericity correction of 1 and a correlation among repeated measures of 0.75 (calculated from the data collected in this study), a total of 10 participants per group would be needed to find a within-factors and/or an interaction effect, and a total of 56 participants (28 per group) to find a between factors effect, suggesting this study is appropriately powered.

While mixed-effects models were deemed most appropriate for the data structure of study 1, I noted in Chapter 3 that at least 17 top-level items are likely required to conduct an appropriately powered three-level mixed-effects (De Jong et al., 2010). In the current study, for conducting analyses with only the Sunday Assembly population, a three-level mixed-effects model would only have four top-level items, while a an inclusion of all ritual sites would have only eight top-level items. Neither of these would provide enough power to help detect an effect. Similarly, the number of participants required to reliably detect a single between-groups effect (i.e., social bonding in secular vs. religious rituals) in a three-level model is approximately 435 participants (see Table 7 in Brysbaert, 2019). Even if I were to use a two-level model instead of a three-level model (measurement occasion within participant; where ritual site was a participant-level variable, instead of a nesting variable), according to reference tables provided by Brysbaert (2019) the number of participants recruited for the current study would not be sufficient for testing a relationship between groups (see Table 7 in Brysbaert, 2019). For this reason, mixed-effects models were not used in the analyses for this study.

Please also note, only the variables specifically mentioned for any given analysis were included in that analysis. By this, I mean that age, gender, education, etc. were only included in the analyses that they are explicitly mentioned in.

4.3. Results

The full analysis script can be found in Appendix 16. Both the script and all anonymised data have also been made available online (see https://osf.io/npdzm/).

4.3.1. Effect of Sunday Assembly attendance on social bonding

A Shapiro-Wilk test was conducted to check whether data met the assumptions for parametric testing. The pre-meeting SB6 score (W = .977, p = .433) was not significantly different from normal, but the post-meeting SB6 score (W = .952, p = .047) was. Therefore, non-parametric tests were used.

To test the hypothesis that there would be an increase in self-reported social bonding, from before to after the Sunday Assembly ritual, a one-tailed, non-parametric Wilcoxon signed-rank test was conducted. As predicted, post-Assembly scores (M = 4.96, SD = 1.16, Mdn = 5.17) were significantly higher than at pre-ritual (M = 4.27, SD = 1.26, Mdn = 4.33, Z = 5.02, p < .001, r_R = .51, r_K = .84). In this case these results suggest a 'moderate-to-high' effect size according to Fergusson's criteria for social science (Fergusson, 2009). These results remain significant when using a two-tailed test (p < .001), and when using the Bonferroni correction for multiple comparisons to account for the follow-up analyses, below (p < .001).

4.3.2. Comparing bonding between church and Sunday Assembly samples

Both pre- and post-service social bonding scores for church participants were significantly different from normally distributed (W = .927, p = .004 and W = .939, p = .011, respectively). Therefore, a non-parametric form of ANOVA was used for the analysis.

Figure 4.1. Notched boxplot showing pre-ritual and post-ritual social bonding in Sunday Assembly (blue) and Church (red) participants. The notch (indent) around the median shows the 95% confidence interval. The whiskers are +/- 1.5*IQR from the upper and lower quartiles. The diagonal lines show the mean change for the two sets of participants.

Using the nparLD package in the R coding language, a non-parametric within-between ANOVA was run via the f1.ld.f1 function (Noguchi et al., 2012). The nparLD package's functions provide an ANOVA-like statistic with the denominator degrees of freedom listed as infinite. The f1.ld.f1 function found that there were significant main effects of both time (F (1, ∞) = 52.06, p < .001) and ritual group (F (1, ∞) = 4.38, p = .036), but there was no significant interaction effect (F (1, ∞) = 3.77, p = .052). As seen in Figure 4.1., there was a significant increase in social bonding from before to after both ritual types (the upward trend of both lines), and there was a significantly higher level of social bonding at both time points for participants at church than at Sunday Assembly (red line vs. blue line). However, there was no significant interaction effect. In other words, the increase from before to after the ritual was not significantly different between groups.

As highlighted in section 4.1.2., a two-one-sided test (TOST) is required to test the hypothesis that there is no difference between the two groups. While the change in social bonding score for the Sunday Assembly participants was normally distributed (W = .968, p = .210), the change in social bonding score for the matched churches was significantly different from normally distributed (W = .675, p < .001). Consequently, a non-parametric TOST was conducted (Wellek, 1996) using the `mawi` function in the EQUIVNONINF R package (Wellek & Ziegler, 2017). In their article providing a method of conducting a non-parametric TOST, Wellek (1996) outlines that, as with the parametric version of a TOST, one must provide the upper and lower bounds for which it would be reasonable to suggest that there is no difference (the epsilon values shown in formula 1.1; Wellek, 1996, p. 697). These epsilon values describe the probability of the same event occurring multiple times. Wellek (1996) originally developed their version of the TOST in the context of bioavailability, and suggested that $\varepsilon_1 = .31$ and $\varepsilon_2 = .27$ in the case of bioavailability studies, but to use $\varepsilon_1 = .20 = \varepsilon_2$ in other contexts. As such, I used the bounds $\varepsilon_1 = .20 = \varepsilon_2$. Using an alpha value of .05, a non-parametric TOST found that there was significant evidence to suggest that there was no difference between the effect of secular ritual on social bonding and the effect of religious ritual on social bonding (W = .594, σ = .057, positive evidence for no difference).

4.3.3. Comparing affect between church and Sunday Assembly samples

As well as assessing the role of bonding I then tested whether affect, as measured by the PANAS, changed from before to after the Sunday Assembly. The pre-meeting PANAS+ (W = .976, p = .445) was not significantly different from normally distributed, however the post-meeting PANAS+ measure (W = .939, p = .017) and both pre- (W = .861, p < .001) and post-meeting (W = .738, p < .001) PANAS- measures were significantly different from normal. Consequently, non-parametric Wilcoxon signed-ranks tests were conducted.

Figure 4.2. Notched boxplots showing pre-ritual and post-ritual (a) PANAS+ and (b) PANAS- in Sunday Assembly (blue) and Church (red) participants. The notch (indent) around the median shows the 95% confidence interval. The whiskers are +/- 1.5*IQR from the upper and lower quartiles. The diagonal lines show the mean change for the two sets of participants.

A two-tailed Wilcoxon signed-ranks test showed that there was a significant change in positive affect, with an increase in positive affect from before (M = 26.21, SD = 9.23, Mdn = 24.0) to after the Sunday Assembly ritual (M = 31.68, SD = 11.57, Mdn = 32.0, Z = 3.90, Bonferroni-corrected p < .001, r_R = .40, r_K = .60), as well as a significant decrease in negative affect (PANAS-) from before (M = 5.00, SD = 4.10, Mdn = 4.0) to after the ritual (M = 3.30, SD = 4.23, Mdn = 2.0, Z = 2.41, Bonferroni-corrected p = .047, r_R = .25, r_K = .44). These results suggest that there was a moderate effect of taking part in secular ritual on positive affect and a small effect on negative affect. Figure 4.2 shows these results and includes the matched church data for comparison.

4.3.4. The role of affect on social bonding

Table 4.4.

Multiple linear regression predicting change in social bonding

Variable	**B**	**95% CI**	***β***	***t***	***Sig. (p)***
(Constant)	- .00	[-.23, .23]		0.00	>.999
ΔPANAS+	.70	[.45, .95]	.70	5.66	<.001
ΔPANAS-	.14	[-.11, .39]	.14	1.15	.257

Note: R^2 = .432, 95% CI = [.19, .58]

I then examined whether this change in affect predicted the significant change in social bonding I observed in Sunday Assembly participants. First, I visualised the Sunday Assembly data using a correlation plot (See Fig A17.1., in Appendix 17). To test the hypothesis that affect change predicted social bonding change, I conducted a multiple regression for Sunday Assembly participants with PANAS+ and PANAS- as predictors. Both social bonding and the PANAS subscales were standardised for the regression analysis. A multiple regression showed that there was a significant model (F(2,44) = 16.76, Bonferroni-corrected p < .001, R^2 = .432, R_{adj}^2 = .407), with change in PANAS+ being a significant positive predictor of change in social bonding score, but not PANAS- (see table 4.4).

4.3.5. Exploratory analyses

In study 1 we found that the feeling of connection to something god was also a significant predictor of social bonding. Further, Price and Launay (2018) suggested that research should account for the length of time one had been attending Sunday Assembly to determine if this plays a role in some of the effects seen. As such, I conducted an exploratory correlation analysis and created a correlation plot to visualise the analysis. As shown in Fig A17.1., in Appendix 17, both the length of how long one had been attending the Sunday Assembly and the feeling of connection to something bigger were positively correlated with social bonding change. Moreover, baseline social bonding score may play a role in the level of change in bonding, i.e. the lower the starting score, the larger the change. Consequently, I conducted stepwise multiple linear regressions to include the control variable of baseline social bonding score, the level of connection to something bigger and how long (in months) participants had been attending Sunday Assemblies. Control variables of age, education, self-rated spirituality, and self-rated religiosity were also added to the stepwise process to determine if they played a role.

The stepwise regression analysis was conducted using the stepAIC function in the MASS package in R. This conducts a stepwise regression using the Akaike Information Criterion (AIC; Akaike, 1973). An AIC provides a numerical indicator of the ratio between the goodness of fit of the model and the simplicity of the model. The lower the AIC value, the lower the level of information loss, meaning it is a better, more parsimonious model (or more likely to be indicative of the true model). The absolute AIC values are not important, but the relative values are compared. The model with the lowest AIC value is the most parsimonious model that best fits the data. This can be run in one of three ways: (1) backwards (aka backwards elimination), starting from a full model with all predictor variables and iteratively removing the predictors that contribute the least to the model; (2)

forwards, starting with a null model and adding predictor variables iteratively until the model no longer improves, or (3) both, where a combination of the two methods is used to determine the best model. The both-direction method starts with no predictors and add predictors that contribute the most value (like the forward method) then removes any variables that no longer provide an improvement to model fit (like the backward method). The default method in the stepAIC function is 'both', as this allows predictors to be added and removed at each step, and is best used if conducting exploratory analyses (Bruce & Bruce, 2017; James et al., 2013).

A both-direction stepwise regression converged on a final model where four variables were included: baseline social bonding, PANAS+ change, connectedness to something bigger and age. The final model was significant (F(4,42) = 23.67, p <.001, R^2 = .693, R^2_{Adj} = .663), and showed that change in social bonding was significantly predicted by baseline social bonding, PANAS+ change, and connectedness to something bigger. Including age improved the model, but this variable was not a significant predictor (see Table 4.5).

Table 4.5.

Final model after both-direction stepwise multiple linear regression predicting change in social bonding in Sunday Assembly participants

Variable	**B**	**95% CI**	***β***	***t***	***Sig. (p)***
(Constant)	- .00	[-.17, .17]		0.00	>.999
Baseline social bonding	- .48	[-.65, -.30]	-.48	-5.47	<.001
ΔPANAS+	.50	[.30, .70]	.50	5.09	<.001

Connected to Something Bigger	.31	[.11, .51]	.31	3.10	.003
Age	.01	[-.00, .03]	.16	1.88	.068

Note: R^2 = .693, 95% CI = [.48, .77]

4.3.6. Church exploratory analyses

First data were plotted on a correlation plot to visualise the data (see Fig A17.2, in Appendix 17 Figures). As with the Sunday Assembly data, a stepwise regression was conducted on the matching church participants to see if similar results were found in the matched participants. The full model included the same predictors and control variables the Sunday Assembly participants apart from spirituality, as self-rated spirituality was not measured in the survey for church participants. The both-direction stepwise regression converged on a final model where five variables were included, baseline social bonding, PANAS+ change, PANAS- change, connectedness to God, and length of attendance. The final model was significant (F(5,41) = 6.90, p <.001, R^2 = .457, R^2_{Adj} = .391), and showed that change in social bonding was significantly predicted by baseline social bonding, PANAS+ change, and length of time one had been attending. Connectedness to God, and PANAS- change improved the model, but were not significant predictors (see table 4.6).

Table 4.6.

Final model after both-direction stepwise multiple linear regression predicting change in social bonding in church participants

Variable	**B**	**95% CI**	***β***	***t***	***Sig. (p)***

(Constant)	- .00	[-.23, .23]		-0.00	>.999
Baseline social bonding	- .42	[-.69, -.15]	-.42	-3.13	.003
ΔPANAS+	.40	[.12, .68]	.40	2.85	.007
ΔPANAS-	- .17	[-.41, .07]	- .17	- 1.43	.161
Connected to Something Bigger	.27	[-.02, .56]	.27	1.88	.067
Months Attended	.27	[-.00, .03]	.27	2.20	.033

Note: R^2 = .457, 95% CI = [.16, .57]

4.4. Study 2 Discussion

Religious rituals occur in all human societies (Brown, 2000), and they seem to confer various benefits to those who take part (VanderWeele, 2017a). It has been suggested that rituals are evolutionarily adaptive by helping foster social bonds (Dunbar, 2013). This hypothesis has received some support from a large body of research showing social bonds provide health benefits (Charles, Farias, & Dunbar, 2020; Holt-Lunstad & Smith, 2012; Holt-Lunstad et al., 2010). It has also been proposed that attending secular rituals, such as Sunday Assembly meetings, may lead to improved wellbeing (e.g., Price & Launay, 2018). However, whether the social bonding effect reported from religious rituals is also seen in secular rituals that mimic the behaviours of religious rituals had not been tested before. In study 1, we found inconsistent results as to whether religiosity played a role in the social bonding that takes place during religious ritual. In this study my colleagues and I compared participants that attended Sunday Assembly, a secular ritual that mimics a Christian Sunday Mass ritual, with those that attended church. In doing so this study provides the first evidence that the fostering of social bonds occurs in a secular ritual setting in a comparable way to a religious ritual.

Follow-up analyses found that the increase in social bonding from before to after the Sunday Assemblies was positively related to the change in positive affect, as was found in study 1 for churches across the UK. These findings are in line with the 'broaden and build' hypothesis, which suggests that positive affect increase the scope of one's attention to others to allow for the formation of social connections, which themselves lead to improved mental wellbeing (Fredrickson, 2002, 2013; Van Cappellen, Toth-Gauthier, et al., 2016). This hypothesis has also been used to suggest that the link between religion and wellbeing stems from changes in positive affect (2002; Van Cappellen, Toth-Gauthier, et al., 2016), which in turn leads to protective social benefits, such as social bonding (Diener et al., 2011).

Stepwise regression analysis found that neither level of self-reported spirituality nor level of self-reported religiosity played a significant role in social bonding change, despite both variables having been related to wellbeing in the past (Kim-Prieto & Miller, 2018), as well as having played a role in the effects of religious priming studies on prosocial behaviour (Shariff et al., 2016). This could be the result of the methodology of previous studies, which have often used attendance of religious services as a measure for religiosity itself (Koenig & Büssing, 2010; VanderWeele, 2017a), which could conflate the effect of ritual attendance with the effect of belief in the super-empirical (Galen, 2018). Diener and colleagues (2011) have noted that the reported relationship between religiosity and wellbeing is conditional on social support and social structure, suggesting that the religiosity-wellbeing relationship is really a social bonding-wellbeing relationship and that religiosity is only related to wellbeing via attendance at religious ritual. This may explain why religiosity was not significantly related to social bonding change in either Sunday Assembly or church participants.

Price and Launay (2018) have specifically suggested that future research should account for the length of time one had been attending Sunday Assembly, to see if this could explain the wellbeing effects they reported. In the stepwise regression model, the length of time one had been attending did not add predictive value for the change in social bonding in the Sunday Assembly participants. If, as

Price and Launay (2018) suggest, the improved wellbeing stems from social bonding, these results may suggest that protective effects of participating in secular ritual could occur quickly. I must note that it is possible that I failed to detect an effect of longer-term attendance for Sunday Assembly participants, if it does exist, because there were a number of people attending the ritual for the first time in the Sunday Assembly population. This was not the case with the Christian church participants, for whom we found that length of attendance was positively related to the strength of social bonding (i.e., the more months they had been attending for, the greater the upward change in bonding). Future research should attempt to account for the effect of newcomers on social bonding during group rituals, such as using longitudinal methods, to track social bonding over time.

In the stepwise analysis conducted only on the sub-sample of UK churches, inclusion of feeling of connection to God significantly improved the model fit, but the variable did not significantly predict social bonding (where it did in study 1). This could be because a greatly reduced number of participants (approximately half of all UK church participants) included in the analysis presented in study 2 compared to study 1. Because of the lower number of participants, the power to detect an effect size that is comparable to pain threshold could be too low in the smaller sample size, which would lead to a much higher likelihood of finding a false negative (see the similar effect sizes for the two variables in the β column in Table 3.7.).

Given the results of the study presented in this chapter, namely that religious ritual and secular ritual did not differ in their ability to increase feelings of social bonding, I must revisit one of the core questions raised at the start of the thesis: why is *religious* ritual ubiquitous? (Brown, 2000; Norenzayan, 2010). Ahead of study 1 of this thesis, one of the reasons I suggested that it was important to study *religious* ritual was that religious ritual might be distinct or unique in some capacity in its ability to lead to social bonding. Religious ritual (i.e., ritual that is conducted in reference to the super-empirical) is apparently a human universal (Brown, 2000; Norenzayan, 2010), and its ability to socially bond participants has been hypothesised to be what has made it universal (Dunbar, 2013, 2017b; Durkheim, 1912). There are at least four possible ways in which the results from the study presented in this chapter relate to this hypothesis.

Firstly, it is possible that finding evidence of no difference between the two types of ritual was simply a fluke, where replication of research on a comparison between the two (especially in more controlled conditions) might find that there is actually a difference. Secondly, it could be the case that religious ritual's ubiquity is caused by something else other than the social bonding. For example, it could be that religious (vs. secular) rituals are ubiquitous because of something to do with imagistic modes of expression, and not doctrinal modes of expression. If it is identity fusion, and not social bonding, that makes religious rituals evolutionarily advantageous, then imagistic rituals may be what needs to be studied. If religious rituals are better able at creating identity fusion in participants than secular ritual, this could be a reason for its ubiquity. Alternatively, it may simply be more difficult to convince people to engage in secular imagistic modes of expression compared to religious ones: convincing people to endure significant amounts of pain – as seen in religious imagistic modes (Konvalinka et al., 2011; Whitehouse et al., 2014; Xygalatas et al., 2011) – may not be as easy without a religious/doctrinal context. Thirdly, it could be that what has historically been described as *religious* ritual is simply a misattribution: maybe it is simply *ritual* that is universal (which is one potential interpretation of Brown (2000), one that Pinker (2002/2016) ascribes to). The focus on religion, in this interpretation, is incorrect due to the conflation of 'ritual' and 'religious ritual' into a single construct (cf. Galen, 2018). To clarify, in this third point, 'religious' ritual was *never* special.

Finally, the fourth way these findings might be related to the idea that religious ritual is special is somewhat related to the third point. Specifically, different definitions of 'religious' could lead to different interpretations of what is meant when discussing the ubiquity of "religious ritual". For this thesis, I have defined 'religious' acts as acts conducted directly relating to the super-empirical (Schilbrack, 2013), in large part because of its analytic usefulness. However, in Chapter 2, I noted that there is no such thing as a 'correct' definition, only more or less useful ones for your purpose (Berger, 1967/1981). Were I to have used a more functionalist definition (cf. Durkheim, 1912), then it is possible that both sets of rituals in this study might have been considered 'religious'. So, by a more functionalist approach, the anthropological observation that religious ritual is ubiquitous because of its ability to cause social bonding may be correct, but the category of religious ritual would simply be too general to be of analytic usefulness. Points three and four are more theoretical in nature, and could be debated purely on theoretical approach. However, the first two points are of more interest to the empirical, scientific study of religion – which this thesis seeks to do. To address the potential of there actually being a difference, future research should be conducted to attempt to replicate the findings of the current study. For the second point, research on secular vs. religious *imagistic* rituals may be needed to assess identity fusion differences. Research on identity fusion and imagistic rituals is beyond the scope of this thesis, but I will attempt to replicate the findings from the study presented in this chapter to rule out this result being a fluke.

4.4.1. Limitations and directions for future research

This work is the first to demonstrate that secular rituals, much like religious rituals, promote feelings of social bonding. However, I acknowledge that there are limitations to this study. Firstly, this study was not pre-registered. Given the changes suggested by those promoting Open Science methodologies since the advent of the replication crisis (Charles et al., 2019; Open Science Collaboration, 2015; van't Veer & Giner-Sorolla, 2016), the methods and analysis plans could have been registered in advance of conducting the study. Although pre-registration was not done in this case, the research materials are provided in the appendices, and are also available alongside the full anonymised dataset in an online repository in accordance with other Open Science practices. Additionally, a power analysis was provided to support the sample size used in this study.

Another limitation of this study is that I only conducted research with one type of secular ritual, the Sunday Assembly meetings. Sunday Assembly meetings are not the only secular ritual that mimic religious ritual, with other examples including the Church of Positivism (Mill, 2015) – still active in Brazil – and the Religious Humanism movement in the United States. Getting data from the Church of Positivism would have meant that I could also compare secular ritual with the Brazilian data collected in study 1. Although, given there is now only a single Church of Positivism site, such a comparison might not be possible due to small sample size issues.

One avenue for future research is to conduct studies investigating whether the same positive health effects found in those who regularly attend religious rituals can also be seen in those who regularly attend Sunday Assemblies, or other similar non-religious rituals that mimic the behaviours of religious rituals, compared to those who do not attend such rituals. Examples of such positive health effects are better immune function and lowering levels of all-cause mortality (Chida et al., 2009; Gillum et al., 2008; Hummer et al., 1999; Musick et al., 2004), depression (Balbuena et al., 2013; Barton et al., 2013; Li et al., 2016; Norton et al., 2008; Strawbridge et al., 2001) and suicidality (VanderWeele, 2017a). Here, my colleagues and I have examined the role of ritual on social bonding. Other research could also seek to better understand the mechanisms underlying the protective factors that have previously been related only to religious participation. VanderWeele et al. (2020) have since suggested ways in which research might be designed such that future research could make more causal conclusions even when using observational data, as in the current study, by using outcome-wide longitudinal designs. These methods, while complex, time consuming, and analytically complex, could provide stronger evidence on the effects of ritual on health outcomes. Future research could use these methods to compare health outcomes from those who attend secular rituals to those who do not, while taking affect and social bonding into account. I also recommend that, much like in the study presented in this chapter, feelings of social bonding should be explicitly measured in future ritual and health research, as this may provide a more comprehensive understanding of the mechanism by which ritual attendance appears to improve wellbeing.

Future research could also be conducted on secular rituals that mimic religious ritual, but have since been removed from their religious contexts. For example, there are many martial arts (such as Tai Chi) that are practiced in non-religious contexts in the modern world. These martial arts often began life as activities or rituals that were conducted in relation to some kind of super-empirical belief (e.g., the ying and yang of Taoism and Confucianism, in the case of Tai Chi). In this sense, the acts originated as religious acts. However, in the many years since their inception, martial arts, like Tai Chi, have been spread, with specific forms, behaviours, and mediative rituals providing apparent health benefits. In this sense, in countries such as the UK and the USA, Tai Chi has changed from being a religious ritual (in reference to the super-empirical concepts of ‘ying and yang’) into secular rituals that are performed for the purpose of health benefits. They are still rituals, because they still are repetitive performances of more-or-less invariant actions encoded by others, and that many of the acts don’t have the direct instrumental purpose of improving health (e.g., it is not clear how the “Pushing

Hands" – "Tuishou" – drills directly lead to health benefits). I would predict that such secular ritualistic acts, when performed in a group, would also lead to enhanced feelings of social bonding.

But what of rituals that did not have a religious origin? I would argue that many of these have converged (to borrow a term from evolutionary biology) on the same behaviours as religious counterparts. For example, a weekly dinner party among friends that always occurs on the same night. This is, behaviourally, incredibly similar to the Jewish ritual of the Shabbat Friday Night Dinner. Consequently, I would expect that such group secular rituals – even though they are not based on, nor are they derived from, religious rituals – would lead to similar outcomes in terms of the social bonding that occurs.

Given the finding that greater feelings of a connection to something bigger than the self was significantly related to increases in social bonding, future research could be conducted on gatherings of secular groups, which are not rituals (i.e., they contain actions that have direct instrumental purpose) but nonetheless may create a sense of connection to something bigger than oneself. One example would be sporting events, where one feels connected to a team spirit (Halldorsson, 2020; Sullivan, 2018), which might allow the creation of social bonds in ways not dissimilar to rituals. Those of the functionalist school of thought might describe these gatherings as a form of 'implicit religion' (Aicinena, 2017; Bailey, 2002; Lord, 2006). Rappaport (1999) argued that ritual is one behaviour in a family of behaviours (i.e., ritual, competition, theatre, and drama are different but related behavioural phenomena). Despite being related to other behaviours, ritual in particular may simply be "without equivalents or even…satisfactory alternatives" (Rappaport, 1999, p. 31) with regard to its ability to lead to feelings of social bonding.

Of course, this is just one potential interpretation of the findings in this study. Given that there were no control settings/behaviours in this study (i.e., both sets of participants took part in a ritual), social bonding may have increased simply because participants took part in any group behaviour. Though, given evidence that rituals lead to performing more behaviours correlated with social bonding than other group behaviour (Wen et al., 2016), I think that it is likely that there is something specific about ritual that caused the increase in feelings of bonding. Also, there are other plausible reasons that we found a significant increase in social bonding from before to after the rituals. Instead of the ritual being the cause of increased feelings of social bonding, it could simply be that the anticipation of being able to chat more with others in attendance after the ritual finished brought to mind the relationships, and thus increased feelings of bondedness. This might explain why church-goers who had been attending for longer had a greater increase in social bonding than those who had not been attending for as long: long-standing attendees might anticipate such conversations more than those who had not been attending as long. Due to the repeated measures design of the study presented in this chapter, these plausible (albeit not theoretically grounded) reasons for increased levels of social bonding cannot be ruled out, especially in naturalistic settings.

4.4.2. Study 2 Conclusion

To conclude this chapter, I would like to outline where the literature stands: throughout the first two decades of the 21st century, levels of religiosity have been on the decline in many Western countries (Brenner, 2016; Bullivant, 2016; Clements, 2017; Pew Research Forum, 2012; Twenge et al., 2016). This may be worrying to some, as there is a wealth of evidence from the religion and health field demonstrating that participation in religious activities provides a variety of health benefits (VanderWeele, 2017a). However, some research suggests that secular rituals, such as the Sunday Assembly, may provide a boost to wellbeing (Price & Launay, 2018). It has also been proposed that the mechanism by which health benefits arise from religious participation is social bonding (VanderWeele, 2017b). Study 1 demonstrated that religious ritual participation was related to increases in feelings of social bonding. In the study presented in this chapter, my colleagues and I have demonstrated that secular rituals, in the form of Sunday Assembly meetings, are also related to increases in feelings of social bonding. A TOST also found that there was significant evidence of no difference between the change in social bonding found between the two types of ritual. This suggests that it is not necessarily the religious nature of rituals that leads to social bonding, but instead the behaviours within a ritual (as predicted).

However, two major issues have arisen from this study. First, the number of participants in the Sunday Assembly group that were new to the ritual was higher than that of the church group. As Hobson and colleagues (2018) have pointed out, the mental processes that allow people to perceive something as a ritual “will vary as a person becomes more familiar with the actions through repeated exposure/practice” (p. 275). Rappaport (1999) also made a salient point that simply attending a ritual for the first time – as an observer, instead of as a performer – meant that one would be taking part in a charade, as opposed to a ritual. If the new attendees to Sunday Assembly were simply observing the ritual, they may have simply been in a charade and not a ritual. This means that it is possible that I was comparing those who had been performing a ritual (the church group) with those who had been taking part in a charade (the Sunday Assembly group). If so, this may mean the premise of the study was not valid. Secondly, it is entirely possible that there was no significant difference between the Sunday Assembly participants’ and the Church participants’ change in social bonding (and, in fact, evidence of no difference) because of some kind of extraneous variable that has not been accounted for due to the nature of field research. As such, the next chapter will outline a third study conducted, which accounts for both of these issues by using longitudinal methods under controlled conditions to compare secular and non-secular ritual, to determine if the religious nature of a ritual plays a role in the level of social bonding that takes place.

5. Chapter 5. Social Bonding Under Controlled Conditions

The two major issues raised at the end of the previous chapter – the novelty of the ritual and the possible role of extraneous variables – could be addressed in various ways. For example, to address the first issue, one could ensure that they exclude those who are completely new to the ritual or exclude those with less than a certain number of attendances. Alternatively, one could run a longitudinal study, where the effect of attending for multiple rituals (instead of just one) is assessed. Similarly, to address the second issue, running a study in more controlled conditions could be considered. One of the major issues with running such a controlled study of ritual is that it can become difficult to ensure that any activity decided upon conforms to definition of ritual provided in Chapter 2 (2.1.2.), while also making sure that it has some kind of ecological validity. The content of this chapter outlines a longitudinal study conducted in controlled conditions. It is adapted from the submitted article "Bending and Bonding: A randomized controlled trial on the socio-psychobiological effects of spiritual versus secular yoga practice", completed alongside Dr Valerie van Mulukom, Ambikananda Saraswati, Dr Fraser Watts, Dr, Robin I. M. Dunbar and Dr Miguel Farias. The contribution of each co-author is listed in Table 5.1.

Table 5.1.

Table showing the CRediT allocation for Study 3. Initials are provided for each author for each role they contributed towards. The order of the initials for each role denotes the level of contribution (i.e., appearing first on a contributor role means this co-author contributed most for this role unless otherwise specific)

Role	Author(s)	Role	Author(s)
Conceptualisation	SC*, MF*, VvM*, AS, FW†, RIMD†	Resources	FW, AS, SM$^{\Delta}$, DR$^{\Delta}$
Data Curation	SC	Software	DR$^{\Delta}$
Formal Analysis	SC	Supervision	MF, VvM, RIMD, DR$^{\Delta}$
Funding Acquisition	RIMD, FW, MF, AS	Validation	VvM
Investigation	SC, AS, VvM, SM$^{\Delta}$, others	Visualisation	SC
Methodology	SC, AS, MF, VvM, RIMD†, FW†	Writing – Original Draft	SC
Project Administration	SC, VvM, MF, RIMD,	Writing – Review and Editing	SC, VvM, MF, RIMD, FW, AS

* Equal primary contribution

† Equal supporting contribution

$^{\Delta}$ Acknowledged non-authors. SM = Dr Scott McGuire, who conducted most of the phlebotomy, and provided some phlebotomy equipment; DR = Dr Derek Renshaw, who provided access to the lab equipment needed for ELISA analysis of bloods and supervised the ELISA analysis. Due to issues with blood freezing (See Appendix 19, section S1), blood analysis outcomes do not appear in the article, nor the thesis, and so co-authorship was not appropriate.

5.1. Background to Study 3

In study 1, pain threshold was used as a proxy measure for μ-opioid activation, which was in line with similar research looking at pain proxies for μ-opioids (Cohen et al., 2010; Tarr et al., 2015; Tarr et al., 2016). In that study, my colleagues and I found that both positive affect and pain threshold were positively related to the strength of social bonding following religious rituals. Despite providing evidence that advances in our understanding of the socio-psychobiological effects of religious rituals, there is an additional underlying question which has rarely been addressed in research: is there something special or unique about the religious component of religious rituals which makes them special?

In study 2, I attempted to answer this question in a field setting and did not find a difference between religious ritual (Christian Sunday Mass) and the secular control (Sunday Assembly). In fact, I found evidence of no difference via a two-one-sided test (TOST). However, evidence from historical and anthropological data, including USA 19th century Utopian communities and contemporary Israeli Kibbutzim, suggests that religious communes are more likely to survive than secular ones (Sosis, 2000) and that individuals feel a greater sense of belonging within the religious groups (Sosis & Ruffle, 2003). In the previous chapter, I noted that it would be important to replicate the finding of there being no difference between the two types of ritual. This is to rule out the possibility that the findings were a result of a Type I (in the case of the TOST) or Type II error (in the case of the non-significant ANOVA). In the last chapter, I also noted that not finding a difference could be due to extraneous variables that could not be controlled for in a field study. As such, a replication study in controlled conditions would be more appropriate to attempt to replicate the results.

A few clinical-oriented longitudinal studies have contrasted the effects of religious compared to secular meditation practice on pain tolerance as well as migraine frequency and severity. In these studies, the religious component consisted of God-oriented statements (e.g. ‘God is joy’, ‘God is love’) while the secular versions used statements focused on self-attributes (e.g. ‘I am happy’, ‘I am good’) (Wachholtz et al., 2017; Wachholtz & Pargament, 2005, 2008). The results from these studies suggest that the effects of the religious intervention were consistently superior to the secular one. Specifically, participants using the religious mediation had a greater pain tolerance after the meditation compared to before it, and had a reduction of migraine frequency after the intervention compared to the secular mediation. However, some experiments using religious recitation techniques from different laboratories are more mixed. One study found that using a religious chant (‘hare krishna krishna krishna’) compared to a pseudo-religious chant (‘sarva dasa sarva dasa’) led to greater reductions in anxiety and depression in the religious chant group (Wolf & Abell, 2003), but another study contrasting the effect of a spiritual *versus* a secular mantra (e.g. ‘one’ instead of ‘aum’) on various physiological measures (including blood pressure and galvanic skin response) found both religious and secular conditions to be significantly superior to a control condition, but not different from one another (Morse et al., 1977). Note that the studies comparing religion and secular activities in controlled conditions that included a pain variable use *pain tolerance* instead of *pain threshold* as their measure of pain (Wachholtz et al., 2017; Wachholtz & Pargament, 2005, 2008).

These studies present some interesting, albeit mixed, preliminary evidence that religious practices may overall produce more powerful effects than secular ones (in contrast to my findings from study 2). Previous studies that assess the effects of religious ritual compared to secular ritual have either been conducted in the field (my study 2), or within experimental individual (i.e., non-group) contexts. Other experiments which may have assessed the effect of religion or secular contexts on social bonding have not used ritual behaviour, but instead used religious primes (Cohen et al., 2014; Johnson et al., 2015). As such, there is no prior research that has aimed to assess the role of the religious component of a ritual on feelings of social bonding in controlled settings. Here I have aimed to conduct a randomized controlled experiment of the effects of a religious *versus* a secular ritual focusing on key social, psychological, and biological dimensions.

In order to conduct such a comparison, I sought to use a ritual that already has been considered 'religious' in many contexts, but that can be practiced in a secularised way. In the discussion of the previous chapter, I mentioned martial arts like Tai Chi as one such ritual that has religious roots, but has been iterated on in the western world to become more secular. As well as martial arts, there are other such rituals that exist in both religious and secular forms. The Hindu ritual of Hatha Yoga, for example, has been co-opted by many in the Western world, stripped of its super-empirical elements to promote fitness while retaining many of the ritualistic elements (i.e., the repeated performance of more-or-less invariant formal behaviours that were encoded by others and that lack direct instrumental purpose).

After consultation with experts on religion, theology, and ritual at the International Society for Science and Religion (ISSR), I decided to use yoga (over, say, martial arts) for four reasons: First, this Hindu-based practice is already practiced by many in the West removed from its religious aspects to encourage a more physiotherapeutic or exercise focus (Yadav et al., 2012). However, unlike some martial arts, given its rising popularity in society the religious components – such as 'dimensions of being' or even inclusion of sutras – can also be included without going against the other religious sensibilities of those who take part, taking the appearance of science via 'scientism' (see Rahmani, 2020). Second, as highlighted above, yoga as a physical practice of repeatedly taking on formal postures ('asanas') that were encoded by someone else, some of which contain no direct instrumental purpose, conforms to my definition of ritual. Thirdly, there is already research linking yoga practice to the release of β-endorphin (Suri et al., 2017; Yadav et al., 2012), and with increases in positive affect (Kiecolt-Glaser et al., 2010), which suggests that using yoga in a controlled, social-based experiment might be able to elicit a social bonding effect similar to that of a ritual in its 'natural' context, as seen in studies 1 and 2 of this thesis. Finally, yoga is already known by most to be a group activity (e.g., group yoga classes are offered at many gyms across the UK) that is open to beginners, and does not expect any kind of competition (unlike, say, the Tuishou – "pushing hands" – aspect of Tai Chi), which means that the ritualised aspects of the activity (and not ritual-adjacent activities like competition) can be the focus.

I considered that simply engaging with the physical postures in a group context would lead to increased levels of μ-opioids and social bonding, regardless of the condition. However, the focus of this study is to assess the added religious elements (references to the super-empirical), which might amplify these effects in some way, (e.g., by making participants feel connected to something bigger than themselves, such as a deity, the universe at large, or some kind of spiritual realm; see effect 'd' in Figure 2.1. in Chapter 2, 2.2.3.1., for the theoretical model). As shown in both studies 1 and 2, higher feeling of connection to something bigger than the self does appear to be related to higher levels of social bonding. Van Cappellen (2017) suggests that "At the heart of many religious and spiritual traditions is the aspiration to transcend the self to achieve a sense of connectedness with the world and/or with a Higher Power" (p. 254). A sense of connection to something bigger than the self, then, conforms to operationalised definitions of 'self-transcendence' (see Thurfjell et al., 2019). Because of religious rituals' more explicit focus on the feeling of connection to something bigger than the self (Van Cappellen, 2017; Van Cappellen et al., 2017), it may be that religious ritual is better able to create feelings of social bonding via this connection.

In addition to feelings of connection to something bigger than the self, rituals have been associated with an increase in wellbeing (Van Cappellen, Toth-Gauthier, et al., 2016), potentially through an increase in positive affect (Fredrickson, 2002), which in turn may contribute to social bonding (Mauss et al., 2011; Waugh & Fredrickson, 2006). Positive emotions have been previously associated with states of self-transcendence and social bonding (Van Cappellen, Way, et al., 2016) so, as seen in studies 1 and 2, it is possible that positive affect plays a significant role as a mechanism underlying the social bonding function of rituals.

To better understand the role of novelty of the ritual that may have affected the results of study 2, I opted to assess people who were new to yoga, and then assess these people over a longitudinal timeframe, such that I can assess how newcomers to Sunday Assembly may have affected the results of study 2. For example, in the church subsample in study 2, it appeared as though the longer someone had been attending the church service for the greater the increase in social bonding they experienced. Using a longitudinal methodology would allow me to assess when this effect may start to occur.

As noted above, many of the studies seeking to assess secular *versus* religious conditions have used pain tolerance, as opposed to pain threshold (Wachholtz et al., 2017; Wachholtz & Pargament, 2005, 2008). There has also been previous work on social bonding that has used pain tolerance instead of pain threshold, which has found an association between them (e.g., Dunbar et al., 2016; Johnson & Dunbar, 2016; Pearce et al., 2016). As such, to conform to the norms used in previous literature comparing secular and religious behaviours in controlled conditions, in this study I have used pain tolerance instead of pain threshold.

Moreover, while the previous two studies were conducted in naturalistic settings, this study takes place under controlled conditions. As such, I also took this opportunity to conduct phlebotomy (to collect blood) in order to measure peripheral levels of β-endoirphin. This was done because Veening, Gerrits & Barendregt (2012) suggest that, although they are not strongly correlated, previous research “does not necessarily indicate that CSF (central) and peripheral plasma levels of β-endorphin are totally unrelated” (p. 2). They later clarify that peripheral levels likely serve no short-term effect, but that they likely serve a “long-term modulatory effect” on central levels (p.4). Consequently, changes in peripheral levels of β-endorphin may have a long-term effect on how centrally-released β-endorphin leads to social bonding changes. This could be measured in a longitudinal study.

5.1.1. Aims and hypotheses

This study sought to better understand the socio-psychobiological effects of rituals by directly contrasting religious and secular versions of the same behaviours – a five-week yoga course – in a controlled setting. My colleagues and I measured levels of social bonding, affect, and pain tolerance (as a proxy for central μ-opioid activation), before and after the sessions. This study was pre-registered (see Appendix 24). Due to the nature of conducting parallel studies required in the timeline of a PhD, the pre-registration was published online before the data from study 2 had been analysed and written up. As such, the pre-registration only contained four hypotheses.

The first pre-registered hypothesis is based on past research (and the results of study 1). Taking part in ritual-like group yoga sessions will lead to increases in levels of social bonding with other attendees. In the pre-registration I also hypothesised that the level of social bonding change measured will be different in those taking part in the religious sessions of yoga compared to those taking part in the secular sessions. This was framed as a difference (as opposed to a 'no change', hypothesis, cf. study 2) because of research suggesting that previous religious *versus* secular ritual had significantly different outcomes based on ritual type in controlled conditions (Wachholtz et al., 2017; Wachholtz & Pargament, 2005, 2008; Wolf & Abell, 2003), as well as because of co-authors' input on how the hypotheses should be framed. Had the pre-registration occurred later on in the PhD, I may have framed it as a no difference hypothesis, both for theoretical reasons (Dunbar (2013, 2017b) suggests that it is the mix of behaviours, and not the beliefs themselves, that leads to social bonding) and because the results of study 2 suggest that no difference may be an appropriate hypothesis.

The other two pre-registered hypotheses related to BOTSA. Specifically, that the change in social bonding would be related to change in the pain tolerance test and that changes in β-endorphin levels in the blood will be related to long-term feelings of social bonding. Due to technical issues experienced with blood analysis (see Appendix 19, S1), the peripheral β-endorphin measure could not be assessed for a majority of participants. As such, no statistical analyses using peripheral β-endorphin levels were conducted.

However, since pre-registering study 3, some further hypotheses were added for theoretical reasons. Firstly, given that it was found, in the church sample, that the change in social bonding was greater in those who had been attending for longer, it was also hypothesised that levels of social bonding will change over time. Also, because religious rituals are more likely to focus on self-transcendence than secular rituals (Van Cappellen, 2017), levels of connectedness to something bigger than oneself was hypothesised to be higher in the religious yoga condition than the secular yoga condition. Also, as positive affect was significantly related to social bonding in both study 1 and study 2, it was hypothesised that a positive affect would be significantly positively related to levels of social bonding.

For clarity, I have numbered the hypotheses below in the order that they will appear in the results section:

1. Taking part in group yoga sessions will lead to increases in feelings of social bonding with other attendees.
2. Feelings of social bonding will change over time (week to week).
3. Feelings of connection to something bigger than the self will be higher in the spiritual yoga condition compared to the secular yoga condition.
4. Feelings of social bonding will be higher in those taking part in the spiritual yoga than those taking part in the secular yoga.
5. Changes in the self-reported measure of social bonding will be positively related to changes in the μ-opioid proxy (assessed as a pain tolerance test).
6. Positive Affect will be significantly positively related to feelings of social bonding.

In these hypotheses, I have not made any *a priori* predictions regarding mediators of social bonding (e.g., would positive affect lead to increased social bonding *via* the connection to something bigger than the self?). The Broaden and Build hypothesis (Fredrickson, 2013) might suggest that such a pathway is possible. I have not included mediation models in *a priori* hypotheses because I am not sure exactly which pathways are most reasonable to expect. However, such potential mediators can be assessed in follow-up, exploratory analyses.

5.2. Study 3 Methods

5.2.1. Participants

Participants between the age of 18 and 65, inclusive, who had never practiced yoga, were included in this study. Those with a diagnoses of arthritis (Kosek & Ordeberg, 2000; Lee et al., 2011; Wessel, 1995), diabetes (Lee & McCarty, 1992; Themistocleous et al., 2016), ADD/ADHD (Stickley et al., 2016; Treister et al., 2015) were excluded from the study due to changes in pain perception reported by those with such diagnoses. Given the required physical exercise of the yoga session, and the use of phlebotomy, those with musculoskeletal, blood clotting or circulatory issues were also excluded from the study. Moreover, as with studies 1 and 2, participants that had taken pain medication, or consumed alcohol prior to attending any yoga session had their data from that session excluded from the analyses. Though, as with attendees at the rituals who met the exclusion criteria due to pain medication or alcohol intake in studies 1 and 2, they were not stopped from taking part in that session of yoga. Participants who did take pain medication or who had drunk alcohol prior to attending were reminded of the data exclusion criteria so that they did not repeat this, so that their data would not be excluded from future sessions.

A total of 52 participants (one non-binary, 10 male, M_{age} = 29.1, SD_{age} = 14.32) took part in the study. Participants were randomly assigned to a condition using a random number generator. Twenty-nine participants (6 male) were randomly assigned to the religious yoga condition and 23 participants (4 male, 1 non-binary) were randomly assigned to the secular yoga condition. Forty participants (8 male, 1 non-binary, M_{age} = 29.5, SD_{age} = 15.68) attended all five weeks of yoga. Of these, 19 participants (3 male, 1 non-binary, M_{age} = 32.4, SD_{age} = 15.97) were assigned to the secular condition and 21 participants (5 male, M_{age} = 27.2, SD_{age} = 15.39) were assigned to the spiritual condition (see Figure 5.1). There was no significant difference in age ($t(49) = 1.65$, $p = .104$), gender

($\chi^2(1) = <.001$, $p > .999$), baseline levels of self-reported religiosity ($t(36.9) = 1.19$, $p = .241$) or spirituality ($t(44) = 0.10$, $p = .924$) between participants assigned to the two yoga conditions.

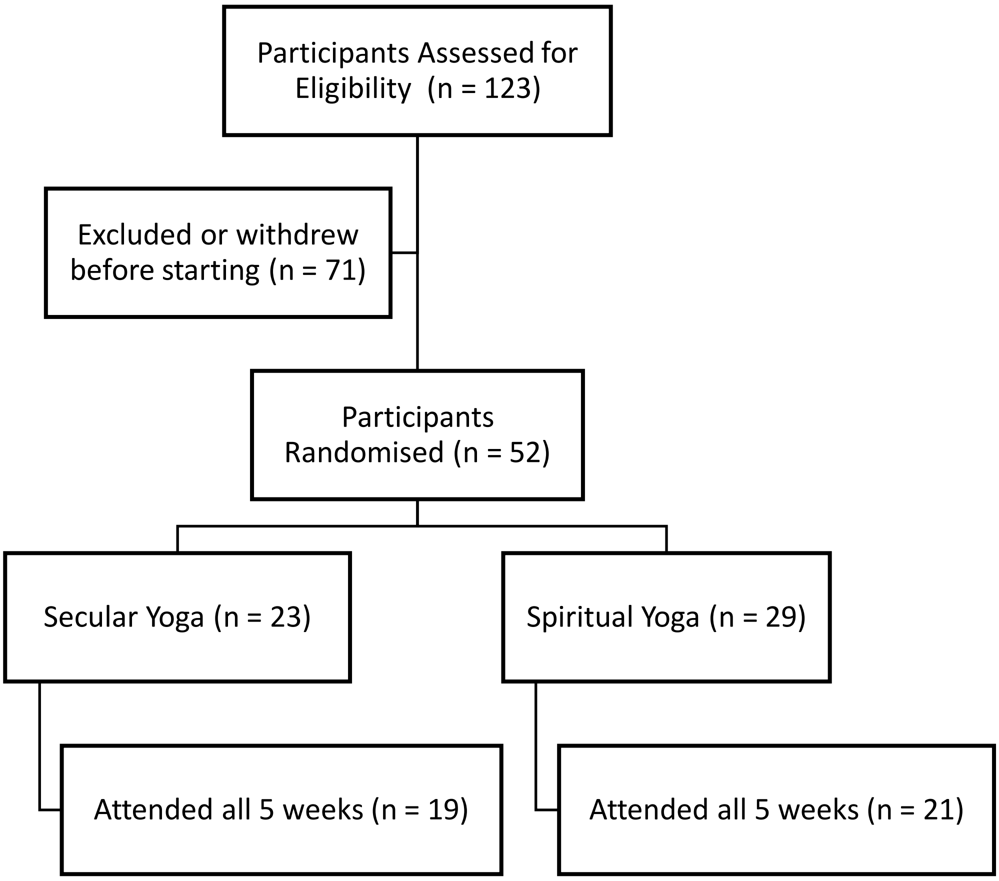


Figure 5.1. A flow chart showing attendance of yoga for participants assigned to each condition. In total, 21 of 29 participants attended all five weeks of spiritual yoga, and 19 of 23 participants attended all five weeks of secular yoga.

5.2.2. *Materials*

5.2.2.1. Social bonding measure.

As with all studies in this thesis, social bonding was assessed using the six-item scale outlined in Chapter 2 (SB6), where the average score was provided. Reliability was calculated using the process described in S2 in Appendix 19. The point estimate for the reliability of the SB6 measure was .80, and the 95% confidence intervals were .73 for the lower bound and .87 for the upper bound.

5.2.2.2. Pain tolerance (μ-opioid proxy)

The wall-sit measure, also known as a wall squat, is an endurance exercise that requires participants to hold a sitting position for as long as possible while against a wall (Wilkerson et al., 2012). It has been used in previous work as a measure of pain tolerance, measured by the length of time one can hold the wall-sit. This is because the endurance test becomes painful after a short period of time (Dunbar et al., 2016; Johnson & Dunbar, 2016; Pearce et al., 2016). The wall-sit measure has a high test-retest reliability (Bruce et al., 2017). The amount of time was detected using an electronic stopwatch.

5.2.2.3. Affect

I used the Positive And Negative Affect Scale (PANAS; Watson et al., 1988) to collect data on the affective state of participants. The rationale for using the PANAS to measure affective state was outlined in Chapter 3, and it is the same for the study presented in this thesis. To avoid duplication, see the rationale outlined in Chapter 3 (section 3.2.3.3.). The PANAS asks participants to say how much they are feeling 20 emotions (10 positive, 10 negative) “at this moment” measured on a 6-point Likert scale, from zero to five, where zero is “not at all” and five is “very much”. Examples of positive emotions include ‘Strong’, ‘Proud’, and ‘Attentive’, examples of negative emotions include ‘Jittery’, ‘Ashamed’ and ‘Upset’. Watson and colleagues (1988) suggest the use of the sum values for the 10 emotions for both positive and negative to provide two scores: the sum of the scores for positive emotions, PANAS+ (reliability in the current study = .71, 95% CI [.58, .77]), and the sum of scores for the negative emotions, PANAS– (reliability in the current study = .51, 95% CI [.36, .58]).

5.2.2.4. Connection to something bigger than oneself

Like in study 2, I wanted to make sure that the feeling of connection to a higher power, or something bigger than oneself could be assessed (for the sake of the thesis, the two are deemed functionally and semantically equivalent, as discussed in Chapter 4, 4.2.2.4.). Here, I have separated such a feeling of connection away from measures of religiosity and spirituality, as it appears that the feeling of connection to something bigger than the self was not correlated with these self-rated measures (see Figure A17.1., Appendix 17). After each session, participants were asked the question “During today’s meeting, did you feel connected to something bigger than yourself, like the universe, and/or feel a sense of awe or wonder?". This was measured on a seven-point Likert scale with "Not at all" (1) being the lowest and "Extremely" (7) being the highest value. Each intermediate value also had a prompt: Very slightly (2), A little (3), Moderately (4), Quite a bit (5), and Very much (6).

5.2.2.5. *Blood collection and Serum β-endorphin analysis*

The initial plan for the study had been to draw blood from participants for later analysis of peripheral βe levels. To draw blood, phlebotomists used Greiner Bio-One Ltd's safety blood collection set needles (23gx19cm), which come with a holder to extract blood into 5ml gold-topped Vacutainer tubes. The Vacutainer tubes contained silica in order to separate the serum from the rest of the blood after centrifuging. After collection, any wounds were covered using cotton wool balls stuck on with micropore surgical tape (in case of plaster allergies). Sharps were disposed of using 7L capacity Sharps Disposal bins (yellow lid), while other, non-sharp, medical waste was disposed of using a 7L capacity pharmaceutical waste bin (blue lid).

Due to technical issues (explained in S1, Appendix 19), a majority of participants' blood could not be analysed. However, the remaining blood was analysed the using an enzyme-linked immunosorbent assay (ELISA). The ELISA kit used was the BioVision QuickDetect™ βe (Human) ELISA Kit (E4458-100). To use this ELISA kit, the manufacturer's guide on protocol was followed. The full document can be found in Appendix 18 (A18.1).

5.2.2.6. *Yoga equipment*

Participants were all provided with a yoga mat, and with a grey yoga training top to wear for the experiment. The idea of this was also to tap into the underlying principle of the minimal group paradigm (Tajfel et al., 1979), where the addition of minor similarities may create the sense of a group, i.e. to heighten levels of group entitativity. The purpose of this was to allow this paradigm to mimic other rituals (e.g. religious services), or other behaviours in the family of ritual-like behaviours (e.g., sporting events or music concerts; Rappaport, 1999), which often have specific clothing that attendees wear to signify they are part of a single group entity.

5.2.2.7. Yoga sessions

The yoga sessions were designed by an instructor with over 30 years' experience, who trains other yoga instructors, and also is an author of spiritual books on yoga. The sessions were planned so that the behaviours in both the religious and the secular forms of yoga were identical. The difference between the two session types was the framing of the behaviours. Details of the schedule for the secular and spiritual sessions can be found in Appendices 20 and 21, and are available online (https://osf.io/3dsyp/). For an example of how the sessions differ, on page 28 of the secular yoga class plan (Appendix 20), in the section labelled "Tiger posture to goose posture to salutations posture", it states that the "tutor engages Participants' attention and directs it to the muscles being engaged and being stretched." (Appendix 20 p. 488; underlined) Conversely, in the religious yoga class plan (Appendix 21), there is an additional section stating "Alongside the physical sensations of the movement, participants will be invited to be aware of the way in which the attention moves from thought to physical sensation. The tutor will explain that in this attention or awareness is known as the 'buddhi' in Yoga." (Appendix 21, p. 497; highlighted). The 'buddhi' is a super-empirical reality that sits within part of the Sukshma sarira (literally 'subtle body'), one of the three Sarira ('bodies') in the Sarira Traya ('Three Bodies') doctrine of Hinduism. The term 'buddhi' is often referred to as the session develops with increased suggestions to move beyond the physical and psychological dimensions. For example, during the corpse or Śavāsana pose, the teacher chants and explains verses 3 and 5 of Patanjali's *Yoga Sutras* (Satchidananda, 1978), emphasizing that in yoga 'we are seeking what is behind the physical and psychological: the subtle unknown from which both emerged.' (see 'Appendix 21, p. 499 highlighted). Once again, the reference to 'the *subtle* unknown' is a guide from the instructor for participants to focus on the super-empirical concept of the Sukshma sarira (the 'subtle body').

There were other differences between the religious and secular sessions: the postures in each of the sessions were given either their traditional yoga name or secular name for the religious or secular sessions, respectively (e.g. Vyagrāsana v.s. Tiger Pose or Pranamāsana v.s. Salutations Posture; more highlighted in Appendix 21). This provided a level of abstraction to each pose, with the intent of implying that the asanas (poses) have some kind of super-empirical effect in the religious sessions that was not present in the secular versions. This conforms to the definition of 'religious ritual' adopted in chapter 2, as the *asanas* in the religious version of the yoga was performed in direct relation to the super-empirical, whereas the *poses* in the secular version of the yoga was only performed in reference to empirical reality.

Moreover, to emphasise the 'religious' nature of the yoga to the participants, the special terminology makes the asanas relate only to something occurring during the yoga ritual, as opposed to being interpretable outside of the ritual context. The intent was to have this match similar such specialist terminology used in naturalistic religious ritual settings, such as the 'Eucharist' (i.e., consumption of bread and wine, also known as 'holy communion') in Christianity, or the 'chibuv hamitzvah' (i.e., the act of kissing the Torah, literally translated to 'showing an appreciation for the commandments') in Judaism. To clarify, the use of the special terminology for the poses is not what makes the yoga religious: only performing the yoga in direct reference to super-empirical realities makes it religious. However, the use of such specialist terminology was done to extend the number of similarities that the controlled ritual has to naturalistic religious rituals, to help improve ecological validity. For this reason, something like doing one's taxes – despite the large amount of tax-specific jargon – is not a religious act, as there is no reference to the super-empirical.

5.2.3. Procedure

5.2.3.1. Participant recruitment

The study was advertised through physical poster advertisements as well as online on social media, and via mailing lists of various universities. Participants were told they would be paid £50 to take part in five weeks of yoga, and their travel expenses were also to be covered. Participants were provided with the information sheet and consent form to sign in advance of attendance. On the information sheet, each of the measures was explained, as well as the fact that blood would be drawn by phlebotomists. The framing of the experiment was to investigate "multiple possible effects that yoga may have, including changes in emotions, social relations, and hormones." Once the consent forms had been signed, they filled in a short online survey to ensure that they were naïve to yoga (an exclusion criterion), as well as getting background demographic data and contact details, to send reminders about the yoga sessions. If, at this stage, it was found they had previous experience of yoga, the participant was informed that they were not eligible for the study.

Once an eligible participant had completed this survey, they were randomly allocated to either the spiritual or secular condition by using a computerised dice-rolling simulator. The dice-rolling simulator simulated the roll of a six-sided die. If it rolled a one, two or three, they were allocated to the secular condition. If it rolled a four, five or six, they were allocated to the spiritual condition. Each condition of yoga was split into three groups, ranging in size from seven participants to ten participants.

5.2.3.2. Sessions

Upon arrival to a session, participants changed into the provided yoga top and signed the continued consent form (this was signed every week to ensure participants acknowledged they had the opportunity to ask questions about the study between sessions). They were then asked to fill in the pre-session questionnaire and take the wall-sit measure. The wall-sit measure was conducted by either me, or one of the multiple research assistants in that session (see Appendix 19, S3.3).

For the wall-sit pain tolerance test, participants were told that they would be taking part in the "*wall-sit measure*" and that "this was to measure how long one can maintain a seated position against the wall". If asked why they were doing this measure, participants were informed that "this is to assess one of the ways that yoga might affect the body." All research assistants had been given training to ensure that they did not use the term 'pain', 'test', or 'endurance' to describe the measure. This was to make sure that participants weren't motivated by competition. Participants were asked to place their back "straight up, with both the back and shoulders against the wall" above a cushioned mat. They were told to place their feet approximately 30cm away from the wall at a shoulder width apart. Participants were told that, when they could no longer hold the wall-sit position, they could allow themselves to slide or fall down onto the cushioned mat below them. Participants were then told to slowly slide their top half down the wall, keeping their back straight against the wall, until their knees were at a right-angle. At this point, the researcher taking the measure started an electronic stopwatch. Once the participants started to fall or slide down more than 1 or 2cm (so that the knee angle changed away from 90 degrees), the stopwatch was stopped and the time recorded. I demonstrated what the wall-sit measure looked like and how to fall onto the cushioned mat to avoid injury to the participants before the first session of yoga, such that all of them could see what was expected of them.

After taking part in the wall-sit measure, on odd weeks (weeks one, three, and five) participants had their blood drawn by phlebotomists in a room next door to the studio where yoga was taking place. There was also a series of distractor tasks that appeared as though participants' flexibility was being measured. These distractor tasks were used for two reasons: (1) to help stop participants from focusing on the wall-sit measure and emotion questions in the questionnaire to avoid them finding out the purpose of the experiment (which was especially needed in the non-phlebotomy weeks) and (2) to ensure that those who were waiting to have blood drawn, or who had already had blood drawn were not waiting idly where they could strike up conversation that might alter the social bonding measure (which was needed in the phlebotomy weeks).

The participants then took part in the 1-hour yoga session based on their condition (either religious or secular). After the session, participants then filled in the post-session section of the questionnaire and re-took the wall-sit measure (and, in odd weeks, had blood drawn again).

Session timeslots were two hours long, with 30 minutes before and after the session to ensure participants had time to change into/out of the yoga tops provided, and to fill in the questionnaire, take the wall-sit measure and have blood collected. The wall-sit measure and questionnaire with the social bonding questions were assessed as soon after the yoga sessions as possible, always occurring within 15 minutes of the end of the session, though most within 10 minutes of the end of the session.

5.2.4. Data analysis

5.2.4.1. Reliability

Scale reliability for longitudinal data was not calculated in the same way as for studies that measure a construct on a single occasion, or in a single day (e.g. α or ω). The method for calculating reliability for all the grouped measures (averaged or summed) used in the article was completed using the CorrMixed R package (Van der Elst et al., 2016). Full details and the rationale for using this method are outlined in S2 of Appendix 19.

5.2.4.2. Mixed-effects models

In this study I deviated from the pre-registered analysis plan. The first reason for a different analysis is that the analysis technique used as a basis for the *a priori* power analysis was not appropriate for the experimental design, nor for the data structure. In the pre-registration, I used a between-participants ANOVA design for the power analysis, where a within-between would have been more appropriate, given the repeated measures design. This error meant that there was a large over-estimation in the number of participants we would need to detect an effect if using an ANOVA. The second reason for a different analysis is that some participants did not attend all five weeks of yoga meaning there was not equal loadings for an ANOVA to be conducted without excluding many participants. A corollary to this issue is that, even if some participants attended all but 1 session, this could still lead to different intervals between data collection time-points – i.e. one participant attended weeks 1, 2, and 5 (a one-week gap followed by a three-week gap) whereas another attended weeks 1, 3 and 5 (consistent two-week gaps). Consequently, we opted to use a multi-level model as it can incorporate data with a different number of data points for each participant as well as different intervals between data collection time-points.

Moreover, in this study, there is data that can vary for each measurement occasion (i.e. either before or after the yoga session such as level of social bonding), week of yoga (e.g. the research assistant who took the wall-sit measure, or how connected they were to something bigger during that week's session) and participant (age, gender, session type). This means that the data falls within a three-level structure best addressed by a multi-level model, also called a linear mixed-effects model. Another option for analysis would have been structural equational modelling (SEM) for latent growth curve modelling (Hox & Stoel, 2005). However, Hedeker & Gibbons (2006) argue that the multi-level approach is more appropriate for data structures such as the one in this study, and it has been suggested that not accounting for multilevel data using an appropriate model can lead to a much higher likelihood of Type I errors (i.e. false positives; Meteyard & Davies, 2020). Aarts et al. (2014) have suggested that not using an appropriate model could inflate the error rate to as high as 80%. To avoid such inflations of Type I errors, I have used linear mixed-effects modelling to analyse the data.

Mixed-effects modelling has grown in prominence in psycholinguistics and in some other subfields of psychology, but its use in the psychology of social bonding is much less prominent (see Lang et al., 2017 for an exception), as is the case with the psychology of religion (Garssen et al., 2021). Moreover, due to the varying ways in which such models can be run, it is vital that I am clear on how I conducted the analyses. As such, I will briefly describe how to use and interpret a mixed-effects model. Magezi (2015) provides a guide on how mixed-effects models might be used in psychology and Meteyard & Davies (2020) have since provided a best-practice primer on how they should be used. I have followed advice provided by these guides in the approach to building and interpreting the mixed-effects models.

Mixed-effects models can be viewed as the logical extension of multiple regression analyses. However, mixed-effects models do not have all of the same assumptions as a multiple regression model. A single participant being measured more than a single time (i.e. in this study where they are measured twice each week, for five weeks) will lead to a correlation between their own results. This would be an issue for a regular regression analysis but is accounted for in a mixed-effects model. However, the way in which such issues are accounted for means that, unlike traditional regression analyses, multilevel models with hierarchical data do not easily provide an output of a *p*-value for the fixed effects (the effects which are constant across individuals) without a high likelihood of Type I errors (Luke, 2017). This means that, in many cases, *p*-values are not reported at all when conducting mixed-effects models, and instead model comparisons are created.

A model comparison uses information about the model and compares it to other models, to see which of the models best fits the data. Often this is conducted using an Akaike Information Criterion (AIC; Akaike, 1973) or a Bayesian Information Criterion (BIC, aka in literature as the Schwarz Information Criterion or Schwarz Bayesian Criterion, SIC/SBC; Schwarz, 1978; Stone, 1979), which are estimates of parsimony[14] (Aho et al., 2014). An AIC provides a numerical indicator of the ratio between the goodness of fit of the model and the simplicity of the model. The lower the AIC value, the lower the level of information loss, meaning it is a better, more parsimonious model (or more likely to be indicative of the true model). However, the absolute value of AIC is not important, only the value relative to other models. These can be compared with one another and a likelihood ratio provided. BIC is the Bayesian counterpart to an AIC. Thankfully, most software that allows for analysis using mixed-effects models provide AIC and BIC values.

Aho et al. (2014) note that there is not a one-size-fits-all rule determining whether an AIC or BIC value is best for model selection, as they serve different purposes: AIC is considered 'asymptotically efficient'. This means that, in a scenario where there are many possible complex models, an AIC will answer the question 'which of the models that were specified *best fits* the data?'. Its use stems from the idea that 'all models are wrong, but some models are useful'. BIC, on the other hand, is 'asymptotically consistent'. This means it is best used when there are a small number of fully specified models (i.e. all possible models are accounted for, in a simple system). It is best used when answering the question 'which model is *correct*?' and is likely best used when conducting highly controlled experiments with few variables and specific hypothesis testing. In short, AIC is best used for exploratory analyses, data where extraneous variables may play a role, or for more complex studies where not all possible models can be specified, and BIC for confirmatory analyses when all possible models can be accounted for. As I cannot reasonably specify every possible model with all possible variables in various interactions, I will be using AIC to compare models. Specifically, I will be using the AIC correction (AICc), which is more appropriate for the number of participants in this study, as recommended by Burnham & Anderson (2002, 2004). Comparing models with one another requires that the models be fitted using a maximum likelihood method.

As noted above, obtaining a *p*-value from mixed-effects model outputs can be difficult. This is because of ambiguous degrees of freedom once multiple cross-level effects are taken into account. However, Luke (2017) recently suggested that there are ways to minimise Type I errors by using

[14] Parsimony, in this context, means to use the minimal number of assumptions (or steps) to still fit the data well.

specific fitting methods and degrees of freedom approximations. Luke (2017) found that the best way to get a more reliable *p*-value is to fit the final model using a "reduced maximum likelihood" (REML) instead of a maximum likelihood (ML) method, along with the Satterthwaite approximation or Kenward-Roger approximation (Luke, 2017). In the appendix of his article, Luke (2017) provides R code for how to run the approximations to get a *p*-value for fixed effects in the model. However, Luke (2017) specifically states that this step can only be done once random effects structures (in this case, effects that vary across participants) have been confirmed using model comparisons (i.e. comparing AICc values between models). As such, the analysis takes two stages.

1. Stage one, model creation and comparison. In this stage, multiple likely possible models of varying complexity are specified, and run using the ML method. These models are then compared against one another to determine the most parsimonious model (the least complex model, which has the significantly lowest AICc value). If two or more models have low AICc values, and are not significantly different from one another, the one with fewer variables (lower complexity) is favoured for parsimony purposes.
2. Stage two, fixed-effects *p*-value estimation. Once the most appropriate model for testing a hypothesis has been determined, it is then re-fitted using the REML method, with the Satterthwaite approximation applied. This model is able to output *p*-values for the fixed-effects, which can be interpreted in a similar manner to a more standard multiple regression output.

For this study, I constructed multiple models of varying complexity (i.e. with different numbers of fixed and random effects and control variables) using a maximum likelihood method and used AICc values to determine which models best account for the data for the research question being asked. Once a model that best fits the data is determined, the Luke (2017) method was conducted on the most parsimonious model to provide *p*-values for the fixed effects, which can be interpreted in a similar way to *p*-values provided by a multiple regression. The step-by-step model creation process (i.e., creating models with increasing complexity) is documented in Appendix 19 (section S4.). and the precise analysis methods can be found in the R analysis script (Appendix 22). All variables were grand-mean centred and standardised before analysis.

5.2.4.3. Building models

When attempting to test hypotheses, there are usually many possible ways one could model the hypothesis. When taking a mixed-effects approach, it is best practice to start from a model of low complexity and slowly building up to models of greater complexity, and comparing these models with one another along the way. Due to the vast number of possible models, it is best practice to constrain the models to include only specific variables relevant to the specific hypothesis being assessed. The most basic model one can make is measuring whether the dependent variable does change at all, and one can then assess the AICc value for this basic model.

As noted in the previous subsection, a single AICc value is of no practical use by itself. However, I am able to specify a more complex model, where I allow for the values of the dependent variable to vary within a participant across timepoints, and then call for an AICc value to compare it to the base model. For example to assess the first hypothesis that social bonding increases from before to after ritual (irrespective of ritual type), one can first assess whether or not there is a significant amount of variability in social bonding at all (a very simple model). Then, one can allow the level of social bonding to vary within a week (i.e., adding the pre-post time component in), and then one can allow social bonding to vary within a participant (here we are building up the multi-level structure into the model one step at a time). As the structure becomes more complex, the level of parsimony may decrease unless adding the complexity greatly improves model fit. This model building process, and the R code that is used to do so is presented in Appendix 19 (S4). Each of the models created to test for each of the hypotheses, as well as for the exploratory analyses, is also presented in Appendix 19 (S5-S10). The most parsimonious model from a run of model-building around a specific hypothesis is the one that fixed-effects *p*-values were generated for. Table 5.3. only shows the most parsimonious models that assess each of the hypotheses related to social bonding.

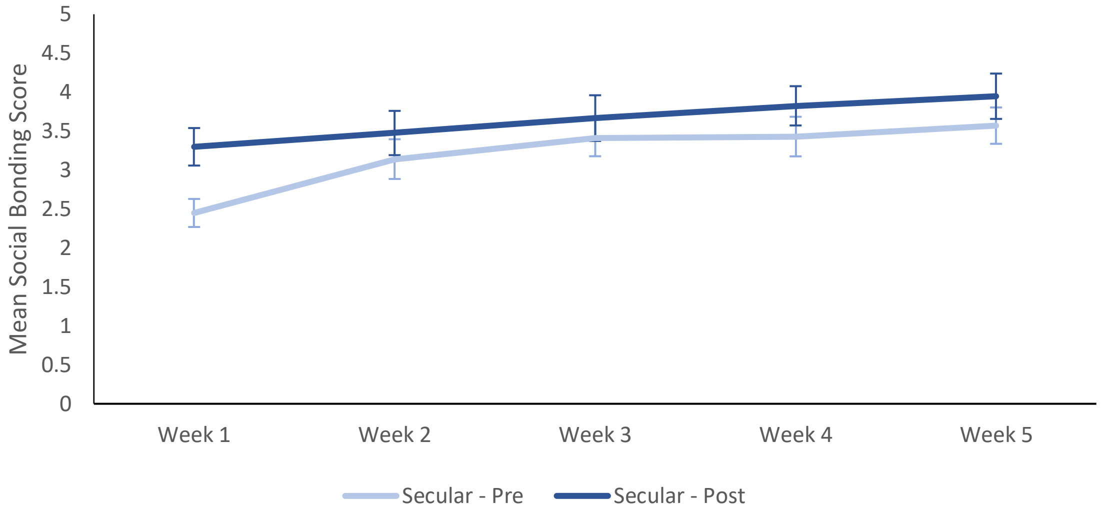
5.3. Study 3 Results

5.3.1. Hypothesis testing

5.3.1.1. Hypotheses 1 and 2: Differences in social bonding over time

First, data was visualised to understand how relevant dependent variables changed over time (see Figure 5.2, 5.3, and 5.4). Next, I investigated the hypotheses that taking part in yoga (irrespective of the condition) would lead to an increase in feelings of social bonding, and that this might change over time. The most parsimonious model produced to test this hypothesis included both measures of time (pre/post * week of yoga interaction), which allowed random effects for participants. The result of the Luke (2017) method for determining the fixed-effects *p*-values are listed in Table 5.2, Model A. The results show that level of social bonding increased from before to after each session (a significant main effect of measurement occasion), and each week (a significant main effect of week), and that the level to which social bonding increased from before to after yoga was significantly lower in all sessions compared to week 1 (a significant measurement occasion * week interaction; See Appendix 23, Figure A23.3.). Table 5.2. shows the change in social bonding from before to after each ritual each week.

A)



B)

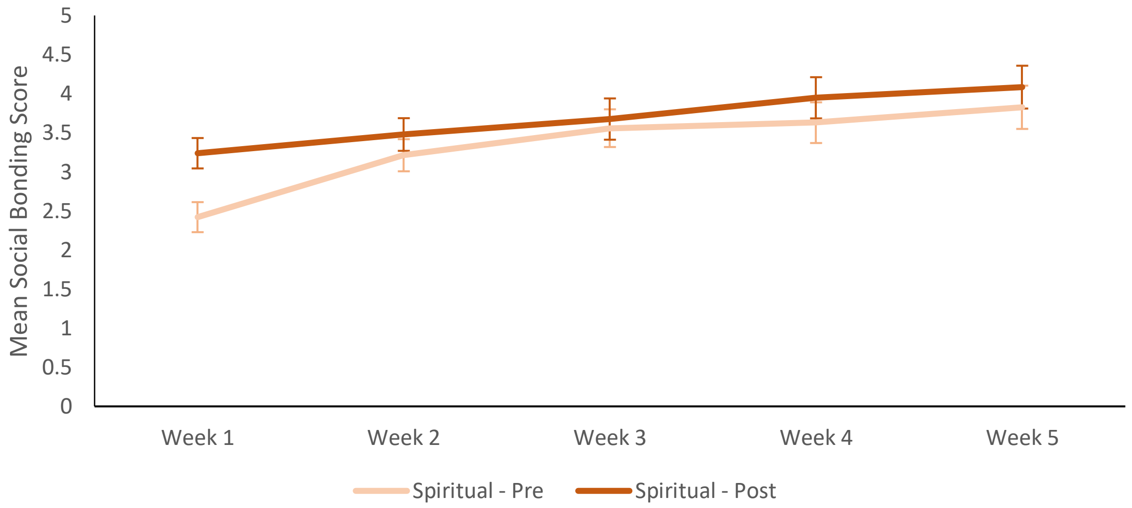
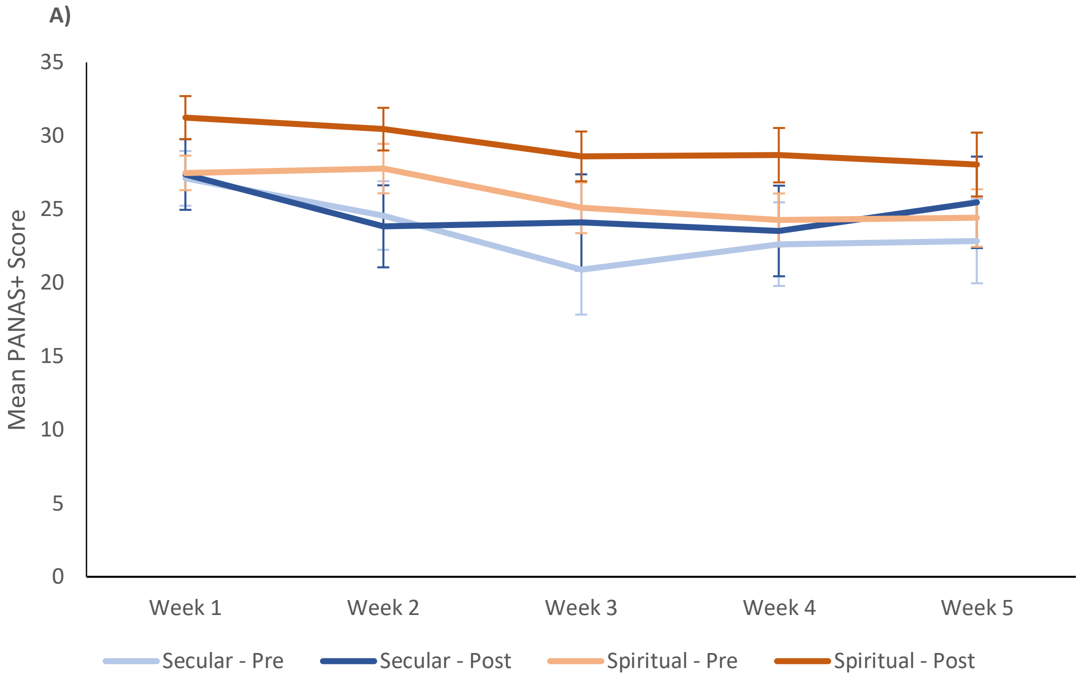


Figure 5.2. The mean social bonding score (full possible range 1-7) over time, with **a)** the data for participants in the secular yoga condition, and **b)** the data for participants in the spiritual (religious) yoga condition. Error bars show ± 1 standard error from the mean.



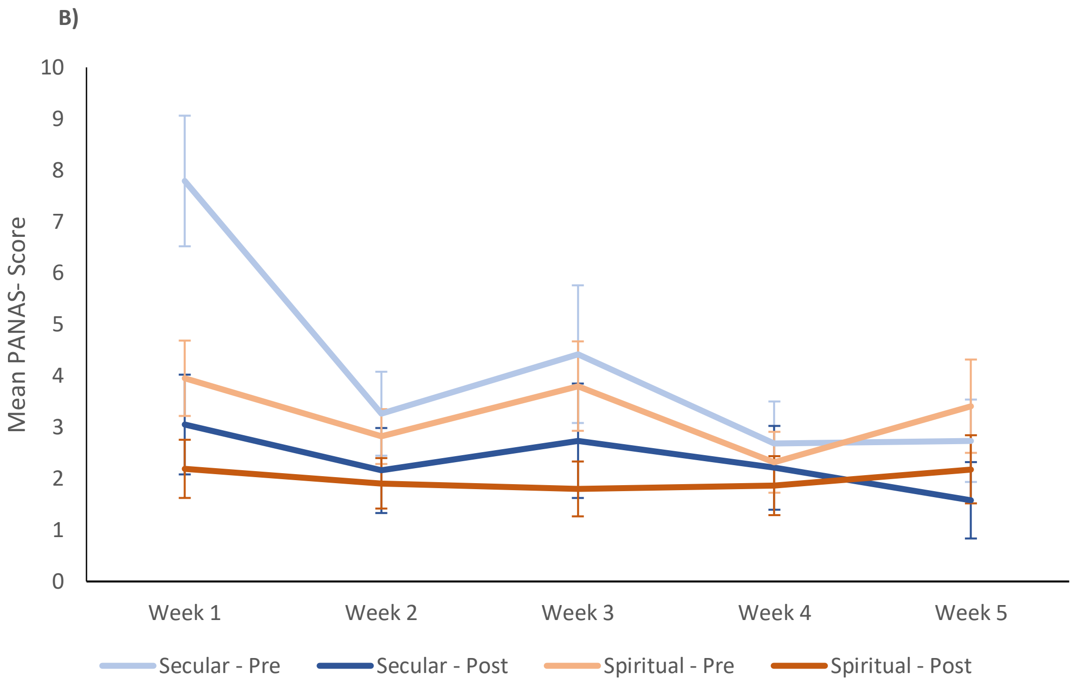


Figure 5.3. The mean **A)** PANAS+ and B**)** PANAS- scores over time in both the secular and spiritual (religious) yoga conditions. Error bars show ± 1 standard error from the mean.

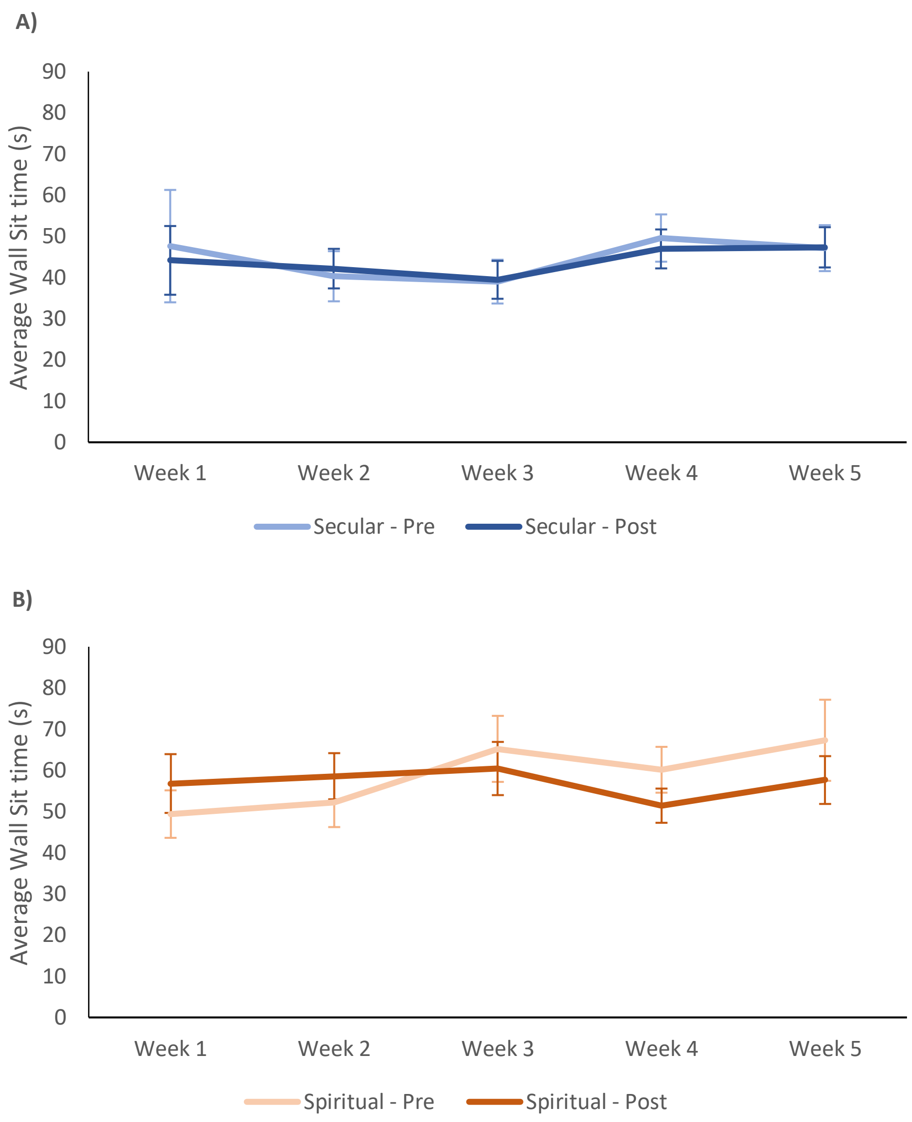


Figure 5.4. The mean pain tolerance duration over time **A)** shows the data for participants in the secular yoga condition, **B)** shows the data for participants in the spiritual (religious) yoga condition. Error bars show ± 1 standard error from the mean.

Table 5.2.

Table showing the mean change in social bonding from before to after the yoga for each week. All values are positive, as all sessions had an increase in the mean level of social bonding from before to after the yoga ritual.

	Week 1	Week 2	Week 3	Week 4	Week 5
Secular Yoga	.849	.335	.254	.395	.377
Religious Yoga	.817	.265	.117	.318	.258
Combined	.833	.300	.186	.356	.317

Table 5.3.

Table with the Fixed-Effects outputs of the three multilevel models predicting social bonding.

Variable	**Model A**			**Model B**			**Model C**		
	Estimate (SE)	**95% CI**	***p***	**Estimate (SE)**	**95% CI**	***p***	**Estimate (SE)**	**95% CI**	***p***
(Constant)	- .86 (.13)	[-.99, -.73]	<.001	- .84 (.12)	[-.96, -.71]	<.001	- .74 (.14)	[-.88, -.60]	<.001
Measurement Occasion	.73 (.08)	[.65, .81]	<.001	.68 (.08)	[.61, .76]	<.001	.68 (.07)	[.62, .75]	<.001
Week 2	.61 (.08)	[.53, .70]	<.001	.66 (.08)	[.58, .74]	<.001	.58 (.07)	[.51, .65]	<.001
Week 3	.87 (.08)	[.78, .95]	<.001	.95 (.08)	[.87, 1.03]	<.001	.86 (.07)	[.79, .93]	<.001
Week 4	.93 (.08)	[.85, 1.02]	<.001	1.01 (.08)	[.93, 1.10]	<.001	0.90 (.07)	[.83, .97]	<.001
Week 5	1.08 (.08)	[1.00, 1.17]	<.001	1.15 (.08)	[1.07, 1.23]	<.001	1.04 (.07)	[.97, 1.12]	<.001
*Measurement Occasion * Week 2*	-.47 (.11)	[-.58, -.35]	<.001	-.47 (.10)	[-.57, -.37]	<.001	-.47 (.09)	[-.56, -.38]	<.001
*Measurement Occasion * Week 3*	-.56 (.12)	[-.67, -.44]	<.001	-.58 (.10)	[-.69, -.48]	<.001	-.59 (.09)	[-.68, -.50]	<.001
*Measurement Occasion * Week 4*	-.44 (.12)	[-.56, -.33]	<.001	-.50 (.10)	[-.60, -.39]	<.001	-.48 (.09)	[-.57, -.38]	<.001
*Measurement Occasion * Week 5*	-.46 (.12)	[-.58, -.34]	<.001	-.49 (.11)	[-.60, -.38]	<.001	-.49 (.09)	[-.58, -.40]	<.001
PANAS+				.22 (.05)	[.17, .27]	<.001	.20 (.04)	[.15, .24]	<.001
PANAS-				-.01 (.04)	[-.05, .03]	.829	-.02 (.03)	[-.04, .01]	.531
Pain Tolerance							.04 (.03)	[.01, .06]	.142
Connection to Something Bigger (C2SB)							.29 (.06)	[.23, .35]	<.001
Yoga Group							-.13 (.16)	[-.29, .03]	.427
Observations (groups)	468 (52)			468(52)			468 (52)		
Marginal/Conditional $R^{2\ddagger}$	0.136 / 0.833			0.178 / 0.881			0.314 / 0.895		
AICc	716.0			670.7			589.4		
log-Likelihood	-345.7			-315.5			-267.1		

Random Effects			
σ^2	0.16	0.12	0.10
τ_{00}	$0.68_{\text{participants}}$	$0.62_{\text{participants}}$	$0.38_{\text{participants}}$
τ_{11}		$0.06_{\text{participants.PANAS+}}$	$0.04_{\text{participants.PANAS+}}$
		$0.04_{\text{participants.PANAS-}}$	$0.01_{\text{participants.PANAS-}}$
			$0.11_{\text{participants.C2SB}}$
ρ_{01}		-0.04	0.24
		-0.55	-0.91
			0.41
ICC	0.81	0.86	0.85

Note. **Model A** shows the model testing hypothesis one, that social bonding would increase from before to after yoga, irrespective of group. **Model B** shows the model testing hypothesis five, that affect would predict social bonding. **Model C** shows the follow-up analysis demonstrating the most parsimonious model with the available variables. Multilevel models were generated using the Luke (2017) method, with the Satterthwaite (1941) correction applied, AICc values are calculated during the Maximum Likelihood method at the model comparison stage, and dAICc is the difference in AICc value from the next most parsimonious model in the comparison process.

‡ Marignal R^2 is the amount of variance explained by the fixed-effects only. Conditional R^2 is the amount of variance explained by the complete model.

5.3.1.2. Hypothesis 3: The difference in connection to something bigger than the self

I then tested whether there was a difference in the feeling of connection to something bigger than oneself between the group conditions (secular vs. religious, see Figure 5.5). I found a significant difference between spiritual and secular yoga on this measure, and that feelings of connection to something bigger increased each week across participants in both groups, see Table 5.4. I also found that the difference between the spiritual and secular yoga conditions on this measure became significantly smaller over time (a significant week*yoga group type interaction).

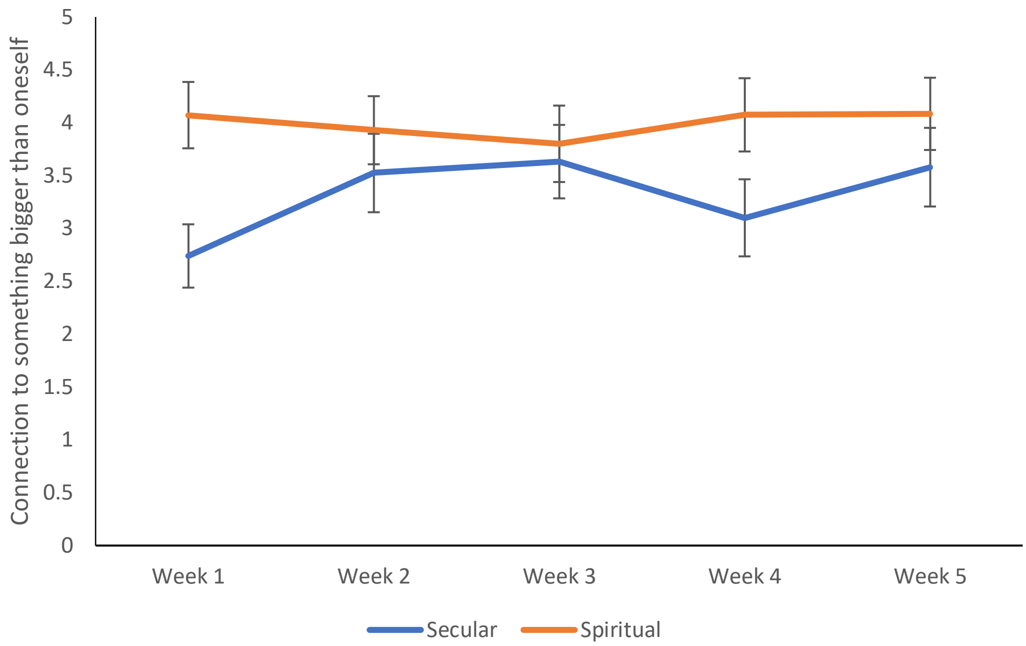


Figure 5.5. Graph showing the self-rated connection to something bigger than oneself (possible range 1-7) in both secular yoga (blue) and spiritual yoga (orange) participants. Error bars show ± 1 standard error from the mean.

5.3.1.3. Hypothesis 4: the role of session type on social bonding

To test the fourth hypothesis, that social bonding will be higher in those taking part in the spiritual yoga than those taking part in the secular yoga, I added the fixed effect of yoga group type (secular v.s. religious) to the model brought forward from hypothesis 1, first looking for a simple fixed effect ($AICc$ = 683.5) and then looking for a possible interaction between yoga group type and week ($AICc$ = 698.1). Including yoga group type in the model in any way resulted in a less parsimonious model than when not included (d$AICc$ = 2.0), suggesting that yoga group type does not provide any significant improvement to the model. To confirm this, the p-values for the fixed effects for the most parsimonious model that still included yoga group type were produced using the Luke (2017) method and showed that yoga group type was not a significant effect (estimate = .06, $t(50.45) = .26$, $p = .79$). This means that, while there was a significant difference between yoga groups in connection to something bigger, this did not lead to differences in social bonding between the yoga groups.

Table 5.4.

Fixed-Effects output for the final model predicting connection to something bigger than oneself.

Variable	**Estimate**	**SE**	**95% CI**	***t***	***Sig. (p)***
(Constant)	- .56	.19	[-.75, -.37]	-2.92	.005
Yoga Group	.78	.26	[.52, 1.04]	3.05	.003
Week 2	.40	.10	[.30, .50]	3.85	<.001
Week 3	.39	.11	[.28, .50]	3.62	<.001
Week 4	.13	.11	[.03, .24]	1.26	.210
Week 5	.36	.11	[.25, .47]	3.35	.001
*Yoga Group * Week 2*	-.47	.14	[-.61, -.33]	-3.42	<.001
Yoga Group Week 3*	-.52	.14	[-.66, -.38]	-3.64	<.001
*Yoga Group * Week 4*	-.10	.14	[-.24, .04]	-0.71	.481
*Yoga Group * Week 5*	-.30	.14	[-.44, -.15]	-2.07	.039

5.3.1.4. Hypothesis 5: the role of pain tolerance on social bonding

To test the fifth hypothesis, that the pain tolerance proxy of μ-opioids would positively predict social bonding, I added the wall-sit measure into the model brought forward from hypothesis 1 in various possible combinations (i.e. to allow for an interaction effect, to allow the wall-sit value to vary by participant, etc.). The most parsimonious model included a single fixed effect of wall-sit (without interactions) and allowed the wall-sit value to vary by participant (d*AICc* = 2.8). While including it in the model did improve model parsimony, the fixed-effect of pain tolerance, measured via the wall-sit, did not significantly predict change in social bonding (estimate = 0.06, $t(20.39) = 1.26$, $p = .222$). Upon looking at a visual representation of the data (see Appendix 23, Figure A23.4.), it is possible that outliers stopped this from being a significant predictor. To explore whether this was the case, outliers (calculated using the Tukey's fences criterion of the relative quartile ± 1.5 IQR) were removed, and the model structure re-analysed. Here it was still found that wall-sit did not significantly predict change in social bonding (estimate = 0.09, $t(418.60) = 1.54$, $p = .124$).

5.3.1.5. *Hypothesis 6: the role of affect on social bonding*

The final hypothesis I had for this study was that positive affect would positively predict social bonding. To test this, I included both PANAS subscales to the model brought forward from hypothesis 1 in various combinations to assess model fit. The most parsimonious model included both PANAS+ and PANAS- as fixed effects and allowed both PANAS+ and PANAS- to vary within participants, but without interacting with one another. As seen in the output of the fixed-effects shown in Table 5.2, Model B, PANAS+ significantly predicted social bonding scores in line with our hypothesis, but PANAS- scores did not.

5.3.2. *Follow-up analyses*

5.3.2.1. *Finding the most parsimonious model, including demographic variables*

As well as main hypotheses, the multi-level model approach allowed us to conduct follow-up analyses based on previous models. To do this, I created a series of possible overall models that incorporated all the variables previously assessed (affect, session type, wall-sit, and time) in various combinations, as well as including demographic variables of age and gender (which were not included in prior models), to predict social bonding. This follow-up analysis was to allow for the inclusion of all the variables that we collected to be accounted for. Due to multiple participants omitting either a pre- or post-experiment rating of religiosity and/or spirituality, these variables could not be included into the model to allow for direct comparisons via AICc. This is because different numbers of participants could be included, meaning the comparison cannot be calculated. For this reason, neither religiosity nor spirituality ratings were included into the final model.

The best fitting model was one that included pain tolerance, PANAS+, PANAS-, connection to something bigger, session type, and an interaction between the time variables as fixed effects, while allowing PANAS+, PANAS- and connection to something bigger to vary within participants (see Table A19.9. in Appendix 19 for full model comparisons). The final output of this model (Table 5.2, Model C) found that positive affect, and connection to something bigger both significantly predicted social bonding, as did all the time variables. No other variables were significant. This shows that, while there was no significant effect of yoga group type on social bonding, a feeling of connection to something bigger than oneself did predict levels of social bonding.

5.3.2.2. Two-one-sided test to detect no difference in session type

Two-one-sided tests (TOST) of equivalence are possible within mixed-effects models (Isager, 2019). Using the method laid out by Isager (2019), using Model C presented in Table 5.3. (the most parsimonious model to include session type as a variable), I was able to assess whether there was significant evidence of there being no difference in effect caused by the religious component of the ritual. In cognitive sciences, the median moderate effect size reported is d = 0.46 (Szucs & Ioannidis, 2017, 2021). It is usually advised that one use moderate effect size estimates as the cut-offs for smallest effect size of interest values when conducting a TOST (as demonstrated in Isager, 2019). Using an upper bound of d = .46 and a lower bound of d = -.46, a mixed-effects two-one-sided test found that the estimate generated by Model C for the type of type of yoga (*religious versus secular*) of -.13 (SE = .16) was significantly lower than the upper bound (t(51.22) = -3.77, p < .001) and was significantly greater than the lower bound (t(51.22) = 2.13, p = .019). This suggests that there is significant evidence that there is no effect of session type (religious *versus* secular) on social bonding.

5.3.2.3. Mediation of positive affect via connection to something bigger

As outlined in the background to this study (section 5.1.), the Broaden and Build theory of positive affect (Fredrickson, 2013) suggests that positive affect may lead to increased feelings of social bonding via increasing feelings of self-transcendence (Van Cappellen et al., 2017; Van Cappellen, Toth-Gauthier, et al., 2016). The question asked in this study about a connection to something bigger than the self meets the definition of self-transcendence given by Thurfjell et al. (2019). Theoretically,

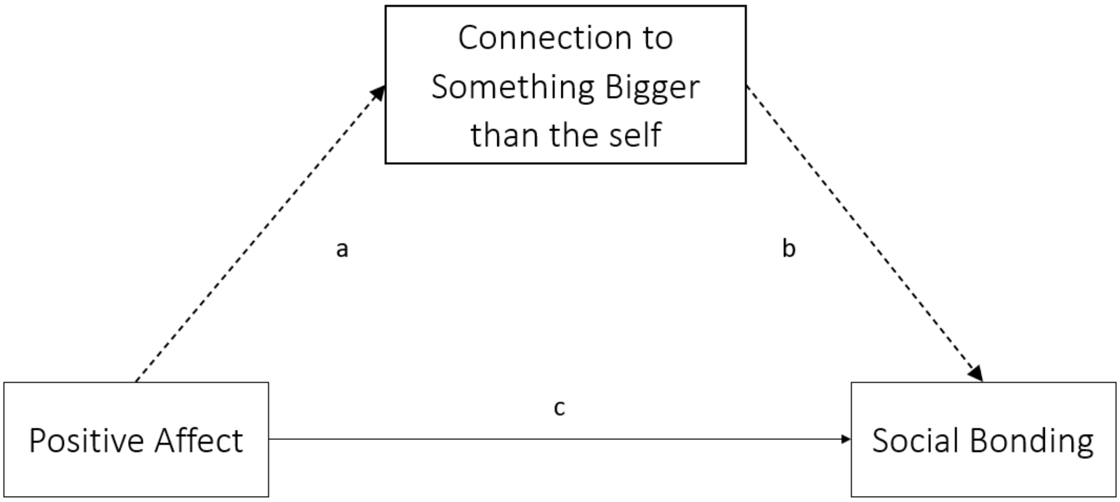


Figure 5.6. The theoretical mediation effect as predicted by the Boraden and Build theory of positive affect, where the direct effect of positive affect on social bonding (effect 'c', solid arrow) would be significantly *positively* mediated by the feeling of connection to something bigger than the self (the combination of effects 'a' and 'b', dashed arrows)

this also suggests that the direction of the mediation would be positive (i.e., it would lead to a 1-sided test, see Figure 5.6.). A multilevel mediation analysis was conducted using the mediation R package (Hicks & Tingley, 2011), which uses the maximum likelihood (ML) model to conduct Monte Carlo simulation analysis. This was done to determine whether the effect of positive affect on social bonding was significantly positively mediated by the feeling of connection to something bigger than the self.

The package uses simulation such that it creates a large number of possible mediation analyses using simulated datasets with the same properties as the original dataset and then provides the average direct effect (effect 'c' from Figure 5.6.) and an average value for the indirect effect (a * b), and provides a two-tailed test of significance by default. It does not provide individual values for effect 'a' or effect 'b'. To turn the indirect effects analysis into a one-tailed test (the Broaden and Build theory suggests an effect with a specific, positive direction), the *p*-value provided by the test can be divided by 2. Because the function uses multiple simulations to conduct the analysis, the values given for the effects of ‘c’ and ‘ab’ slightly deviate from manually calculating the effects using only the single dataset.

To conduct the mediation analysis, further models were constructed to determine the most parsimonious model to predict feelings of connection with something bigger than the self, while ensuring PANAS+ was a predictor (see. The most parsimonious model contained predictors of PANAS+, Session Type, Week and a Session Type*Week interaction, while allowing PANAS+ to vary by participant (AICc = 775.3, dAICc = 16.4; see Table A19.11. in Appendix 19). Using this model as a baseline, I then created the full model to predict social bonding with the same model, but including connection to something bigger than the self as a predictor. The model converged and showed that both the direct effect of positive affect on social bonding (.221, $p < .001$), and the indirect effect via connection to something bigger than the self (.048, $p = .025$) significantly predict level of social bonding.

The average direct effect (effect ‘c’ from Figure 5.7.) from the simulated multilevel mediation analysis after 1,000 simulations was .221 (which deviates only slightly from the direct ML estimate using the actual data, of .227). The average causal mediated effect (effect ‘a’ multiplied by effect ‘b’, Figure 5.7.) after 1,000 simulations was .048. Effects ‘a’ and ‘b’ are not estimated using this method,

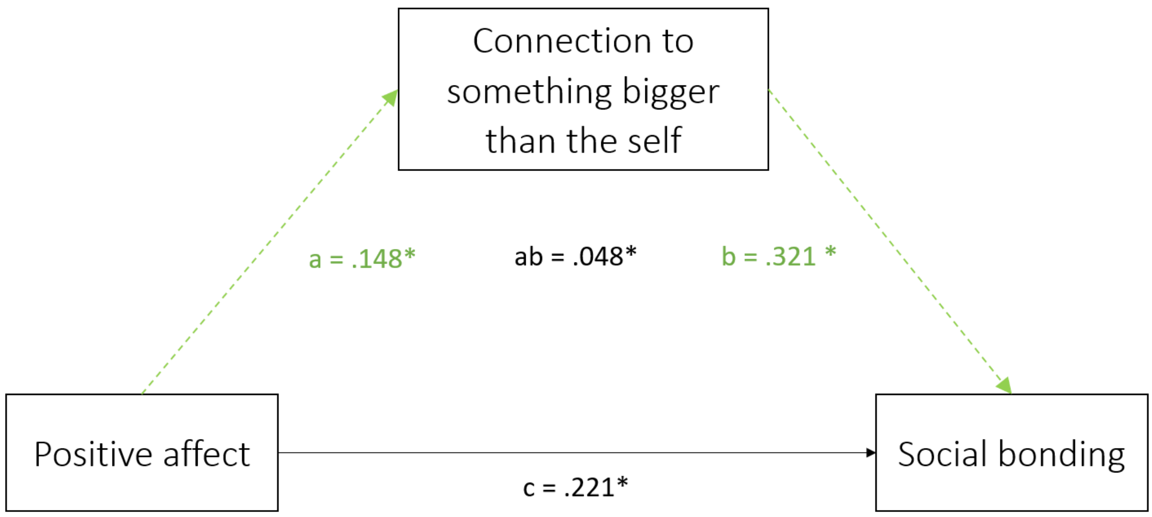


Figure 5.7. The actual mediation effect, where the direct effect of positive affect on social bonding (effect ‘c’, solid black arrow) was significantly mediated by the feeling of connection to something bigger than the self (the combination of effects ‘a’ and ‘b’, dashed green arrows). Values of effects ‘ab’ and ‘c’ were calculated via 1,000 simulations using the mediate function in the mediation package. Values of ‘a’ and ‘b’ (in green) are estimates from a single model.

however estimates from the specific models created (MedModel_model2g for effect 'a', and MedModel_full for effect 'b', see Appendix 19, S12) can be provided. I have shown these in green in Figure 5.7. Manually calculating ab using these estimates also gives an 'ab' effect of .048, suggesting the estimates from the single models are fairly accurate compared to the simulations. In total, the indirect effect ('ab') significantly accounts for 18% (p = .025) of the relationship between positive affect and social bonding.

5.4. Study 3 Discussion

Religious rituals are a human universal (Brown, 2000), thought to be so widespread because of their ability to create the social bonds that enable human societies to thrive (Alcorta & Sosis, 2005; Dunbar, 2013). Although study 1 provided some evidence supporting the idea that religious ritual does play a role in human social bonding, it did not provide a secular comparison to test this effect. Study 2 provided the first evidence from work in naturalistic settings that assessed the role of the religious component of a ritual on social bonding, and found significant evidence of no effect of the religious component of ritual. However, this suffered from possible issues, such as the potential for extraneous variables to change results, or the difference in the length of time that congregants had been attending that ritual.

There have been, to the best of my knowledge, no studies in controlled conditions assessing the role of the religious component of a ritual on the social bonding that takes place during ritual. Here I presented the first study that sought to compare a religious ritual (a yoga ritual conducted directly referencing the super-empirical) and a behaviourally identical secular ritual (yoga not conducted in relation to the super-empirical) in controlled conditions in relation to social bonding. I found that, while there was a difference in level of connection to something bigger than oneself between the religious and secular yoga conditions, there was no difference in levels of social bonding change between the spiritual and secular conditions. In fact, evidence from a two-one-sided test (TOST) suggests that there is significant evidence of no difference between the two types of ritual.

I also examined two main mechanisms thought to underlie social bonding in rituals: μ-opioid release, and positive affect. This study is the first to assess both mechanisms in controlled conditions, using a longitudinal design. My colleagues and I found that, when accounting for other possible variables (Model C), increases in positive affect significantly predicted increases in levels of social bonding with others, whereas I found no such effect for the proxy measure of μ-opioids. This provides support for the Broaden and Build theory, which suggests that positive affect encourages broadening of behaviours and cognition that allows for social bonding to occur (Fredrickson, 2001, 2002, 2013).

Proponents of the Broaden and Build hypothesis have suggested positive affect shifts the focus outside of the self and towards feelings of self-transcendence (Van Cappellen & Rimé, 2013; Van Cappellen, Way, et al., 2016), and that this is what allows for social bonding to occur. In the previous two studies, I found that a feeling of connection to something bigger than the self also predicted feelings of social bonding. This measure (with its focus on feelings of awe and wonder) conforms to definitions of self-transcendence provided in the literature (see Thurfjell et al., 2019). Connection to something bigger than oneself during the yoga also significantly predicted level of social bonding, and follow-up mediation analysis found that a significant proportion of the direct effect of positive affect on social bonding was explained by the indirect effect via a connection to something bigger than the self (see Figure 5.7.). This provides further support for the mechanistic pathway by which positive affect may lead to increased feelings of social bonding.

These findings are also in line with the findings from studies 1 and 2, which showed associations between social bonding and a connection to something bigger than oneself (study 2), or a connection to a religious entity (study 1; see also Pirutinsky et al., 2019). This suggests that, while a ritual being secular or spiritual in nature does not itself lead to greater levels of social bonding, rituals that are promote a greater sense of awe, wonder or connection to something bigger than oneself (be they religious or secular) are those more likely to be related to an increase in the feeling of social bonding. In naturalistic settings, religious rituals are more likely than secular rituals to explicitly focus on the connection to something bigger than oneself (Van Cappellen, 2017). In the study presented in this chapter, it was also found that connection to something bigger than the self was significantly greater in the religious yoga than in the secular yoga condition. Therefore, religious ritual’s ubiquity might be explained by a greater ability to foster feelings of connection to something bigger than the self, which is what later causes feelings of social bonding.

The finding that the feeling of connection to something bigger than oneself lead to an increased sense of social bonding could also be due to the two measures having a similar underlying cause or construct. For example, it could be that both variables are different expressions of the same feeling of 'connection to something outside of oneself', be it another person (i.e., social bonding) or something bigger (e.g. a deity, or the universe). Future work could study whether there is a distinction between social bonding and connection to something bigger than oneself or if they are, instead, the same effect manifested in a different way.

Moreover, secular group gatherings that are able to create a sense of connection to something bigger than oneself – such as sporting events that can allow one to feel connected to a team spirit (Halldorsson, 2020; Sullivan, 2018), or a music concert/festival that allows one to feel a connection to something sacred (Messick, 2019) – may be able to create social bonds in ways similar to religious rituals. As such, I believe that there is scope for future research to be conducted in these settings and to compare them to ritual in order to better understand ritual social bonding. Additionally, a further avenue for future research would be to look explicitly at the role of positive affect, μ-opioids, and social bonding on health and wellbeing outcomes in those that take part in rituals. This is to help further explore the mechanistic pathway proposed by the Broaden and Build hypothesis between positive affect and improve wellbeing, as well as further the understanding of the connection between religion and health (VanderWeele, 2017a).

In terms of the other major mechanism that was studied, contrary to our hypothesis (and contrary to what was found in study 1, as well as previous work (Dunbar et al., 2012; Pearce et al., 2017)), I did not find a significant relationship between the pain tolerance proxy for μ-opioids and social bonding. One reason for not having found this effect could be that the role of μ-opioids on social bonding is not linear. Pellissier and colleagues (2018) have suggested there may be an inverted-U function for the role of opioids on social bonding, where there is an optimal level of opioids to encourage bonding. Thus, using a proxy measure such as pain tolerance in a linear mixed-effects model would not be able to find this relationship.

Another possible reason that I did not find an effect where others have (and one that I think is more likely) is that I used pain tolerance, not pain threshold, as the proxy measure for μ-opioid release. Although some work that has provided evidence of a link between pain and social bonding have used pain tolerance (Johnson & Dunbar, 2016), the majority of this research has used pain threshold as a proxy measure for μ-opioids (e.g. Cohen et al., 2010; Dunbar et al., 2016; Tarr et al., 2015; Weinstein et al., 2016). While pain tolerance and threshold are correlated with one another (Bhalang et al., 2005), pain tolerance and threshold have been shown to be distinct sub-domains of pain perception (Gelfand, 1964; Lacourt et al., 2012; Vaegter et al., 2017).

When planning this study, the use of the wall-sit, pain tolerance measure was adopted for three major reasons: (1) this would conform to past literature that has assessed the difference between religious and secular ritual for therapeutic outcome variables (Wachholtz et al., 2017; Wachholtz & Pargament, 2005, 2008), (2) The wall-sit measure does not have an upper-bound, which is a limitation that the pain threshold (cuff) measure did have in study 1. Using a measure without an upper bound would mean participants would not be excluded on this basis. (3) One of the academic supervisors of this PhD thesis (and a co-investigator on this study) suggested that this would be a better measure to use. In fact, said supervisor suggested using the wall-sit pain tolerance proxy in earlier studies, too. My main rationale (up to this point) for not using the wall-sit measure in earlier work in this thesis was simply that time and space constraints would make using it untenable, as different ritual spaces might have different accommodation capabilities.

However, looking back, and based on learning a lot more about the different ways in which opioids might effect pain perception, I am close to certain that pain tolerance should *never* be used as a μ-opioid proxy. This is because, upon conducting further reading of the academic literature (e.g., Fillingim et al., 2005; Hagelberg et al., 2012; Huang et al., 2008; Kialka et al., 2016) it is now clear that, while there is a link between central μ-opioid receptor activation and pain threshold, no such link between μ-opioid receptor activation and pain tolerance exists. So, future research that does conduct research using a pain proxy for μ-opioid activation should use pain threshold and not pain tolerance. In addition, past research that has used pain *tolerance* as a proxy (e.g., Johnson & Dunbar, 2016) might have a similar issue as studies underlying the Oxytocin Paradox: false positive results. As such, these studies may need to have their findings replicated using pain threshold as an appropriate proxy.

A finding from the church participants in study 2 was that the longer someone had been attending the church, the greater the increase in social bonding from before to after the ritual. Moreover, in the article where Hobson et al. (2018) provide their definition of ritual, they state that the mental processes that allows people to perceive something as a ritual “will vary as a person becomes more familiar with the actions through repeated exposure/practice” (p. 275). In this study, there was a significant interaction between measurement occasion (pre vs. post) and week of ritual. However, it was in the opposite direction than one might expect: where each week after the first week had a significantly lower change in social bonding compared to the first week. Given the results from study 2 and the Hobson et al. (2018) idea of things becoming *more* ritualised over time, this is surprising. Importantly, though, as seen in Figure 5.2. (and Table 5.2.) the difference in social bonding from before to after the sessions decreased from week 1 to week 2, and week 2 to week 3, but after week 3, in both the secular and religious yoga, the change in social bonding increased.

One possible explanation for the lower magnitude of change from before to after the rituals after the first session could be that before the initial ritual, measures of social bonding are far below where they would otherwise be, as all people are considered strangers (and Figure 5.2. does suggest this). An increase from a base level of being low feelings of social bonding up to moderate feelings is a large increase. Then, in each of weeks 2, 4, and 5, the average change was the same as that seen in study 1. Week 3 having a particularly low change in social bonding is more difficult to explain. I think it could be possible that early increases in social bonding are no longer seen after the initial week or two, and then only from the 4th ritual and beyond are the more ‘normal’ effects on social bonding observed. This would conform to Hobson et al.’s (2018) characterisation of ritual, in that it may require repeated exposure to the ritual to have an effect. Interestingly, the level of social bonding (both before and after the ritual) in both types of ritual increased each week, but the absolute value reported by both sets of participants was still only around 4. Compared to the levels reported in study 1 and 2 (around 5), this suggests that there is still scope for overall increases in feelings of social bonding such that, in a 6th week of yoga, we might still expect an increase of about 0.3 points on the scale, but with a higher overall pre- and post-ritual level of social bonding.

5.4.1. Limitations

One limitation to this study is that the analysis used (multi-level modelling) was not the same as the method of analysis I had planned to use in the pre-registration of this study (Appendix 24). This is because the pre-registration for the study did not have a suitable type of analysis for the data that I collected. Another limitation with this study is that, while I used a previously-existing, realistic ritual that has both a secular and religious form (i.e. yoga), it is possible that one of the reasons I did not find an effect of ritual type is that participants who took part in the religious form of yoga may not have felt that the religious yoga reflected their own beliefs (i.e., it is possible that participants were not *actually* performing the ritual with the belief in the super-empirical), unlike naturalistic religious rituals would do. Though, the fact that the results from the study presented in this chapter conform to the results from study 2 (including the TOST results) may mean that this was not an issue.

Another issue with the study is that the theoretical underpinnings for assessing peripheral levels of μ-opioids sits on shaky ground. Part of the work in this thesis was funded by an external funder. This funder wanted to incorporate biomarker analysis into this study as a condition of funding. As such, I openly acknowledge that there was some motivated reasoning for trying to find a rationale for including analysis of peripheral levels of β-endorphin. This motivated reasoning caused me to propose a loose, potential long-term link between peripheral levels and central levels of β-endorphin. In truth, I am somewhat glad that the technical issues surrounding the blood occurred, as it meant that this variable that likely should not have been included could be removed without muddying the analyses and their interpretation.

In addition to the limitation with using pain tolerance as the μ-opioid proxy, highlighted above, there are other issues with using pain as a μ-opioid proxy in any activity that involves exercise. The fact that past studies have found that high intensity (but not moderate intensity), aerobic exercise increases pain tolerance (Jones et al., 2014; O'leary et al., 2017; Vaegter et al., 2017) means that rituals that involve high-intensity exercise (e.g., vigorous dance acts seen in some imagistic modes of religious expression) may not be appropriately measured via pain. Similarly, exercise of moderate intensity may change pain threshold in healthy participants (Pacheco-Barrios et al., 2020). As yoga includes moderate-to-low intensity exercise, attempting to use any kind of pain proxy to assess the effects of *ritual* (as opposed to exercise) may not be appropriate. Future research might be improved if using pharmacological methods to manipulate neurotransmitter receptor binding (e.g. Inagaki et al., 2019a, 2019b; Tarr et al., 2017) or they might need to directly monitor release via neuroimaging-tracer methods (e.g. Ashok et al., 2019; Karjalainen et al., 2019; Nummenmaa et al., 2020).

5.4.2. Study 3 conclusion

In summary, here I have presented the first study to assess differences in social bonding between religious and secular ritual in controlled conditions, using a longitudinal design. I found that positive affect plays a significant role in social bonding, as does the feeling of connection to something bigger than oneself during the ritual. I also found that the feeling of connection to something bigger than the self mediates some of the relationship between positive affect and social bonding. This supports the Broaden and Build hypothesis (Fredrickson, 2013). However, I did not find support for the μ-opioid theory of social bonding (Machin & Dunbar, 2011), and I also found significant evidence of there being no difference in social bonding between religious and secular ritual.

One of the most likely reasons that I found no evidence for the μ-opioid theory of social bonding (Machin & Dunbar, 2011) is because of using a poor, indirect proxy measure of pain threshold. Because of this, I plan to use more direct methods to assess the role of μ-opioid receptor activation on ritual social bonding in future studies. Moreover, given the results from both study 2 *and* the study presented in this chapter, one of the primary aims of the thesis – to assess the importance of the religious component in ritual social bonding – has been addressed. The two studies found significant evidence for there being no difference between religious and secular ritual on social bonding. Moreover, evidence from study 1, study 2 and the study presented in this chapter have all demonstrated that ritual (be it religious or not) is reliably related to increases in social bonding, thus addressing another primary aim of the thesis. However, because of inconsistent results in the assessment of the role of μ-opioid, the studies presented in the next chapter of this thesis will focus purely on the role of μ-opioids of ritual social bonding, to address the final primary aim of the thesis.

6. Chapter 6. Mu-Opioid Antagonism During Ritual

So far in this thesis, I have shown that increases in social bonding is reliably related to participation in rituals (be they religious or secular). In study 1, I found that the increase in social bonding was related to an increase in pain threshold. However, in study 3, I did not find a relationship between pain tolerance and the change in social bonding that took place during the rituals. From this, there are two major interpretations that I have: 1) ritual reliably leads to an increase in the feeling of social bonding with others in the group, and 2) there is inconclusive evidence for the role of μ-opioids in this process, with study 1 suggesting there is an association between μ-opioid activation and social bonding, while study 3 (albeit using a poor proxy) suggested μ-opioid activation did not play a role. One issue with these studies is that they did not directly measure μ-opioid receptor activation, but instead used pain as a proxy.

In the discussion of study 3, I suggested that a way to better illuminate the role of μ-opioids on ritual social bonding would be to find a way to directly measure or manipulate μ-opioid activation, such as with neuroimaging and tracer studies (e.g. Ashok et al., 2019; Karjalainen et al., 2019; Nummenmaa et al., 2020) or with the use of exogenous agonists/antagonists (e.g. Inagaki et al., 2019a, 2019b; Tarr et al., 2017). As group rituals seldom take place in contexts where neuroimaging and tracing can be conducted, the use of agonists/antagonists is a far more appropriate method to use. This chapter covers two smaller-scale studies that I conducted, with the help of some colleagues, which used the μ-opioid-preferred receptor antagonist Naltrexone as a method of blocking μ-opioid activation to examine whether this plays a direct role in group social bonding outcomes.

The contents of this chapter is adapted from the published article “Blocking mu-opioid receptors inhibits social bonding in rituals”. The other co-authors were Dr Miguel Farias, Dr Valerie van Mulukom, Ambikananda Sawaswati, Dr Simon Dein, Dr Fraser Watts, and Dr Robin I. M. Dunbar. The contribution of each co-author is listed in Table 6.1.

Table 6.1.

Table showing the CRediT allocation for Study 3. Initials are provided for each author for each role they contributed towards. The order of the initials for each role denotes the level of contribution (i.e., appearing first on a contributor role means this co-author contributed most for this role unless otherwise specific)

Role	Author(s)	Role	Author(s)
Conceptualisation	SC*, MF*, VvM*, AS, SD, FW†, RIMD†	Resources	SD, FW, AS
Data Curation	SC	Software	
Formal Analysis	SC	Supervision	MF, VvM, RIMD,
Funding Acquisition	RIMD, FW, MF, AS	Validation	VvM
Investigation	SC, AS	Visualisation	SC
Methodology	SC, AS, MF, VvM, SD, RIMD†, FW†,	Writing – Original Draft	SC
Project Administration	SC, MF, VvM, RIMD	Writing – Review and Editing	SC, VvM, MF, RIMD, FW, SD, AS

* Equal primary contribution

† Equal supporting contribution

6.1. Background to Studies 4 and 5

As outlined throughout the thesis, there is growing behavioural, physiological and genetic evidence that social bonding, in primates and humans, is underpinned by the μ-opioid receptor system (Loseth et al., 2014; Machin & Dunbar, 2011; Pearce et al., 2017; Pearce et al., 2018). In humans, the same mechanism seems to underpin both dyadic bonding and group bonding. Religious rituals have long been suggested to play a significant role in community bonding (Durkheim, 1912), and a number of studies indicate that ritual participants often feel a strong connection with others (Fischer & Xygalatas, 2014; Fischer et al., 2014; Power, 2018). However, so far, no studies have investigated the pharmacological mechanisms involved.

Rituals often contain many components which are known to release μ-opioids, such as synchronized movement (Launay et al., 2016), music making (Tarr et al., 2014; Weinstein et al., 2016), and, in more imagistic expressions of religious ritual, pain (Fischer & Xygalatas, 2014; Xygalatas et al., 2011; Xygalatas et al., 2013). These components are also known to independently foster feelings of social bonding (Cohen et al., 2010; Lewis & Sullivan, 2018; Nummenmaa et al., 2016; Tarr et al., 2015). Throughout this thesis, I have shown in studies 1, 2, and 3 that participation in rituals (be they religious or secular) is significantly related to increases in feelings of social bonding. While study one provided prima facie evidence of a role for μ-opioids, study three did not support the role of μ-opioids. In both cases, pain was used as a proxy measure, so the hypothesis that these effects explicitly involve μ-opioids has yet to be tested directly.

Since μ-opioids don't pass the blood-brain barrier (Witt & Davis, 2006), I use the opioid antagonist Naltrexone[15], which has a preferential binding for μ-receptors (Codd et al., 1995; Raynor et al., 1994), in a reverse-cause design. Although other studies have used Naltrexone in such a design before (Inagaki et al., 2019a; Inagaki et al., 2016; Tarr et al., 2017; Tchalova & MacDonald, 2020), none have investigated the specific context of religious ritual. Indeed, Inagaki (2018) has emphasized that more research is needed to study the direct role of opioids in social bonding *during interaction* with others. Moreover, except for one study that used groups of three or four (Tarr et al., 2017), all prior work that has used Naltrexone to assess social bonding has been conducted on dyads (Tchalova & MacDonald, 2020), on single individuals during a neuroimaging task (Inagaki et al., 2019a; Ross et al., 2021), on individuals who were alone when reading pleasant sentences provided by close others (Inagaki et al., 2016), or on individuals alone holding onto warm, cold, or room temperature packs (Inagaki et al., 2015). Moreover, Most of the studies did not measure *change* in social bonding, but instead only social bonding after the experimental procedure (Inagaki et al., 2019a; Inagaki et al., 2015; Inagaki et al., 2016; Tarr et al., 2017).

[15] For a full rationale of why Naltrexone was used as the μ-opioid antagonist see section 6.2.2.3. For information on why non-opioid neurotransmitter antagonists were not also used given the opportunity, please see Appendix 30

Tarr et al. (2017) provide the only study that, to my knowledge, assessed feelings of social bonding after participation in group activity. In their study, they had participants (who were strangers to one another) take one of (a) no pill, (b) placebo, (c) 50mg of Naltrexone, or (d) 100mg of Naltrexone before participation in a synchronised dancing activity. They found that only 100mg of Naltrexone significantly affected pain threshold (their method to assess if the drug had taken effect). While they did not find a significant effect of Naltrexone on their measure of social bonding (which included four of the six questions included in my measure of social bonding: the IOS (Aron et al., 1992), connectedness (Wiltermuth & Heath, 2009), likability (Hove & Risen, 2009), and similarity (Valdesolo & DeSteno, 2011)), Tarr et al. (2017) did not measure feelings of social bonding *before* the dancing – only after. This suggests that they did not actually measure the effect of Naltrexone on *changes* in social bonding, simply absolute levels after a behaviour.

Tchalova and MacDonald (2020) did measure feelings of social bonding (using the average score of six items: the IOS, connectedness, liking, closeness, partner responsiveness, and social reward experience) both before and after dyad interaction. However, in their mixed-effects analysis, they only use the post-interaction feelings of social bonding (which they call social reward expectation). They do not assess a time-condition interaction with regard to social bonding. So, to date, there have been no studies using a μ-opioid antagonist to assess *change* in social bonding during *group* activity. In Chapter 2, I provided the theoretical model the role of μ-opioids, in that they cause an increase in social bonding (i.e., a change). This is further highlighted in Chapter 3 (Figure 3.1. section 3.1.4.), I highlighted that it the mechanism by which μ-opioids lead to bonding is by *changing* feelings of social bonding. As such, analysing differences in feelings of social bonding only at a single timepoint (i.e., only after the behaviour of interest) is not necessarily informative. It is for this reason that conducting studies using an antagonist must assess social bonding both before and after the activity, and measure the change (i.e., the time-condition interaction is what is of interest, not a main effect of pill type, nor a main effect of time).

While it is entirely possible that the non-significant effect of Naltrexone on social bonding in the two studies that actually involve some kind of person-to-person interaction (Tarr et al., 2017; Tchalova & MacDonald, 2020) suggests that μ-opioids are not necessary for human social bonding, I believe that further research is warranted. This is because both of these studies suffer with the major issue of not measuring a change in social bonding. Moreover, it is possible that these two failed to find an effect of pill type on social bonding simply because the behaviours they were measuring were not ritual behaviours: i.e., there could be something special about the combination of behaviours that are included in ritual, as has been asserted throughout this thesis.

In this chapter, I wanted to test whether the opioid system is necessary for the feelings of social bonding that have been reliably shown to increase after participation in rituals. To do this, I conducted two double-blind studies. To ensure that the results were not specific to a particular religious context, nor a specific population study four used a small-scale lab-study of yoga classes in the United Kingdom, while study five used a larger field study of an Afro-Brazilian Umbanda ritual. While the aim was to ensure diversity in the populations studied, the specific use of a yoga in the UK, and Umbanda in Brazil was influenced by availability bias. Because of the work conducted in study 1, presented in Chapter 3, I had access to a Brazilian Umbanda ritual (one of the ritual sites in Brazil from study 1 consented to have us return using Naltrexone, approximately 15 months after study 1). And, because of the work conducted in study 3 presented in Chapter 5, I already had a yoga ritual that people were attending on a weekly basis. It is for this reason that the two, distinct populations that were chosen were from Brazil and the UK.

From this, my theoretically driven hypothesis across the two studies was: if μ-opioids play a significant role in social bonding during rituals, participants taking a μ-opioid blocker will, compared to those taking a placebo, experience a reduced sense of bonding. Phrased more formally, I hypothesised that there would be a time-condition interaction, where participants who took Naltrexone would have a lower level of social bonding after the ritual than before the ritual when compared to those who took placebo.

6.2. Study 4: Naltrexone during yoga in controlled conditions

As outlined in study 3, yoga is a form of structured exercises with religious overtones that conforms to the definition of religious ritual given in Chapter 2. There is also some research linking yoga with the release of β-endorphin (Suri et al., 2017; Yadav et al., 2012). As such, I recruited a subset of participants from those who took part in study 3 (the five-week, lab-based study of yoga), who agreed to take part in an additional, 6th, session involving the administration of Naltrexone. The participants were all recruited from the religious condition of yoga, and the 6th week of yoga conformed to the religious yoga that they were taking part in for the 5 prior weeks.

The pre-registration for this study (see Appendix 25), was written before study 3 had finished data collection, due to the proximity in time between the end of study 3 and this study (a one week gap between the end of study 3 and data collection for this study taking place). As such, some of the hypotheses in the pre-registration, were influenced by the pre-registration of study 3. Specifically, there were three hypotheses:

1. That taking part in the yoga ritual would lead to an increase in feelings of social bonding
2. Participants that took Naltrexone would have significantly smaller change in feelings of social bonding than those who took placebo, and
3. That the wall-sit, pain tolerance measure would predict change in social bonding.

The third of these hypotheses was registered before I understood that pain tolerance was not an appropriate proxy measure for μ-opioid receptor activation (see the discussion of study 3, section 5.4.). Because pain tolerance is not linked to μ-opioid activation (see Fillingim et al., 2005; Hagelberg et al., 2012; Huang et al., 2008; Kialka et al., 2016), analyses that would involve the wall-sit pain tolerance measure were not conducted. In addition to this, as outlined in section 6.1., the effect of interest for this study was the time-condition interaction effect of pill type on feelings of social bonding. This was hypothesis 2 in the pre-registration. Hypothesis 1 would be measured by a main effect of time, whereas hypothesis 2 is measured via the interaction.

6.2.1. Study 4 Participants

In the pre-registration, an *a priori* power analysis was conducted in order to assess how many participants might be necessary to detect the desired effect. In this, using the more conservative effect size (d = .59) based on a pain tolerance study (Dunbar et al., 2016), 37 participants in each group was desired. For the larger potential effect size (d = .90), based on a Naltrexone study conducted on lone behaviour (Inagaki et al., 2016), 17 participants would be needed in each group. Unfortunately, only data for 9 participants was successfully collected.

After advice from peer-reviewers, the planned analysis (a between-samples comparison of change of social bonding) was deemed not to be appropriate for the study design (as it would not account for the repeated measures). As such a sensitivity power analysis was conducted after data collection was completed to assess the effect size that would be detectable with at least 80% power, given the new analysis type and the known number of participants. Using G*Power, a sensitivity power analysis was conducted using the F test family, using a repeated-measures ANOVA within-between interaction test, with nine participants, and an alpha value of .05 and power of 80%. The correlation among repeated measures was calculated using the data collected within this study, and was calculated to be 0.683. The interaction effect size that the test would be able to reliably detect is f = 0.43 (d = .86). This means that for effects smaller than d = .86, there is a greater chance for a Type II error to occur. This effect size (d = .86) is in line with the less conservative effect size (d = .90) provided by a previous Naltrexone study (Inagaki et al., 2016), and so data was still analysed

Another sensitivity power analysis was conducted to see what the smallest effect size that is reliably detectable for within group tests (i.e., post-hoc tests, or for tests of a main effect of time). Again, it was found that the smallest effect size that can be reliably detected at 80% power is f = 0.43 (d = .86). For any analyses looking at a main effect of time, effect sizes smaller than d = .86 may not be reliably detected, i.e., Type II errors are more likely. Results will be interpreted with this in mind.

Ten participants (nine female) agreed to take part in this study. One participant (male) had an adverse reaction to Naltrexone (this participant felt nauseous and some stomach pain). This participant withdrew from the study before the yoga session because of the adverse reaction. In total, nine participants were included (M_{age} = 25.8, SD_{age} = 11.7, all female). Five participants (M_{age} = 28.0, SD_{age} = 15.9) were randomly allocated to the placebo group and four (M_{age} = 23.0, SD_{age} = 2.9) to the Naltrexone group. The pill allocation was conducted in a double-blind manner, where I (as the researcher present on the day) was unaware of which bottles contained which pills, as were the participants. Due to logistics issues, the co-investigator Dr Robin Dunbar who was supposed to be allocating the pills to bottles was unable to do so. Instead, Alison Keenan (who was working at the Centre for Trust, Peace and Social Relations at Coventry University) followed the protocol that was outlined in the ethics application. The information of which pills were associated with which bottles was stored securely on an encrypted external drive that was securely locked in a cabinet only accessible to Alison Keenan. The unblinding only occurred for the data analysis stage, approximately 2 months after all data had been collected.

Participants were screened (and potentially excluded ahead of time) based on a medical questionnaire created with the aid of medical consultant Dr Simon Dein. For the full recruitment and screening procedure, see the pre-registration (Appendix 25; also available online: https://osf.io/7gn3j/). Exclusion criteria applied in selecting participants are listed in Appendix 26 (and online: https://osf.io/y4gw7/). All participants in this study were of European background/ethnicity.

6.2.2. Study 4 Materials

6.2.2.1. Social Bonding

As with all previous studies in this thesis, the measure of social bonding consisted of the six-item scale described in chapter two. A reliability analysis was completed and is presented in the results subsection.

6.2.2.2. Yoga

As with study 3, a religious form of hatha yoga was used. The yoga session was designed by the same professional instructor who designed study 3. The yoga session for this study was the 6th consecutive week of yoga that these participants took part in.

6.2.2.3. Naltrexone

There are two major μ-opioid antagonists that are widely available and have been used in psychology studies, i.e., outside of medical contexts: Naloxone and Naltrexone.

Naltrexone an opioid antagonist with a stronger μ-opioid affinity than Naloxone (Codd et al., 1995; Raynor et al., 1994). The ratio at which Naloxone binds to mu- receptors compared to delta- and kappa-opioid receptors is between 1:18:2 and 1:65:9 (Codd et al., 1995; Raynor et al., 1994) However, Naltrexone has a stronger preferential binding for the μ-opioid receptors, with affinity ratios of (μ-, δ- and κ-receptors) somewhere between 1:149:4 (Raynor et al., 1994) and 1:97:6 (Codd et al., 1995). This would make Naltrexone a better choice, as it can be better considered a μ-opioid antagonist, instead of a more general opioid antagonist.

Moreover, Naloxone has a half-life of between 30 and 60 minutes, whereas Naltrexone has a half-life of four hours. This means that if an experiment lasts longer than 30 minutes, the effects of Naloxone may start to wear off, whereas Naltrexone would only wear off after four hours. Consequently, for rituals which may last between 60 and 90 minutes (as is the case in this thesis), Naltrexone's longer half-life makes it the more appropriate choice.

As a fast, short-term effect was required (Schmitz et al., 2009), and based on recommendations from two of the co-investigators (supervisor Robin Dunbar, and medical consultant Dr Simon Dein), I used an oral administration of 100mg of Naltrexone. This was also in line with research that showed a significant effect on a pain threshold proxy of μ-opioid blockade at 100mg, but not at a lower dose of 50mg (Tarr et al., 2017). This dose produces few if any side effects in healthy volunteers (Gonzalez & Brogden, 1988; Schmitz et al., 2009). Participants were made aware ahead of time of the drug that they could be given, and a procedure was in place in the event of adverse effects (see 6.2.4.).

6.2.2.4. Change in perception

A question was asked of participants to see if they felt that this week's yoga felt different than normal. One participant who took Naltrexone reported feeling lower levels of focus than usual, said that this did not affect how she felt about the yoga.

6.2.3. Procedure

The majority of the procedure was identical to study 3, in that participants arrived for yoga, got changed, and did the yoga practice. However, there were some key differences. For this study, participants arrived at the lab one hour prior to the yoga session, instead of 30 minutes prior. Upon arrival, each participant was given a pill bottle that contained two pills of either 2x50mg pills of Naltrexone or 2x pills of placebo. Each bottle had a three-character alpha-numeric code assigned to it (e.g., Q6W, KRT). After taking the pills, participants answered a short questionnaire, which included the social bonding scale. They were then given distraction reading material for a 60-minute waiting time to allow the Naltrexone to become active (the same waiting time as in Tarr et al., 2017), after which the yoga session commenced. After a one-hour yoga class, participants completed the post-session questionnaires and were debriefed.

Approximately 15 minutes into the 60-minute waiting time, one of the participants (of the initial 10) had a negative reaction to the pills, where they started to feel nauseous and had a stomach ache. They were taken into a room next door, provided water and monitored for the next 30 minutes. They started to feel better, but wished to withdraw from the study.

6.2.4. Study 4 Ethical considerations

Prior to taking part in the study, participants were screened via an online questionnaire for the exclusion criteria, which were devised by the medical consultant Dr Simon Dein. Once eligibility had been confirmed, responses to the medical exclusion checklist were deleted, such that no medical information about participants was retained for data protection purposes. Beyond medical exclusion I received first aid training for the purpose of running this experiment. The university department's other first aiders were also informed ahead of the study about dates and times of experimental sessions in case of emergencies, and so that procedures were in place in the event of any serious adverse events (SAEs). In preparation for the possibility of an SAE, the university medical team had been made aware of the clinical trial being conducted. Had an SAE occurred, I would have reported it to the UK Medicines and Healthcare products Regulatory Agency (MHRA) using the electronic 'Yellow Card' System. The severity of any non-serious adverse events (AEs) were assessed on the following scale: 1 = mild, 2 = moderate, 3 = severe. Only 1 AE occurred, with the participant who withdrew from the study. The slight nausea and stomach ache were only considered a mild (level 1) AE. Participants were visually monitored every 10 minutes during the yoga ritual to ensure that no other AEs occurred.

This study followed all ethical guidelines as set out by the Declaration of Helsinki, as well as the ICH Good Clinical Practice (GCP) guidelines. These guidelines are the unified standardised guidelines for safe, and high quality clinical research practice for the EU (The UK was within the EU at the time of this study), Japan and the United States. The GCP guideline was developed with consideration of the current good clinical practices of the European Union, Japan, and the United States, as well as those of Australia, Canada, the Nordic countries and the World Health Organization (WHO).

Ethical approval for the study was given by the Coventry University Ethics Approval Team (reference: P89708; see Appendix 34)

6.2.5. Study 4 Results

The pre-yoga social bonding measure had a McDonald's total omega value of ω_t = .87, 95% CI [.76, .98] and the post-yoga questions had a ω_t = .86, 95% CI [.70, >.99], indicating moderate-to-high internal reliability, comparable to previous studies in the thesis.

A Shapiro-Wilk tests showed that all social bonding scores for both Naltrexone (pre-yoga: W = 849, p = .224, post-yoga: W = 950, p = .714) and placebo (pre-yoga: W = .911, p = .475, post-yoga: W = 988, p = .971) were not significantly different from normally distributed and the homogeneity of variances assumption was not violated. Even so, due to the small sample, and given that this measure had not been normally distributed in previous studies, it is possible that the parametric assumptions were violated without being detected. Based on this input from peer reviewers of the academic article that stemmed from this study, I used a non-parametric ANOVA analyses.

I used the nparLD package in R to run a non-parametric within-between ANOVA via the f1.ld.f1 function; this produces an ANVOA-like statistic but treats the denominator degrees of freedom as infinite (Noguchi et al., 2012). A non-parametric ANOVA showed that there was no significant main effect of pill type (placebo vs. Naltrexone; $F(1, \infty) = 0.07$, p = .943) or time (from before to after the ritual; $F(1, \infty) = 2.34$, p = .071). However, there was a significant time-pill interaction effect, where participants who took Naltrexone had lower levels of social bonding after the ritual than before it, compared to the Placebo group (F $(1, \infty) = 4.05$, p = .012). Note that effect sizes cannot be directly calculated using the non-parametric within-between ANOVA, but Feys (2016) suggests an indirect method for interaction effect sizes. Here I found the interaction effect size to be d = .77. This interaction effect means participants who took Naltrexone had significantly lower social bonding scores after the ritual than those who took placebo, when compared to before the yoga session (Figure 6.1). Figure 6.1. makes it appear that participants who took Naltrexone started with a greater level of social bonding than those in the placebo condition, a comparison found no significant difference between the two starting levels of social bonding (Z = -0.61, p = .539).

The analysis here differs from the pre-registered plan (a between-samples test of change in social bonding) due to the realization that the original analysis plan was not the most appropriate for the study design. This is because a t-test does not account for the repeated-measures nature of the data (measures taken at both pre-ritual and post-ritual), and so the amount of variance that is accounted for is less than if using a model that does account for the repeated-measures (i.e., an ANOVA). I have, nonetheless, completed the pre-registered analysis, in the analysis script (Appendix 27). The results in the pre-registered plan were also significant, supporting the hypothesis that the change in social boding in the. Specifically, as predicted, a Mann-Whitney U test showed that participants who took Naltrexone (*M* = -1.00, *SD* = .816, *Mdn* = -1) had significantly lower change in social bonding than participants who took placebo (*M* = 0.2, *SD* = .447, *Mdn* = 0, U = 2, p = .022, r = .72).

Post-hoc analyses were conducted to deconstruct the interaction effect found. There was no significant change in feelings of social bonding from before (*M* = 3.17, *SD* = 1.118, *Mdn* = 2.67) to after the ritual in participants who took placebo (*M* = 3.37, *SD* = 1.089, *Mdn* = 3.17, Z = 1.34, p = .181, r_R = .42). This contrary to the first hypothesis that participation in the ritual would lead to a significant increase in feelings of social bonding. There was also no significant change in feelings of social bonding from before (*M* = 3.58, *SD* = .500, *Mdn* = 3.5) to after the ritual in participants who took Naltrexone (*M* = 2.67, *SD* = .304, *Mdn* = 2.67, Z = -1.53, p = .125, r_R = .54).

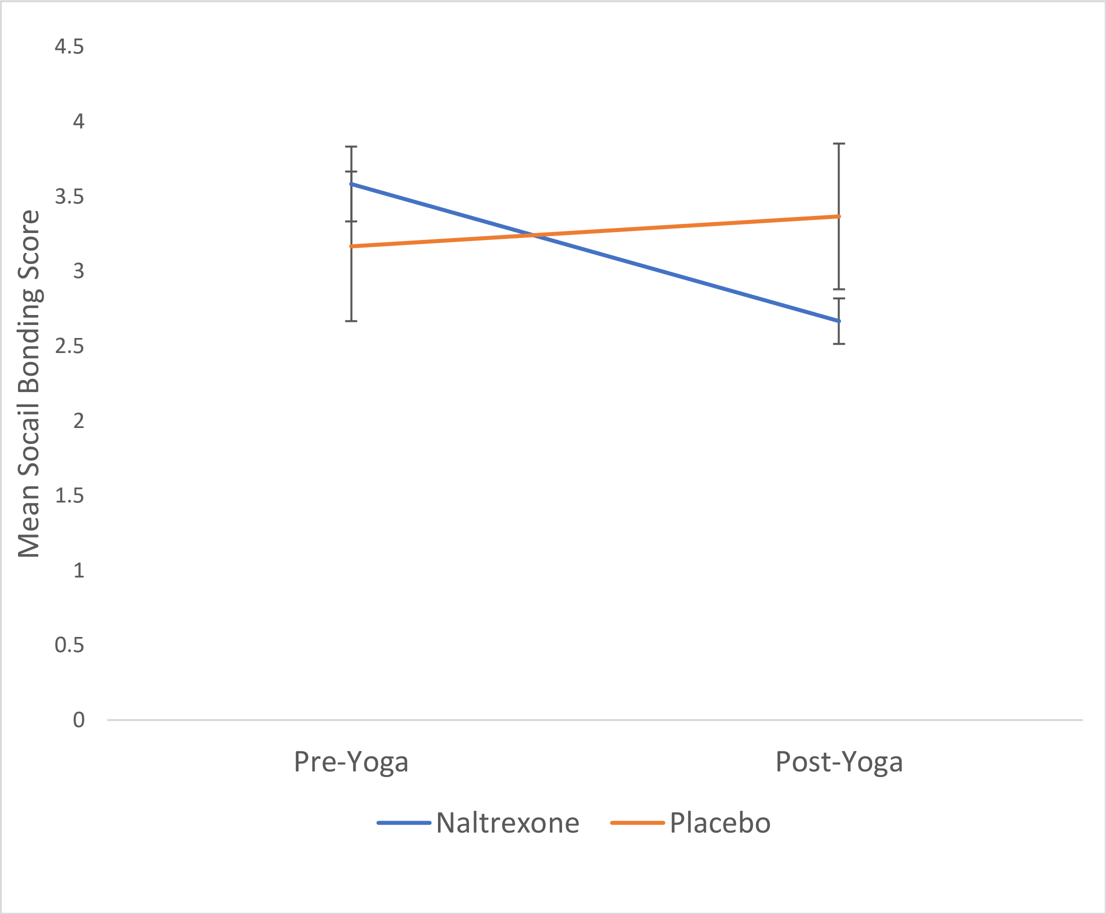


Figure 6.1. The effect of Naltrexone versus placebo on social bonding before and after a yoga session. Error bars represent +/- 1 standard error.

6.2.6. Study 4 mini-discussion

The results shown in figure 6.1. show two surprising results: (1) There was no significant increase in social bonding from before to after the ritual in the placebo condition, and (2) Naltrexone appeared to *reduce* feelings of social bonding in participants who took it (albeit not to a significant degree). The non-significant results for these post-hoc analyses may be due to the small sample size leading to a higher likelihood of Type II errors (false negatives). For example, for the first surprising result (that the increase in the placebo group was not significant), the increase in social bonding found in the placebo group (r_R = .42) is comparable to the significant effects found in prior studies (study 1, r_R = .30; study

2, r_R = .51; study 3[16], r = .48). This means that a non-significant result may simply be caused by the lower power of the analysis.

The second surprising result, albeit also not significant, that Naltrexone appeared to reduce feelings of social bonding has a moderate effect size (i.e., a decrease, r_R = .54). It is unclear why this might be the case. One reason could be that because Naltrexone blocks the activation of μ-opioid receptors in the brain, feelings of pleasure do not occur (Berridge & Kringelbach, 2013; Berridge & Kringelbach, 2015). Without feelings of pleasure (which might be part of positive affect), it may be that feelings of discomfort caused by the yoga poses take focus away from people outside of the self and cause a focus on the self (an inverse of the Broaden and Build mechanism), causing lower feelings of social bonding. The significant interaction effect, then, may have been found because of a combination of the increase (albeit non-significant) in feelings of bonding in the placebo group and the decrease (again, not significant) in the Naltrexone group. Each effect on its own may not have been strong enough to produce the effect, but the combined effect caused a significant interaction to be detected. A major limitation of the study is definitely that the sample size was likely too small to be appropriately powered to detect significant effects in the post-hoc analyses.

Despite this limitation of a small sample, these results provide the first direct evidence for the role of μ-opioids in creating the feeling of *group* social bonding. To provide corroboration, I undertook another double-blind placebo-controlled study in Brazil, as part of a follow-up to both this study and to the larger scale field study conducted in Chapter 3. The ritual in Brazil was used to help ensure that the findings are also applicable to non- Caucasian populations. Not being able to demonstrate results in non-Caucasian, an issue that past psychobiological research has been criticised for (Bakermans-Kranenburg & van Ijzendoorn, 2014).

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[16] The effect size was calculated using the *t*-value and the df given via the Luke (2017) method, taken from Model C in study 3. The formula used was $r = \sqrt{\frac{t^2}{t^2+df}}$, where t = 10.37 and df = 354.66

6.3. Study 5: Social bonding in an Afro-Brazilian religious ritual

Study 5 was conducted during an Umbanda ritual in Brazil. This is the same type of ritual that was assessed in study one (see 3.2.2.2. for a fuller description). The full ritual lasted two hours.

This study was pre-registered (See Appendix 28). In the pre-registration, there were four hypotheses that were established:

1. Taking part the group ritual would lead to an increase in self-reported feelings of social bonding for those who take a placebo.
2. The change in level of self-reported social bonding measured from before to after the religious service will not be significantly different from zero in those who are given Naltrexone.
3. There may be a mediating or moderating role of affect in the change in social bonding from before to after the religious service.
4. Pain threshold will increase in the placebo group but not the Naltrexone group from before to after the religious service.

However, since pre-registering the study, I realised that the most theoretically important aspect of the analysis was not incorporated into these hypotheses. Specifically, testing for an interaction between time and condition to assess the necessity of μ-opioid activation on the group social bonding process. As such, further analyses are included in the results section to assess this (6.3.3.2.). Information about the power of this analysis is provided in section 6.3.1.1., below.

6.3.1. Study 5 Methods

6.3.1.1. Study 5 Participants

Participants were recruited from an Umbanda ritual in Sao Paulo, Brazil, that had been part of study one. Twenty-four participants (M_{age} = 42.7, SD_{age} = 15.3, 16 females) who did not meet any exclusion criteria (see Appendix 26; or online: https://osf.io/y4gw7/) completed a short questionnaire which included a measure of social bonding. Of these, 11 participants (M_{age} = 38.8, SD_{age} = 13.6, 6 female) were randomly allocated to the Naltrexone group and 13 participants (M_{age} = 47.7, SD_{age} = 15.3, 10 female) were randomly allocated to the placebo group. There were no adverse effects reported by any participants.

As in Study 4, in the pre-registration for this study, the same *a priori* power analysis was conducted in order to assess how many participants might be necessary to detect the desired effect. As such, the same two effect sizes were used: The more conservative effect size (d = .59) based on a pain tolerance study (Dunbar et al., 2016), suggested 37 participants in each group was desired, whereas the the larger potential effect size (d = .90), based on a Naltrexone study conducted on lone behaviour (Inagaki et al., 2016), suggested 17 participants (34 in total) would be needed in each group. In this study, 24 participants were successfully recruited.

As this study was published alongside study 4, the same criticism from peer-reviewers that applied to study 4 (that the planned analysis was deemed not to be appropriate for the study design) applied here. They recommended use of an ANOVA. As such a sensitivity power analysis was conducted after data collection was completed to assess the effect size that would be detectable with at least 80% power, given the new analysis type and the known number of participants (24). Using G*Power, a sensitivity power analysis was conducted using the F test family, using a repeated-measures ANOVA within-between interaction test, with nine participants, and an alpha value of .05 and power of 80%. The correlation among repeated measures was calculated using the data collected within this study, and was calculated to be 0.788. The interaction effect size that the test would be able to reliably detect is f = 0.19 (d = .38). This means that for effects smaller than d = .38, there is a greater chance for a Type II error to occur. This effect size (d = .38) is in line with both the more conservative effect size (d = .59) provided by Dunbar et al. (2016) as well as the less conservative effect size (d = .90) provided by a Inagaki et al. (2016), and so data was still analysed. An effect of d = .38 was also found to be the reliably detectable effect for the within-group main effect of time in the sensitivity analysis.

Alternatively, the sample size can be somewhat justified by using the effect size found in study 4 (which is the only study directly analogous to the current study). Using the interaction effect size from study 4 (d = .77; f = .39) and the same correlation among repeated measures from study 4 (.683), one can conduct an *a priori*-like analysis (i.e., finding the number of participants that would be required to have an appropriately powered study). Using this method, assessing the minimum number of participants for an analysis of an interaction ANOVA, using an effect size of f =.39, alpha of .05, power at 80%, 2 groups, with 2 measurements, the correlation among repeated measures of .683 and a nonsphericity correction of 1, G*Power suggests that a total of 12 participants (6 in each condition) would be required to reliably find an effect. However, I would need 46 participants to successfully detect a main effect. Given that it is the time-condition interaction effect that is of most interest, theoretically (see the background section of this chapter, 6.1.), the ability to detect an interaction effect meant that the analysis was still conducted.

6.3.1.2. Materials

I used the same measures of social bonding and the same amount of Naltrexone (100mg) as for study four. On top of this, I also measures pain threshold using the pressure cuff measure method outlined in study 1 and used the PANAS (Watson et al., 1988) to assess affect.

A question asking participants if they felt that the pills they had consumed had somehow effected their experience of the ritual was also asked. (specifically, the question deemed appropriate by co-investigator Miguel Farias was "Seu estado psíquico estava diferente do normal durante a sessão de hoje?", literally translates to "Was your psychic state different from normal during today's session?"). This was asked to make sure no participants felt the Naltrexone negatively affected their worship. No participants reported Naltrexone negatively affecting their ritual compared to normal.

6.3.1.3. Procedure

Religious group members were informed in advance of when data collection would be taking place. They attended the religious ritual as usual, but they arrived 1 hour early to allow for Naltrexone to take effect. Those who consented to take part were first given a medical screening questionnaire. If the participant did not meet any exclusion criteria, they were then provided with a bottle of either 2x50mg pills of Naltrexone or 2 placebo pills. After taking the pills, they completed the pre-ritual questionnaire. After a 1-hour period, participants attended the Umbanda ritual as usual. Within 5 minutes of the end of the ritual, participants filled out the post-ritual questionnaire, and then had their pressure cuff measure taken. before being debriefed.

I conducted a power analysis using a within-between ANOVA instead of a between-participants *t*-test (as in the pre-registration). Using G*Power to calculate the minimum number of participants needed to have an appropriately powered within-between ANOVA with an effect size of $f = .295$, $\alpha=0.05$, power of 0.8, two groups, two measurements and with a sphericity correction of 1. The correlation among repeated measures, calculated using the current study's data, was $r = .788$. Using these values, an ANOVA with 12 total participants (six in each condition) would be appropriately powered to find an interaction. Thus, the sample size of 24 participants that I used is more than satisfactory.

6.3.2. Study 5 Ethical considerations

As with study 4, there were multiple ethical considerations to take into account. On top of the potential issues with conducting a double-blind controlled trial outlined in study 4, doing so in a field setting adds extra ethical considerations. Firstly, a local practicing medical doctor was present at the ritual to observe what was going on, and to ensure that any potential adverse effects were dealt with by a medical professional on site. Secondly, it was possible that taking Naltrexone may alter one's perception of the ritual to make one lose a feeling of connection with their religious deity. This was an ethical concern that was difficult to avoid. To help address such a concern, discussions were had with the head medium at the Umbanda ritual as well as the main organiser of the rituals ahead of time. In these discussions, the possible effects of Naltrexone were explained. They said that, so long as the information we provided was added to the information sheet provided to participants before the study, they would be happy for their congregation members to consent to this.

6.3.3. Study 5 Results

Internal reliability was checked on the social bonding score for both pre- and post-ritual measures, with a pre-ritual McDonald's total $\omega = .86$ 95% CI [.72, .99] and a post-ritual McDonald's total $\omega = .90$ 95% CI [.84, .95], which falls within the range of what is considered good reliability.

Shapiro-Wilk tests were conducted to check whether the data met the assumptions for parametric testing. The post-service social bonding scores for placebo participants did significantly differ from a normal distribution ($W = .793$, $p = .006$). Social bonding scores did not differ significantly from normality for the Naltrexone condition (pre- and post-service), or the pre-service placebo condition (all $p > .05$). As parametric assumptions failed to be held, analyses including placebo participants were non-parametric.

6.3.3.1. Pre-registered hypotheses

To assess the first pre-registered hypothesis, that participants who took placebo would have an increased level of social bonding from before to after the ritual, a Wilcoxon signed ranked test was conducted. It was found that participants in the placebo group did not have a significant change in feelings of social bonding from before ($M = 5.55$, $SD = .906$, $Mdn = 5.83$) to after the Umbanda ritual ($M = 5.77$, $SD = .803$, $Mdn = 0$, $Z = -1.57$, $p = .116$, $r_R = .31$).

To assess the second pre-registered hypothesis, that change in Naltrexone would not be significantly different from zero, a two-one-sided test (TOST) must be conducted. A parametric, one-sample TOST was conducted using the dataTOSTone function from the TOSTER package in R (Lakens, 2017). This conducts three one-sample t-tests. The first uses a comparison of 0 (as per the hypothesis), and then the next two are conducted against the lower and upper bounds of the effect size specified. The effect sizes used as the upper and lower bounds were $d = +/-.46$, as this is the median moderate effect size in cognitive science research (Szucs & Ioannidis, 2017, 2021). The first t-test found that the change in feelings of social bonding was not significantly different from zero ($t(10) = -1.13$, p .284, $d = -0.27$). The effect size was significantly lower than the upper bound ($t(10) = -2.66$, $p = .012$)

but it was not significantly larger than the lower bound ($t(10) = 0.39$, $p = .351$). This suggests that, while the effect is not significantly different from zero, there is not enough evidence to suggest there is no difference (see Figure 6.2.). As there was no significant difference between pre- and post-ritual social bonding, both mediation and moderation analysis do not make sense. For this reason, hypothesis three

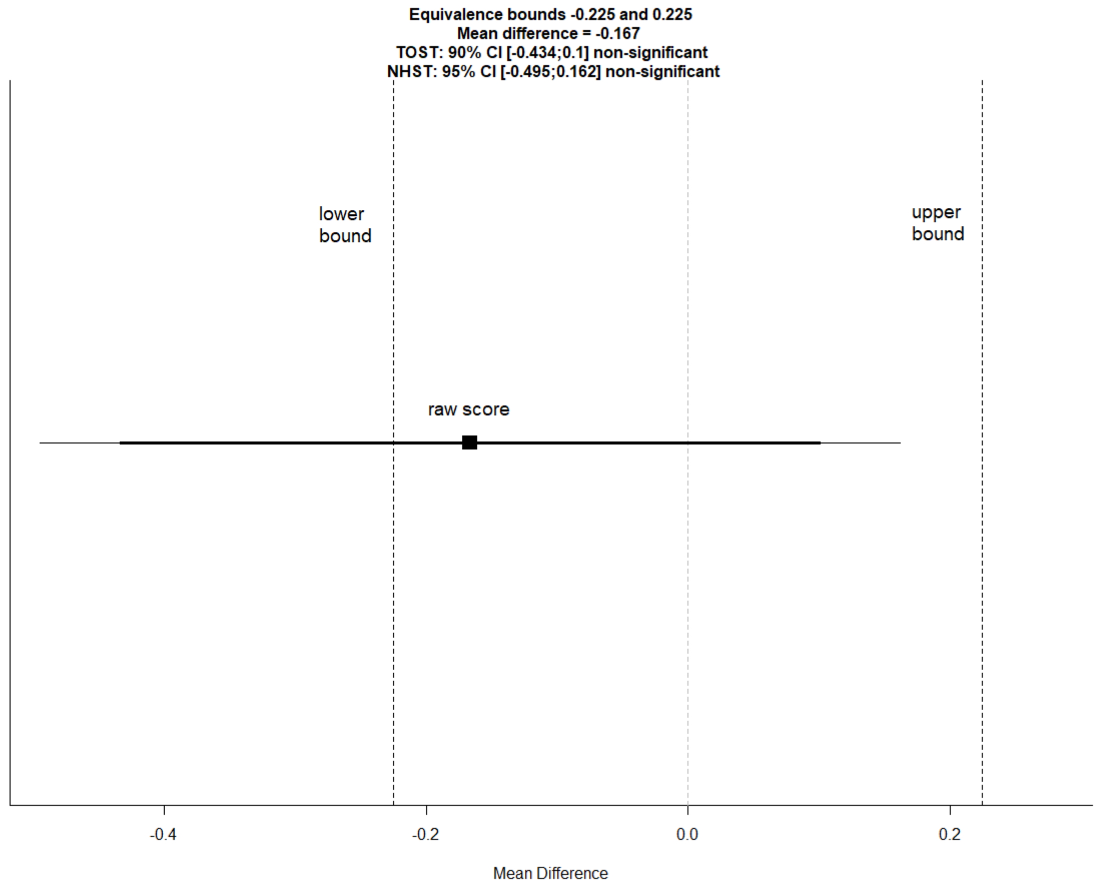

Figure 6.2. The effect of Naltrexone on social bonding caused a raw-score change in social bonding of -0.167. The thick black lines show the 90% confidence intervals provided by the TOST, the thin lines the 95% confidence intervals provided by the normal null-hypothesis significance test (NHST). The lower and upper raw-score bounds were converted from the *d* = +/- 0.46 bounds. The x-axis shows the mean raw-score difference on the social bonding scale.

was not tested.

Finally to assess the fourth pre-registered hypothesis, that pain threshold would increase for the placebo condition but not the Naltrexone condition, first pain threshold measures were assessed to see if they met parametric assumptions. Pressure cuff measure for both pre- ($W = .899$, $p = .180$) and post-Umbanda ($W = .901$, $p = .189$) did not differ significantly from normal for those in the Naltrexone condition. However, both pre- (W = .760, p = .002) and post-Umbanda (W = .868, p = .049) pressure cuff measures did differ significantly from normal for the placebo group. To test whether the pressure cuff measure increased for placebo condition, a Wilcoxon signed rank test was conducted. It was found that, contrary to the hypothesis, pain threshold as measured via the pressure cuff was not significantly different after (M = 179.23, SD = 76.42, Mdn = 160) the Umbanda ritual than before it (M = 168.46, SD = 81.53, Mdn = 140, Z = 0.71, p = .474, r_R = .14). To assess whether pressure cuff measure in the Naltrexone group did not increase, a parametric TOST was conducted. The first t-test found that there was no significant difference in pressure cuff measure from before to after the Umbanda ritual ($t(10)$ = 0.77, p = .462, d = .15). This score was significantly greater than the lower bound ($t(10)$ = 2.29, p = .022), but not significantly lower than the higher bound ($t(10)$ = -0.76, p = .232) meaning there is not enough evidence to suggest no difference.

6.3.3.2. *Theoretically driven analyses*

At the end of section 6.1., I noted that my main theoretically-driven hypothesis across both studies was to assess the interaction effect of time (pre vs. post ritual) and condition (placebo vs. Naltrexone). In order to do this, an ANOVA had to be conducted. Due to the assumptions underlying parametric testing nor being met, I used the nparLD package in R to run a non-parametric within-between ANOVA via the f1.ld.f1 function. There was no significant main effect of either pill type (F (1, ∞) = 0.60, p = .440) or measurement occasion (F (1, ∞) = 0.22, p = .640), but there was a significant interaction effect (F(1, ∞) = 5.28, p = .022), indicating, when compared to before the ritual, participants who took Naltrexone had significantly lower social bonding scores after the ritual than those who took placebo (Figure 6.3). Note that effect sizes cannot be directly calculated using the non-parametric within-between ANOVA, but Feys (2016) suggests an indirect method for interaction effect sizes. Here I found the interaction effect size to be d = .64 (see R analysis script, Appendix 29 - https://osf.io/dw98k/ lines 371 – 407 for more detail).

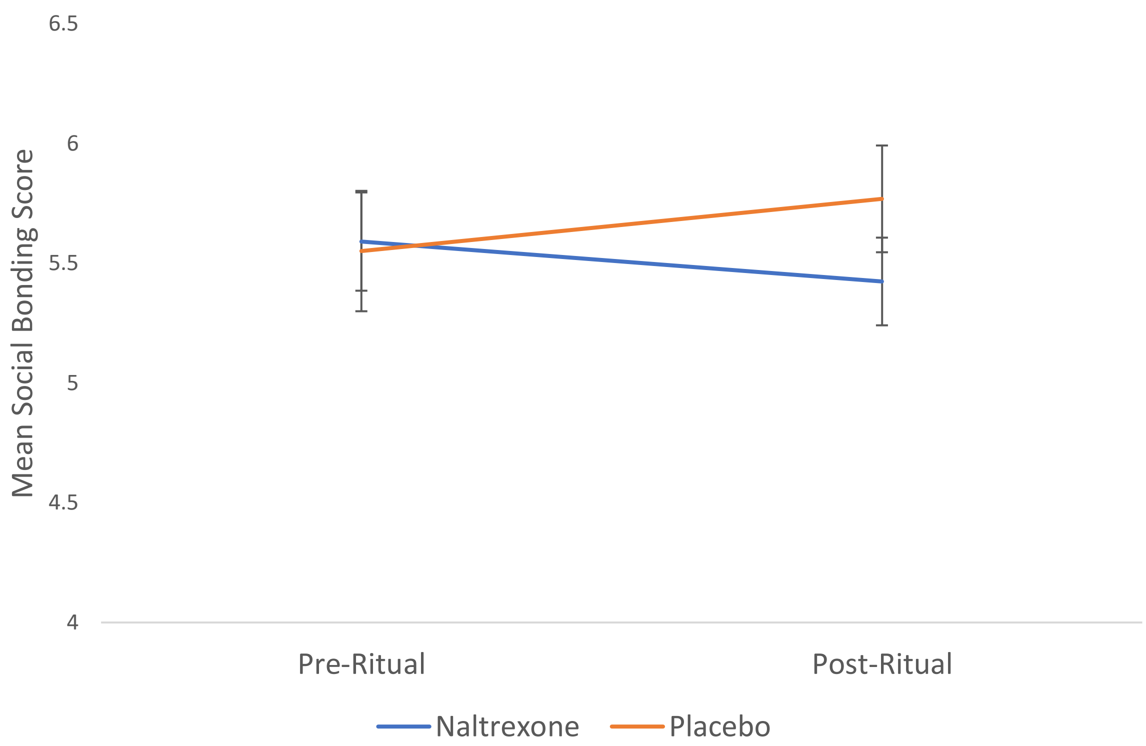

Figure 6.3. The effect of Naltrexone versus placebo on social bonding before and after a religious ritual. There was a significant interaction between pill type and time of measurement. Error bars represent +/- 1 standard error.

The results shown in figure 6.3. are in line with those found in study 4. Despite the non-significant results for the first pre-registered hypothesis (that the placebo condition would see an increase in social bonding), the effect size for the increase in social bonding (r_R = .31) was comparable to the significant effects found in prior studies. In my opinion, the low sample size in each study suggests that data should be pooled for analysis to assess the effects of participation in ritual within each condition.

6.3.3.3. Exploratory pooled analysis

Given the issues with sample size in both studies 4 and 5, which may be the cause for not finding a significant increase in social bonding from participation in the ritual, I conducted some simple follow-up analyses where I pooled the data from study 4 and 5 together. Pooling the data from a Brazilian ritual and a ritual that took place in the UK is something that was already done in study 1, and so doing so is not entirely unfounded. The main reason to have not done so initially was that the two studies were conceived of, and conducted separately initially.

Parametric assumptions were not met for the pooled social bonding scores of the placebo group at the pre-ritual stage (W = .860, p = .012), so a Wilcoxon signed ranks test was conducted to see if the pooled data across both rituals found an increase in social bonding from before to after the ritual in the placebo group. The analysis showed that, after pooling data across both sets of ritual, feelings of social bonding were significantly higher after ritual (M = 5.10, SD = 1.40, Mdn = 5.) the than before it in the placebo group (58M = 4.48, SD = 1.44, Mdn = 5.58, Z = -2.02, p = .043, r_R = .34).

Similarly, a pooled analysis was conducted to determine if taking Naltrexone significantly reduced feelings of social bonding. Once again, parametric assumptions were not met, this time for the post-ritual Naltrexone social bonding scores (W = .864, p = .028) so a Wilcoxon signed ranks test was conducted. The analysis showed that, after pooling data across both sets of ritual, feelings of social bonding were significantly lower after ritual (M = 4.49, SD = 1.37, Mdn = 5.17) than before it in the Naltrexone group (M = 5.06, SD = 1.11, Mdn = 5.67, Z = -2.07, p = .039, r_R = .38).

6.4. Overall discussion of studies 4 and 5

Previous work on the role of opioids on social bonding has either been conducted via proxy measures (e.g. study one; study three; Cross et al., 2019; Tarr et al., 2018), after lone behaviour (Inagaki et al., 2015; Inagaki et al., 2016) or is only measured after an activity, but not before it (Tarr et al., 2017; Tchalova & MacDonald, 2020). Across the two studies presented in this chapter, I sought to understand the role of opioids on social bonding in two ecologically valid settings: during yoga and during an Umbanda ritual. I have demonstrated that μ-opioids appear to play a key role in the social bonding experience during group behaviour by showing that Naltrexone, compared to placebo, lowers feelings of bonding. These results were consistent across the two studies. Moreover, after pooling the data for the two studies to account for low the sample sizes, I found that, as expected, participants in the placebo group showed increased levels of social bonding from before to after social bonding.

Moreover, after pooling the data across the two rituals, I found a surprising result: taking Naltrexone significantly *reduced* feelings of social bonding. That Naltrexone (a μ-opioid antagonist) not only blocks social bonding from occurring, but also appears to reduce feelings of social bonding, the pooled data from these studies provide the first evidence in humans that μ-opioid receptor activation might be necessary for feelings of social bonding.

I think this is an important finding, because of two reasons. (1) It validates the brain-opioid theory of social attachment (Machin & Dunbar, 2011; Panksepp, Herman, et al., 1980), in that feelings of social bonding are increased by μ-opioid activation. Study 1 did provide some evidence of this, but it was only indirect, via a proxy measure. Study 3 also did not find a relationship between the pain proxy and social bonding (albeit, likely because of pain tolerance not being an appropriate proxy measure). (2) This finding suggests that μ-opioid antagonism can directly reduce feelings of social bonding even after they took part in a behaviour that has been shown to be related to an increase in feelings of social bonding (see studies 1, 2, 3, and placebo participants in the pooled data from studies 4 and 5). This suggests that μ-opioids are not only necessary for an *increase* in feelings in social bonding, but they might be necessary for those feelings to be maintained at the current level.

Studies of what percentage of μ-opioid receptors are blocked with naltrexone are rare. However, Weerts et al. (2008) found that, in recovering alcoholics, Naltrexone blocked approximately 95% of all μ-opioid receptor binding throughout the brain after 4 doses (2x50mg on day one, then 50mg on day two and another 50mg on day three). The fact that a significant decrease in levels of social bonding was found only 3 hours after intake of Naltrexone (before complete blockade is likely to have occurred) it is possible that longer-term Naltrexone intake (such that 95% blockade is achieved) might lead to even lower levels of social bonding than found in the post-ritual participants in the current study.

Although it is possible that other neurochemicals, such as oxytocin (Atzil et al., 2011; Kohli et al., 2019) might also play a role in the social bonding experience, studies of the receptor genetics for these other neurochemicals suggests that these play a more specialized and much less prominent role compared to μ-opioids (Pearce et al., 2017; Pearce et al., 2018). Dopamine is the only other neurochemical that has been implicated across all types of social bonding, including group social bonding (Pearce et al., 2017). Future research could seek to rule out the role of dopamine in further double-blind studies to determine which neurochemicals are necessary and/or sufficient for social bonding to occur. Study four (but not study five) suffered from the limitation that it recruited no males, and it would be desirable to increase the gender representation in future studies. The pooling of data also helped in this regard to better-account for the gender disparity. It should also be noted that naltrexone may also block the kappa-opioid receptors (Codd et al., 1995; Raynor et al., 1994), which have a particular affinity with dynorphins. Although this makes it difficult to be absolutely certain that the primary mechanism of action of the blocking and lowering of social bonding was the μ-receptors, previous research on primate social bonding has explicitly identified β-endorphins (μ-opioid agonists) as playing a key role (Bales et al., 2007).

A major limitation with both of the studies presented in this chapter is that there is no control, non-ritual group behaviour presented. Because of this, the two studies can only be used to provide evidence that μ-opioid activation does appear to be necessary to increase feelings of group social bonding. However, these studies cannot be used as evidence that *ritual* (be it religious or not) is somehow special at eliciting group social bonding. There is evidence that group ritual is more likely to lead to social bonding than other, non-ritual group behaviour (Wen et al., 2016), but replicating that finding was not the aim of the studies in this chapter.

In fact, the three primary aims of the thesis were made explicit in Chapter 1 (section 1.2.): The first aim was to determine if religious ritual did reliably lead to increases in social bonding. This was demonstrated in studies 1 and 3, and there was also evidence in the pooled data of the placebo group in the studies within this chapter. The third aim was to determine whether the religious component of a ritual had an additive or modulatory effect on the feelings of social bonding that occurred as a result of ritual. Studies 2 and 3 showed not only that there was no significant difference in the change of social bonding, but also that there was significant evidence of no difference between religious rituals and secular equivalents regarding the effect on social bonding. The second primary aim highlighted in

Chapter 1 was to assess whether μ-opioid activation played a key role in social bonding that takes place at religious ritual. Study 1 demonstrated some evidence via a proxy measure, while study 3 did not find significant evidence in favour of the effect of μ-opioids (albeit this may be because of a poor choice of proxy measure). The two studies in the current chapter show, via the significant interaction effects, that μ-opioids appear to play a necessary role in allowing the increase in social bonding from occurring. Moreover, evidence from the pooled data shows that μ-opioid blockade actually leads to a decrease in feelings of social bonding, providing even stronger evidence for the necessity of μ-opioid activation for feelings of social bonding.

In summary, in each of these two studies, and with pooling the data across the two settings, I provide the first placebo-controlled, double-blind studies to examine the pharmacological basis for the role of μ-opioid receptor activation in adult human *group* social bonding, where the change of social bonding from before to after participation in a group activity was assessed. These studies support the theoretical model laid out in Chapter 2 (2.2.3.1.), and provide a clear-cut case for the importance of μ-opioid receptor activation as one of the necessary neurochemical mechanisms underlying group social bonding.

7. Chapter 7. Thesis Discussion

In the introduction to this thesis, three primary aims and two secondary aims were outlined. The primary aims were: (1) to determine if the feeling of social bonding can be reliably found to be caused by religious ritual; (2) to assess whether the body's μ-opioid system plays a key role in social bonding that occurs during religious ritual; and (3) to determine whether the religious or spiritual components of ritual play a significant role in the feeling of social bonding. The secondary aims were: (a) to create a reliable measure of social bonding, which can be used across settings, and (b) the creation of a novel paradigm in which one can study religious ritual's role on social bonding in controlled conditions. In attempting to fulfil these aims, this thesis provided a methodologically diverse, yet rigorous and comprehensive, investigation of the psychobiological mechanisms underlying social bonding during ritual.

The first secondary aim was partially addressed in chapter two, where a six-item social bonding scale was developed. This scale was based on the various definitions, interpretations, and measures used to examine social bonding in previous literature. In doing this, the scale had high levels of face-validity. The aim was to not only create such a measure, but also to demonstrate that it is a reliable measure that can be used across settings. To demonstrate this, exploratory factor analyses were performed in the studies, to test whether the scale was only measuring a single underlying construct (social bonding). The scale demonstrated evidence of high construct validity, as well as being unidimensional. A partial confirmatory factor analysis (Gignac, 2009) was also conducted after study one, which further demonstrated that the measure was unidimensional, and that the six-item structure was sound. Beyond this, in each study, the measure demonstrated high or very high levels of reliability (see Table 7.1). This shows that the novel social bonding measure created within this thesis does provide a valid, and reliable measure of social bonding that is applicable across both naturalistic and laboratory settings, as well as across both UK and Brazilian participants.

Table 7.1.

Reliability of the social bonding measure (SB6) created for this thesis.

Study	Measurement Occasion	Reliability Statistic	Point Estimate	95% CIs
Study 1 – Religious Ritual	Pre-Ritual	ω_t	.87	[.85, .90]
	Post-Ritual	ω_t	.90	[.87, .92]
Study 2 – Secular Ritual	Pre-Ritual	α	.93	[.91, .95]
	Post-Ritual	α	.91	[.88, .94]
Study 3 – Yoga	Longitudinal	Ω	.80	[.73, .87]
Study 4 – Naltrexone Yoga	Pre-Ritual	ω_t	.87	[.76, .98]
	Post-Ritual	ω_t	.86	[.70, .99]
Study 5 – Naltrexone Naturalistic	Pre-Ritual	ω_t	.86	[.72, .99]
	Post-Ritual	ω_t	.90	[.84, .95]

Note. As a rule of thumb, a reliability estimate of .80 or above is considered high; .90 or above is considered very high (George & Mallery, 2003).

After the creation of this measure, five studies were conducted to address the remaining aims of the thesis. In study one – a large-scale, international field study conducted in churches in the UK and Umbanda rituals in Brazil – I found that both positive and negative affect, pain threshold and a connection to a higher power were significantly related to the level of social bonding with others at the religious ritual. In study 1, I also found inconsistent evidence for a role of the religiosity of an individual on the social bonding they may feeling during a religious ritual, which appears to match inconsistent results from religious priming studies (Shariff et al., 2016). In the first study, the role of μ-opioids as significant part of the neurochemical underpinnings of ritual social bonding was also supported, as the proxy for μ-opioid release, pain threshold, was significantly related to the increase in social bonding (somewhat addressing the second primary aim of the thesis). Affect, and the feeling of connection to a higher power were also significantly related to ritual social bonding, which provided a better understanding of the cognitive-affective aspects of religious ritual that lead to feelings of social bonding (which are related to the third primary aim).

Following on from this, in study two – a comparison of naturalistic religious ritual and a behaviourally similar naturalistic secular ritual, Sunday Assembly – I found that, once again, positive affect and a connection to something bigger than oneself (analogous with connection to a higher power) were significantly related to increases in feelings of social bonding. However, there was not a significant role of negative affect. This provided a clarification of the results from study one, suggesting that negative affect may not play a significant role in feelings of social bonding across all contexts, and further addressed the third primary aim of the thesis – to better understand the role of specifically religious component of a ritual on social bonding. In this study, no significant difference was found between religious and secular rituals in naturalistic settings, and instead significant evidence of *no* difference between the two was found.

Using these findings, and with advise from esteemed academic advisors, I was able to address the other secondary aim of this thesis – the creation of a novel paradigm where one can reliably study social bonding in controlled conditions, while still providing pseudo-naturalistic validity. To do this, in study three I enlisted the help of a professional yoga instructor and practitioner who helped co-design a series of yoga sessions to enable studying ritual social bonding in controlled conditions. In doing this, I was also able to further address the third primary aim. I helped co-design two sets of behaviourally almost identical yoga classes, that had specific, targeted differences that allowed one set of classes to be considered ‘religious’ and another set to be secular because of a difference in the focus on the super-empirical.

As there was a significantly higher level of participants’ perception of a connection to a higher power in the religious group, and this is a key difference between a religious/spiritual ritual and a secular ritual (Van Cappellen, 2017), the manipulation was found to be successful. I found, as in study two, that there was no significant difference in levels of social bonding between the secular and religious yoga groups, and that there was significant evidence of no difference. Similarly, as in the previous two studies, positive affect and a feeling of connection to something bigger than oneself were significantly related to increases in levels of social bonding. Based on the theoretical outline of the Broaden and Build theory of positive affect (Fredrickson, 2013; Fredrickson & Branigan, 2005), a mediation analysis was conducted to see if the feeling of connection to something bigger than oneself mediated the effect of positive affect on social bonding. Mediation analysis found that the feeling of connection to something bigger than oneself did significantly mediate the effect of positive affect, by accounting for 18% of the effect of positive affect (See Figure A19.A). However, unlike study one, the pain proxy for μ-opioid activation did not significantly predict social bonding. While there are multiple possible reasons for this (the use of pain tolerance instead of pain threshold as the proxy measure being most likely), these inconsistent results did raise a question of whether or not μ-opioids actually play a role in the group social bonding seen during ritual. Consequently, two further studies were conducted to specifically assess the role of μ-opioids in social bonding more directly.

In studies four and five, I conducted two double-blind, placebo-controlled studies using the μ-opioid antagonist Naltrexone. This was needed to address the inconsistent results found between study one and study three, where the pain proxy for μ-opioids significantly predicted social bonding in study one but not in study three. In both studies four and five, as predicted, there was no main effect of pill type or time, but there was a significant interaction between time and pill type, where those who were given Naltrexone reported significantly lower levels of social bonding after the ritual than before, when compared to those who were given placebo. In both instances, there was a moderate-to-strong effect size for the role of μ-opioid blockade on social bonding (study four d = .77, study five d = .64).

Moreover, in follow-up analyses, pooled data from the two studies showed that participants who took placebo had a significant increase in feelings of social bonding, with an effect size similar to that seen in study 1, also conducted in a naturalistic religious ritual setting (r_R = .34 in pooled data, r_R = .30 in study 1). Interestingly, participants who took Naltrexone not did not see an increase, but actually saw a decrease in feelings of social bonding with the effect a similar size to the increase in placebo participants, but in the opposite direction (r_R = .38). These studies provided the first direct evidence for a role of μ-opioids in group social bonding, and addresses the inconsistency found between study one and three. These studies also help to tackle the second primary aim of the thesis.

7.1. Limitations

While there are many strengths that run through this thesis, there are limitations that were not addressed in the discussion subsections of the individual studies. One of the major limitations that runs through this thesis is that there was not a direct measure of central levels of μ-opioid receptor activation. While the reason for this was addressed in each of the chapters – central levels of μ-opioids cannot be directly assessed without invasive procedures. Without such a measurement, the conclusions drawn from each of the studies of this thesis cannot be considered as truly direct evidence of central μ-opioid receptor activation, but as proxy measures, either via the pain experience or assumed via the psychoactive properties of the drug Naltrexone.

Where circulating levels of μ-opioids was attempted to be measured, via blood serum beta-endorphin levels, technical difficulties caused more than 50% of all blood samples to be lost or unable to be processed. Moreover, a different proxy measure was used in the field studies conducted in naturalistic settings (pain threshold) compared to in controlled conditions (pain tolerance). While the reasons for using pain tolerance in controlled conditions seemed reasonable at the time – similar studies comparing spiritual with secular mediation had used pain tolerance (Wachholtz et al., 2017;

Wachholtz & Pargament, 2005, 2008) – it is highly likely that it was not actually the correct proxy measure to use: pain threshold would have been a better proxy to use in controlled conditions for both consistency across the thesis, and for a more appropriate proxy measure of μ-opioid (see Appendix 6.2). The inconsistency of the proxy measure used may also explain the inconsistent findings between study one and study three. To address this issue, future research would benefit from using a combination of tracer-neuroimaging techniques to assess the level of μ-opioid receptor binding that takes place during social bonding. Alternatively, if the rare opportunity arises, future research could assess central nervous system levels of μ-opioids via measuring levels in cerebral spinal fluid.

Another limitation of this thesis is that, while I was able to show – via double-blind, placebo-controlled studies – that μ-opioid activation is necessary for social bonding to take place from participating in a ritual, this thesis was not able to demonstrate that μ-opioids are *sufficient* to produce social bonding within ritual settings. Moreover, due to the inability to access appropriate dopamine or oxytocin antagonists (See Appendix 30), the sufficiency or necessity of other neurotransmitter that are thought to play a role in social bonding was not assessed. To address this issue, future research could conduct further double-blind studies to assess the difference between μ-opioid, dopamine and (to address the popularity of oxytocin), oxytocin antagonists on *group* social bonding outcomes.

Another limitation that runs throughout this thesis is that the measure of social bonding, created for this thesis, did not have its psychometric properties and validity confirmed in a dedicated study with a confirmatory factor analysis. This could be addressed in future research, so that social bonding researchers can use the measure in their research with full knowledge, and direct evidence, of the validity of the measure and its psychometric properties. Moreover, much like many measures used in psychology, the social bonding measure could be considered an ‘arbitrary measure’ (Blanton & Jaccard, 2006). By this I mean that this scale does not necessarily directly map onto a non-arbitrary output, such as prosocial behaviour (often measured through economic games). This is an issue because, as noted by Blanton and Jaccard (2006), while an arbitrary measure is good for testing psychological theories, it cannot necessarily be understood outside of such contexts: i.e., what does a 1-point increase in the social bonding measure mean in terms of the strength of the emotion, or on behaviour? A related question is 'does a 1-point increase in social bonding always mean the same thing: does moving from 3/7 to 4/7 have the same behavioural/emotional/cognitive implications as moving from 6/7 to 7/7 on the scale?' To address the issue of arbitrariness and understanding what the measure maps to, future research could use the social bonding measure alongside well-established economic games to map the measure onto a less-arbitrary metric, such as prosocial behaviour.

7.2. Implications on the wider literature

In this thesis, the primary and secondary aims have made it very clear, in my opinion, that the focus has been squarely on group social bonding: one of the key neurochemical mechanisms underlying group social bonding, and looking at ritual as a method of eliciting group social bonding. However, the context of religious ritual, and the wider literature of the psychology and anthropology of religion, have played a major role in shaping this thesis. It is, thus, important to discuss the implications of some of the findings from the thesis in relation to (1) the wider social bonding literature, and (2) the wider literature on religion and ritual.

7.2.1. Literature on social bonding

With regard to social bonding, when I started the work that made up this thesis it was well-established that what made up the construct of what was named 'social bonding' was not universally agreed upon (Holt-Lunstad & Smith, 2012; Holt-Lunstad et al., 2010). The theoretical and definitional breakdown of what social bonding should be considered, provided in Chapter 2 of this thesis, is something that I belief is a major contribution to the field of social bonding research. Establishing social bonding as an emotion not only allows one to create better theoretical models of how it might be evoked, but it also makes it clear (importantly) what should *not* be considered social bonding, e.g., Identity Fusion. The distinction between the short-term, experiential, state-like construct of social bonding and the long-term, more amorphous, trait-like construct of Identity Fusion should allow researchers who are interested in human social behaviour (especially pro-social behaviour) better disentangle the gordian knot that had been tied between the terminology of 'social bonding' and 'identity fusion'.

Moreover, in each of the five studies presented in this thesis, I demonstrated that the state-like, emotional construct that I used to define social bonding successfully incorporated different conceptions of what was 'social bonding' into a single, unidimensional scale. This unidimensional scale had high levels of both internal reliability (shown across all studies), as well as test-retest reliability (shown by intraclass correlation – ICC – values ranging from .81 to .86 depending on the model used in study 3). Having done this, I think this thesis makes a significant contribution to the study of social bonding be it from a social psychological perspective, or a neurobiological one.

7.2.2. Literature on religion and ritual

A large segment of this thesis is dedicated to establishing useful definitions of religion, ritual and religious ritual. This is because the impetus for the work in this thesis was to help better understand what might have made religious ritual ubiquitous across human cultures (Brown, 2000; Norenzayan, 2010). The major hypothesis that was tested throughout the thesis is that religious ritual is ubiquitous because it, somehow, causes increases in social bonding in a more effective or efficient manner than other behaviours (Dunbar, 2013, 2017b). The work throughout this thesis has found that this hypothesis does not hold water: religious rituals are no better than secular rituals at fostering a sense of social bonding. This is a major contribution to the study of religious ritual, as it helps rule out one of the major hypotheses underlying religious ritual's ubiquity.

However, the work in this thesis has more than a single interpretation. As highlighted in the discussion of Chapter 5 (5.4.), one possible interpretation Brown (2000) is that it is not *religious* ritual that is universal, but instead that it is simply *ritual* that is universal. Pinker (2002/2016), when providing a list of human universals, suggests that rituals (especially *death* rituals) are a human universal and that, separately, *religion* (i.e., belief in the super-empirical) and musical performances conducted in relation to the super-empirical (i.e., religious music performance) are also human universals. It is possible that many have conflated the universal nature of religious music performance as being the same as religious ritual. However, given the definition of ritual laid out in Chapter 2 (2.1.2.), and more importantly what I outline as *not* being ritual (2.1.2.3.), music performance and ritual, while related to one another, should not be conflated. As such, *religious* ritual does not necessarily need to be interpreted as being universal.

A separate way of interpreting the results found throughout the thesis is that, because of the focus on social bonding (a short-term emotion), I only studied doctrinal modes of religious ritual. It is possible that there is something special about *religious* rituals, but that this 'special' property is only found in imagistic modes of religious ritual, such as via a better ability to create the 'extended' subtype of identity fusion (which is still a social feeling, just not an emotion). Alternatively, given the existence of both doctrinal and imagistic modes of religion across most known religions and cultures (Whitehouse, 2000, 2002, 2004a; Whitehouse & Lanman, 2014), it might be that there is something special about the *combination* of the modes of expression that allows religion to be ubiquitous.

In short, while the work in this thesis does suggest that there is no difference in the ability for (doctrinal modes of) religious rituals and secular rituals to cause increases in feelings of social bonding, it does not completely rule out that there could be still be something special about religious practice that has allowed religion itself (with or without ritual) to become universal. Future theoretical models, hypotheses for what might have made religion and/or ritual universal and research on religious ritual should ensure that they are much clearer in the terminology they use to discuss social feelings: distinguishing between social emotions (short-term, state-like constructs) and other social feelings (e.g., 'identity fusion'). Hopefully, in doing so, the term social bonding can become a more specific and theoretically consistent construct to be used not only in the cognitive sciences, but also in the sociology and anthropology of religion.

7.3. Post-graduate research studies as a learning process

As well as implications on the wider literature, I feel that this chapter is the most appropriate place for self-reflection about the multiple years of work that has gone into this PhD thesis. Throughout the PhD, I have found that I have been learning new things. Firstly, I went from having never fully organised my own research study from start to finish before the PhD process to having not only organised, but run, manage and successfully complete five different studies that took place across two continents, while having to teach myself enough Brazilian-Portuguese to be able to successfully run a double-blind clinical trial while jet-lagged. I also taught myself how to use R (instead of relying blindly trusting the button-pressing nature of SPSS), how to conduct more complex analyses, in the form of mixed-effects models, mediation analyses, and TOSTs, as well as contributing to academia outside of the PhD (both in an intra-university sense, and via peer-reviews and wider research network contributions).

This has been an exceptional learning experience by itself. However, these achievements were not only because of my work. I received an incredible amount of useful help and advice from my two internal academic supervisors, Dr Miguel Farias and Dr Valerie van Mulukom. The amount of times that they have advised on my writing, and guided my academic curiosity is too large to count. Beyond these two, Dr Robin Dunbar, as an external supervisor, provided some useful, stoic advice on how to not let the usual stress of academic life to overwhelm me. Of course, I was also incredibly lucky to have had parts of this PhD funded by the Templeton Religion Trust via the International Society for Science and Religion (ISSR). The ISSR also provided an academic advisory board for me to report to semi-frequently to ensure that the work I was conducted made sense from a theological and theoretical perspective. Key members that helped contribute to the work that appeared in this thesis includes Dr Fraser Watts, Dr Joseph Watts, and Dr Leon Turner. Without their input and advice, many of the studies in this thesis would not have been possible. Reflecting back on the number of esteemed academics who provided advice on the studies contained within the thesis makes me realise how collaborative academia both is and should strive to be.

Speaking more on the collaborative element of the PhD, I did find that, while more established academics do have a wealth of experience to draw upon, taking their word as gospel is not advised. One of the major issues within this PhD was with the use of pain tolerance as the pain proxy in study 3 (presented in Chapter 5). Pain tolerance was used over pain proxy at the insistence of one of the academics supervising my work, and corroborated by the academic advisory board due to his experience in the area of using pain as a proxy for μ-opioid release. In initial versions of the design of study 3, the pressure cuff pain threshold measure was to be used as the pain proxy of choice. In future, I now know that I would fight harder for keeping design decisions to being theoretically justified (e.g., using evidence of the link between pain threshold, but not pain tolerance, and μ-opioid levels).

Something else that, looking back on, I feel I could have conducted much better was the incorporation of aspects of Open Science recommendations. As a proponent of the Open Science paradigm shift myself (see Charles et al., 2019), I think that the work in this PhD, and the attempts at pre-registering the work, are a good demonstration of the "Couch to 5K" and "learn from making mistakes" approach that has been described about the adoption of Open Science practices (Charles & Bartlett, 2019, 2021). By this, I mean that the errors in the pre-registration cited across the studies in the thesis (e.g., incorrect analysis types for the data structure, and poorly worded hypotheses) have been fantastic learning experiences for me such that work that I have conducted since the work shown in this PhD (e.g., the pre-registration for Charles, Martin, et al., 2021) does not suffer with the same pitfalls as seen in the pre-registrations that were made over 2 years before the submission of the thesis. Despite the pitfalls throughout the thesis on this front, I am glad to have attempted to incorporate the suggestions and make all of my code, and (anonymised) data available so that others can go away and replicate my findings. Moreover, making the materials available should allow for others to replicate the studies, or conduct further studies that utilise some of the same methodologies that I opted to use within the thesis.

7.4. Conclusions

The findings produced across the five studies within this thesis provide strong support for the Broaden and Build theory of positive affect (Fredrickson, 2013), as well as for the brain-opioid theory of social attachment (Machin & Dunbar, 2011). However, the findings from studies 2 and 3 in this thesis suggest that (at least doctrinal) religious rituals are no better at leading to feelings of social bonding than secular equivalents. I found a positive relationship between proxy measures of μ-opioid receptor activity and social bonding, thus providing support for the brain-opioid theory of social attachment. In doing so, this thesis provides the first direct evidence that μ-opioids play a key role in not *group* social bonding. I found that the exact nature (secular or religious) of the ritual does not play a significant role in ritual social bonding. Were one to favour rhetorical flourish, in combination with the μ-opioid findings presented in this this, Marx’s (1843/2009) infamous statement of religion being the opium of the people may need to be amended: Ritual is the μ-opioid of the people.

One unexpected finding that was consistent across the thesis is that rituals that are better able to create a feeling of connection to something bigger than oneself, be they secular or religious rituals, are also able to produce stronger feelings of social bonding. Thus, it is possible, due to the fact that religious and spiritual ritual directly aims to achieve such a feeling of connection (Van Cappellen, 2017), that religious and/or spiritual rituals are more prominent in all human societies than secular rituals due to the underlying focus on a connection to something bigger than the self. Future research could seek to better understand this connection to something bigger than the self.

Social bonding has long been thought to play a key role in religious ritual, to the point that academics from various backgrounds believe that it is a major part of how such ritual evolved (e.g., Alcorta & Sosis, 2005; Dunbar, 2013; Sosis, 2005). However, the causal mechanisms (i.e., the cognitive and neurobiological causes) underlying group social bonding had not been explored within the scientific study of religion. Recent advances in cultural evolution (e.g., gene-culture coevolution theory) allows for a more broad, nuanced view of the evolution of religious ritual. The surprise finding of this thesis – that a feeling of connection to something bigger than the self predicts increases in feelings of social bonding from rituals – support the idea proposed by Handfield (2020) that the coevolution of sacred value and religion may have played an important role in the ‘coalitional mechanism’ (i.e., social bonding) that allowed ritual to evolve.

In their article, Taylor and Davis (2018) discuss the evolution of mechanisms underlying social cohesion from an anthropology perspective. They suggest that social bonding plays a key role, and that future research should explore the proximate mechanisms underpinning the social bonding process during rituals. In providing an improved understanding of the psychobiology of social bonding, I have provided some answers to these proximate mechanisms: μ-opioid receptor activation, positive affect, and the feeling of connection to something bigger than oneself appear to be some of the proximate mechanisms underlying the feelings of social bonding experienced during ritual. With a better knowledge of these psychobiological mechanisms that are at play, future research can focus on these mechanisms and understand their intricacies with more fine-grained tools such as brain-imaging, gene-expression analysis, or so-called ‘omics’ methods. In doing so, the cultural coevolution of ritual, and its power to foster feelings of social bonding, can be better understood within both a cultural anthropological *and* a psychobiological context.

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Appendix 1 – Social Bonding Measure

In response to the need for a social bonding measure that accounts for the different historic interpretations used in past literature I created a multi-item social bonding measure. This measure contains six items, which covers all six components identified in Chapter 2.3: (1) Trust (e.g. Kosfeld et al., 2005), (2) Identification with the group (e.g. Aron et al., 1992), (3) Commonality (e.g. Valdesolo & DeSteno, 2011), (4) Liking (e.g. Hove & Risen, 2009), (5) Connection (e.g. Wiltermuth & Heath, 2009), and (6) Emotional Closeness (e.g. Inagaki & Eisenberger, 2013; Inagaki et al., 2019b). The questions are designed such that they can be applicable to any group setting. The questions are as follows:

(1) "At this moment, how connected do you feel to [The Group]?" (adapted from Wiltermuth & Heath, 2009)

(2) "At this moment, how emotionally close do you feel to the other members of [The Group] as a whole?"

(3) "Thinking about everyone in [The Group] now, how much do you trust the others in this group?"

(4) "How much do you like the people in [The Group] overall?" (adapted from Hove & Risen, 2009)

(5) "Thinking about everyone in [The Group] now, do you feel you have a lot in common with others in [The Group]?" (adapted from Valdesolo & DeSteno, 2011).

(6) The last question is the pictorial IOS scale (Aron et al., 1992), already shown in Chapter 2, Figure 2.1.

Each question is measured on a Likert scale, from one (lowest value) to seven (highest value), with each option along the scale providing a verbal prompt (see Figure A1.1.), except for the non-verbal IOS. The use of seven points is, in part, to conform to the already well-established IOS (Aron

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Figure A1.1. The response options for the five verbal questions in the six-item social bonding et al., 1992) format. However, it was also because a seven-point Likert scale leads to a faster completion time than for scales with more points (Matell & Jacoby, 1972), while also leading to a lower proportion of mid-point responses than a five-point Likert scale (Matell & Jacoby, 1972), which allows for the detection of greater nuance. It has also been demonstrated that there is no significant psychometric difference between a six- and seven-point length scale (Simms et al., 2019), and that shorter than six items have lower short-term retest validity, while scales longer than seven items are not significantly more useful (Simms et al., 2019).

In creating this six-item measure I have addressed part of the first secondary aim of the thesis, to create a measure of social bonding that is both comprehensive and concise that can be used across settings. However, when outlining the aims of this thesis, I also noted that the aim was to ensure that the measure was reliable. As this thesis features the first series of studies to contain this six-item measure of social bonding, a factor analysis to demonstrate it measures a unidimensional latent variable of “social bonding” and a validity check are conducted alongside the appropriate reliability analysis for the measure in each of the studies conducted within the thesis. The factor analyses are conducted across each study for two reasons: (1) To confirm that the scale is reliably unidimensional across all the research settings it is used within and (2) it has been recommended that a factor analysis is produced whenever using a scale to check for conditions of appropriate reliability statistics (Charles, 2020; Raykov & Marcoulides, 2019; Raykov et al., 2017). Now that the issue of measuring social bonding has been addressed, the following section of the thesis will focus on the experimental phase.

Appendix 2 – Study 1 Multi-Level Model Information

S1. Data analysis – multi-level models

In this study we have performed -a multi-level model analysis upon the recommendation of peer reviewers. This was not part of the pre-registered analysis plan. The main reason given by the reviewer for the inclusion of a multilevel model analysis is we have data that can vary for each measurement occasion (i.e. either before or after the ritual), for each participant (e.g. age, gender) and ritual site (e.g. country, size of congregation, length of service). This means that the data falls within a multi-level structure best addressed by a multi-level model, also called a linear mixed-effects model. Another option for analysis would have been structural equational modelling (SEM) for latent growth curve modelling (Hox & Stoel, 2005). However, Hedeker & Gibbons (2006) argue that the multi-level approach is more appropriate for data structures such as ours, and it has been suggested that not accounting for multilevel data using an appropriate model can lead to a much higher likelihood of Type I errors (i.e. false positives; Meteyard & Davies, 2020), than if not used. Aarts et al. (2014) have suggested that not using an appropriate model could inflate the error rate to as high as 80%.

Multilevel modelling has grown in prominence in psycholinguistics and some other subfields of psychology, but its use in research looking at ritual is limited. Moreover, due to the varying ways in which such models can be run, it is vital that we are clear on how we conduct the analyses so that others can replicate the findings. As such, we feel it is important to briefly describe how to use and interpret a multilevel model. Magezi (2015) provides a guide on how multilevel models might be used in psychology and Meteyard & Davies (2020) have since provided a best-practice primer on how they should be used.

Multilevel models are akin to multiple regression analyses. However, unlike regression analyses, they allow for measurements to not be completely independent of one another (i.e. auto-correlation is allowed). This is because a single participant being measured more than a single time (i.e. in this study where they are measured once before the ritual and then again after the ritual) will lead to a correlation between their own results. This would be an issue for a regular regression analysis, but is accounted for in a multilevel model. However, the way in which such issues are accounted for means that, unlike traditional regression analyses, multilevel models with hierarchical data do not easily provide an output of a *p*-value for the fixed effects (the effects which are constant across individuals) without a high likelihood of Type I errors (Luke, 2017). This means that, in many cases, *p*-values are not reported at all when conducting multilevel models, and instead model comparisons are created.

A model comparison uses information about the model and compares it to other models, to see which best fits the data. Often this is conducted using an Akaike Information Criterion (AIC; Akaike, 1973) or a Bayesian Information Criterion (BIC, aka in literature as the Schwarz Information Criterion or Schwarz Bayesian Criterion, SIC/SBC; Schwarz, 1978; Stone, 1979), which are considered estimates of parsimony (Aho et al., 2014). An AIC provides a numerical indicator of the ratio between the goodness of fit of the model and the simplicity of the model. The lower the AIC value, the lower the level of information loss, meaning it is a better model (or more likely to be indicative of the true model). However, the absolute value of AIC is not important, only the relative value compared to other models. These can be compared with one another and a likelihood ratio provided. BIC is the Bayesian counterpart to an AIC. Thankfully, most software that allows for analysis using multilevel models provide AIC and BIC values.

Aho et al. (2014) note that there is not a one-size-fits-all rule determining whether an AIC or BIC value is best for model selection, as they serve different purposes: AIC is considered 'asymptotically efficient'. This means that, in a scenario where there are many possible complex models, of the models that were specified, it will determine which model best fits the data. Its use stems from the idea that 'all models are wrong, but some models are useful'. BIC, on the other hand, is 'asymptotically consistent'. This means it is best used when there are a small number of fully specified models (i.e. all possible models are accounted for). It is best used when answering the question "which model is correct?" and is likely best used when conducting experiments in controlled conditions where hypothesis testing can be exhaustive. In short, AIC is best used for exploratory analyses, or data where extraneous variables may play a role, and BIC for confirmatory analyses in cases where *all* possible models can be accounted for. As we will not be able to specify every possible model, due to extraneous variables, we will be using AIC to compare models. Specifically, we will be using the AIC correction (AICc), which is more appropriate for our data size as recommended by Burnham & Anderson (2002, 2004). Comparing models with one another requires that the models be fitted using a maximum likelihood method.

As noted above, obtaining a *p*-value from multilevel model outputs can be difficult, due to ambiguous degrees of freedom. However, Luke (2017) recently suggested that there are ways to minimise Type I errors by using specific fitting methods and degrees of freedom approximations. The best way to get a more reliable *p*-value is to fit the model using a "reduced maximum likelihood" (REML) instead of a maximum likelihood (ML) method, along with the Satterthwaite approximation or Kenward-Roger approximation (Luke, 2017). In the appendix of his article, Luke (2017) provides R code for how to run the approximations to get a *p*-value for fixed effects in the model. However, this step can only be done once random effects structures (effects that vary across participants) have been confirmed using model comparisons (i.e. comparing AIC/AICc/BIC values between models).

S1.1. Power analysis in multi-level models

We have also conducted a multi-level model analysis. The calculation of power for a multi-level model, while possible (Snijders, 2005), is not simple for three-level data. As our level-one variable is a time variable, the three-level longitudinal power analysis method provided by De Jong and colleagues (De Jong et al., 2010) (where measurement occasion is the level-one variable) is appropriate. As shown in figure III in (De Jong et al., 2010), adding more measurement occasions (level-one objects) within a participant (level-two objects) doesn't significantly alter the power of a study. As such, treating two measurement occasions (pre- v.s. post-ritual) as a longitudinal design, for power analysis purposes is appropriate. De Jong and colleagues show, in Figure I and II of their article (De Jong et al., 2010), that the number of level-two objects does affect power: a greater number of level-two objects nested within each level-three object leads to higher power.

As this is the first study to research how pain threshold, synchrony and affect predict social bonding using this type of design, we could not use past data to conduct an *a priori* analysis. Therefore, we have used estimation to conduct the power analysis. Scherbaum and colleagues (Scherbaum & Ferreter, 2009) suggest an intra-class correlation (ICC) between .10 and .15 as a conservative estimate to be used for these purposes (note: the larger the ICC value, the more top-level objects required). In the simulation study conducted by De Jong and colleagues (De Jong et al., 2010), they assumed a large ICC value at the top level (ICC_{level3} = .18) and found that 31 level-three objects would be needed, assuming only 8 level-two objects were nested within each level three object. However, they also note that in other (i.e. non-therapeutic) naturalistic settings lower ICC values are more likely and, as a result, there would be sufficient power with a lower number of level-three objects. De Jong and colleagues (De Jong et al., 2010) note that in another naturalistic setting, with an ICC_{level3} value lower than .18, they calculated that only 17 top-level objects would be required. Though, they do not state at what ICC_{level3} value this would be the case. Given that, for conservative estimates, the top-level ICC value should be between .10 and .15 (Scherbaum & Ferreter, 2009) and that we have, on average, 9.5 participants per ritual site (more than in De Jong et al.'s (De Jong et al., 2010) calculations), 24 ritual sites should be enough to detect an effect.

S2. Model Creation, presentation and description

When creating models to test our hypotheses, due to the vast number of possible models, we initially constrain the models to include only specific variables. These models start from a basic model and progress into more complex models, which can then be compared against each other. The most basic model one can make is measuring whether the dependent variable does change at all. In R script this can be done using the lm function with the following format:

```
require(stats) # the required package to run the lm function
basemodel <- lm(dependent.variable ~1 , data = mydata)
```

This code reads: "perform the lm function, to test whether the dependent variable varies at all (against a constant of 1) where the dependent variable comes from the dataframe labelled mydata. This will produce a basic model, which will have its own AICc value if called for it:

```
require(MuMIn) # A package able to run the AICc function
AICc(basemodel)
```

As noted in the data analysis subsection in the main article, a single AICc value is of no practical use by itself. However, we are then able to specify a more complex model, where we allow for the values of the dependent variable to vary within a participant across timepoints, and then call for an AICc value to compare it to the base model. To do this we need the lmer function from the lme4 package:

```
require(lme4) # A package able to run multilevel models
Model <- lme4::lmer(dependent.variable ~ 1+
                      (1|Participant), data=mydata, REML = F)
AICc(Model)
```

Here, you will notice that we have specified that we do not want the model to be fitted with the REML method (REML = F). This is because, in order to compare models with one another, the ML method is needed. The syntax we have used here is also somewhat different to how the lm function was called above. We have specified the package ahead of the function (lme4::lmer). This is because the Luke (2017) method of calculating p-values from the final model uses the lmer function from a different package, lmerTest.

From this point, we can slowly add fixed or random effects, one by one, to create more and more complex models. These models can then be compared using the anova function from the lavaan package, to provide the $\chi 2$ test for the likelihood ratios. If a model significantly improves the fit of the data in a way that is more parsimonious, this will be represented in the output. Finally, once all of the specified models that relate to a single hypothesis have been created, all models can be compared with one another, and then the Luke (2017) method for determining fixed-effects p-values can be determined:

```
TestModel <- lmerTest::lmer(final.model.structure, data=mydata, REML
= T)
summary(TestModel)
```

This Appendix provides a full output for the comparisons of each of the models designed and compared against one another. We provide AICc values for them, among other important information. The tables showing the model comparisons will take the form shown in Table A2.1. Outputs of the results of the most parsimonious model will take the form shown in Table A2.2.

Table A2.1.

Example table showing how model comparisons will be presented

Model	**LogLiklihood**	**AICc**	**Difference in AICc (cf. most parsimonious)**	df	Weight
Most parsimonious model	Value A	Value B	0	Value C	Value D
...	…	…	…	…	
Least parsimonious model	Value E	Value F	Value F – Value B	Value G	Value H

Note: Weight is calculated as $\frac{e^{(-\frac{AICc_i}{2})}}{\sum_i^N e^{(-\frac{AICc_i}{2})}}$, where i is the individual instance of AICc value, and N is the total number of AICc values.

Table A2.2.

Example table showing how individual model's Fixed Effects results will be shown.

Variable	**Estimate**	**S.E.**	**95% CI**	***t***	***Sig. (p)***
(Constant)	-1.25	(2.d.p)	[C, D]	E (2.d.p)	F (3.d.p)
Variable 1	G (2.d.p)	H (2.d.p)	[I, J]	K (2.d.p)	L (3.d.p)
...	…	…	…	…	…
Variable N	M (2.d.p)	N (2.d.p)	[O, P]	Q (2.d.p)	R (3.d.p)

Note: All final output results were calculated using the Satterthwaite (1941) correction (see Luke, 2017). This is the case for all future tables, though this note will not be repeated in future tables.

S3. Hypothesis 1 – The effect of measurement occasion

Models Specified

```
basemodel <- lm(SB6Z~1 , data = data_long)

Model <- lme4::lmer(SB6Z ~ 1+
        (1|ParticipantID), data=data_long, REML = F) # Allow variance within participants


Model1 <- lme4::lmer(SB6Z ~ Occasion + #fixed effect of pre v.s. post
        (1|ParticipantID), data=data_long, REML = F)
```

```
Model2 <- lme4::lmer(SB6Z ~ Occasion +
        (1|ChurchID/ParticipantID), data=data_long, REML = F) # vary participant within ritual site

Model3 <- lme4::lmer(SB6Z ~ Occasion +
        (1|ParticipantID/ChurchID), data=data_long, REML = F)
```

Table A2.3.

The model comparisons for models that test the hypothesis that social bonding would increase from before to after the ritual

Model	**LogLiklihood**	**AICc**	**Difference in AICc (cf. most parsimonious)**	df	Weight
Model2	-632.2	1274.5	0	5	.998
Model1	-639.7	1287.5	13.1	4	.001
Model3	-639.7	1289.6	15.1	5	< . 001
Model	-663.1	1332.2	57.7	3	< . 001
basemodel	-751.5	1507.1	232.6	2	< . 001

Table A2.4.

Fixed-effects output for Model2 using the Luke (Luke, 2017) method

Variable	Estimate	S.E.	95% CI	*t*	*Sig. (p)*
(Constant)*	-.20	.09	[-.29, -.11]	-2.27	.030
*Pre v.s. Post Ritual****	.31	.04	[.27, .36]	7.13	< .001

S4. Including other predictors as covariates

Models Specified

```
CovbaseModel <- lme4::lmer(SB6Z ~ Occasion +
                (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

CovModel <- lme4::lmer(SB6Z ~ Occasion + Gender +
                (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

CovModel1 <- lme4::lmer(SB6Z ~ Occasion + Gender + AgeC +
                (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

CovModel2 <- lme4::lmer(SB6Z ~ Occasion * Gender + AgeC + # check for interaction between
gender and occasion
                (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
```

```
  CovModel3 <- lme4::lmer(SB6Z ~ Occasion * Gender * AgeC + # check for interaction between gender, occasion and age
                    (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

  CovModel4 <- lme4::lmer(SB6Z ~ Occasion + Gender + AgeC + DataCategory + # check for effect of country
                    (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

  CovModel5 <- lme4::lmer(SB6Z ~ Occasion * Gender * AgeC * DataCategory + # check for interactions
                    (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

  CovModel6 <- lme4::lmer(SB6Z ~ Occasion * DataCategory + Gender + AgeC  + # check for interaction between only country and occasion
                    (1|ChurchID/ParticipantID), data=Covdata_long, REML = F
```

Table A2.5.

The model comparisons for models that test the hypothesis that social bonding would increase from before to after the ritual, including covariates of Gender, Age and Country

Model	**LogLiklihood**	**AICc**	**Difference in AICc (cf. most parsimonious)**	df	Weight
CovModel4	-616.1	1248.4	0	8	.597
CovModel6	-616.1	1250.5	2.1	9	.213
CovbaseModel	-620.9	1252.0	3.5	5	.102
CovModel	-620.5	1253.2	4.8	6	.054
CovModel1	-620.4	1255.1	6.7	7	.022
CovModel2	-620.4	1257.0	8.6	8	.008
CovModel3	-618.2	1258.9	10.4	11	.003
CovModel5	-612.0	1263.6	15.1	19	< .001

Table A2.6.

Fixed-effects output for CovModel4 using the Luke (Luke, 2017) method

Variable	Estimate	S.E.	95% CI	*t*	*Sig. (p)*
(Constant)*	-.72	.24	[-.96, -.48]	-3.00	.030
*Pre v.s. Post Ritual****	.31	.04	[.27, .35]	7.16	< .001
Gender	.11	.11	[-.00, .23]	0.98	.329
Age	.00	.00	[-.00, .01]	0.50	.616
Country**	.52	.17	[.34, .69]	2.98	.005

S5. Hypothesis 2 – Does Pain Threshold Predict Social Bonding

Models Specified

[CovModel4 brought forward]

```
PT_basemodel <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory +
                (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

PT_Model <- lme4::lmer(SB6Z ~ CuffC * Occasion + Gender + AgeC + DataCategory +
                (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
```

```
PT_Model1 <- lme4::lmer(SB6Z ~ CuffC * Occasion + Gender + AgeC + DataCategory *CuffC +
        (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

PT_Model2 <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory *Occasion +
        (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
```

Table A2.7.

The model comparisons for models that test the hypothesis that social bonding would be predicted by pain threshold, including covariates from previous model

Model	**LogLiklihood**	**AICc**	**Difference in AICc (cf. most parsimonious)**	df	Weight
PT_basemodel	-614.0	1246.4	0	9	.432
PT_Model	-613.9	1248.2	1.7	10	.181
CovModel4	-616.1	1248.4	2.0	8	.158
PT_Model2	-614.0	1248.5	2.1	10	.153
PT_Model1	-613.7	1249.9	3.5	1	.075

Table A2.8.

Fixed-effects output for PT_basemodel using the Luke (Luke, 2017) method

Variable	Estimate	S.E.	95% CI	*t*	*Sig. (p)*
(Constant)**	-.76	.24	[-1.00, -.52]	-3.15	.002
Pain Threshold*	.00	.00	[.00, .00]	2.04	.042
*Pre v.s. Post Ritual****	.28	.05	[.24, .33]	6.25	< .001
Gender	.14	.12	[.03, .25]	1.23	.220
Age	.00	.00	[-.00, .01]	0.44	.658
Country**	.52	.18	[.35, .70]	2.99	.004

S6. Including Affect in the model.

Models Specified

Include PANAS+ only, PANAS- only or both?

PANAS_basemodel1 <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory +
PANASPZ+ # Only Positive Affect
(1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

PANAS_basemodel2 <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory + PANASNZ+ # Only Negative Affect

(1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

PANAS_basemodel3 <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory + PANASPZ + PANASNZ+ # Both PANAS subscales

(1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

Basic AICc table

```
#                      logLik AICc   dLogLik dAICc  df weight
#  PANAS_basemodel3 -575.9 1174.4   38.1     0.0 11 1          # <- by far best model
#  PANAS_basemodel1 -588.9 1198.2   25.1    23.9 10 <0.001
#  PANAS_basemodel2 -603.9 1228.3   10.1    53.9 10 <0.001
#  PT_basemodel     -614.0 1246.4    0.0    72.1 9  <0.001
```

Inclusion of both PANAS subscales leads to most parsimonious model, no table necessary

Model variants

PANAS_Model <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory + PANASPZ*PANASNZ+ # check for PANAS interaction

(1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

PANAS_Model1 <- lme4::lmer(SB6Z ~ CuffC * PANASPZ * PANASNZ+ Occasion + Gender + AgeC + DataCategory + # check for PANAS interaction with cuff

(1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

PANAS_Model2 <- lme4::lmer(SB6Z ~ CuffC + DataCategory * PANASPZ + PANASNZ + Occasion + Gender + AgeC + # check for PANAS+ interaction with country

(1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

PANAS_Model3 <- lme4::lmer(SB6Z ~ CuffC + PANASPZ + PANASNZ * DataCategory + Occasion + Gender + AgeC + # check for PANAS- interaction with country

(1|ChurchID/ParticipantID), data=Covdata_long, REML = F)

```
PANAS_Model4 <- lme4::lmer(SB6Z ~ CuffC +  DataCategory + PANASPZ + (PANASPZ * DataCategory)
+ PANASNZ + (PANASNZ * DataCategory) + Occasion + Gender + AgeC  +  # check for both PANAS
subscales interaction with country
                        (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
```

Table A2.9.

The model comparisons for models that test the hypothesis that social bonding would be predicted by pain threshold, including covariates from previous models and PANAS subscales

Model	**LogLiklihood**	**AICc**	**Difference in AICc (cf. most parsimonious)**	df	Weight
PANAS_Model2	-571.5	1167.6	0	12	.706
PANAS_Model4	-571.5	1169.7	2.1	13	.247
PANAS_basemodel3	-575.9	1174.4	6.7	11	.024
PANAS_Model3	-575.7	1175.9	8.3	12	.011
PANAS_Model	-575.9	1176.4	8.8	12	009
PANAS_Model1	-573.6	1178.2	10.6	15	.004

Table A2.10.

Fixed-effects output for PANAS_Model2 using the Luke (Luke, 2017) method

Variable	Estimate	S.E.	95% CI	*t*	*Sig. (p)*
(Constant)	-.45	.23	[-.69, -.22]	-1.95	.052
Pain Threshold*	.00	.00	[.00, .00]	2.37	.018
Country	.31	.18	[.13, .49]	1.71	.090
*Pre v.s. Post Ritual***	.14	.05	[.09, .19]	2.99	.003
*PANAS+****	.59	.10	[.50, .69]	6.20	< .001
*PANAS-****	-.23	.05	[-.27, -.18]	-4.99	< .001
Gender	.13	.10	[.03, .24]	1.26	.210
Age	-.00	.00	[-.00, .00]	-0.14	.890
Country * PANAS+**	-.32	.11	[-.43, -.21]	2.99	.003

S7. Final Model

Models Specified

```
C2G_basemodel <- lme4::lmer(SB6Z ~ CuffC +  DataCategory * PANASPZ + PANASNZ + Occasion + Gender + AgeC +
                              (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
  C2G_Model <- lme4::lmer(SB6Z ~  CuffC + ConnectedGod + DataCategory * PANASPZ + PANASNZ + Occasion + Gender + AgeC +
                  (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)

  C2G_Model1 <- lme4::lmer(SB6Z ~  CuffC + ConnectedGod + RelZ + DataCategory * PANASPZ + PANASNZ + Occasion + Gender + AgeC +
                           (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)

  C2G_Model2 <- lme4::lmer(SB6Z ~  CuffC +  ConnectedGod + RelZ + ServiceAttend_Yrs + DataCategory * PANASPZ + PANASNZ + Occasion + Gender + AgeC +
                           (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)

  C2G_Model3 <- lme4::lmer(SB6Z ~  CuffC +  ConnectedGod * RelZ + ServiceAttend_Yrs + DataCategory * PANASPZ + PANASNZ + Occasion + Gender + AgeC +
                            (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
```

Table A2.11.

The model comparisons for models that test the hypothesis that social bonding would be predicted by pain threshold, including covariates from previous models plus Connection to God and Religiosity.

Model	**LogLiklihood**	**AICc**	**Difference in AICc (cf. most parsimonious)**	df	Weight
C2G_Model1	-487.6	1004.2	0	14	.662
C2G_Model2	-487.6	1006.2	2.1	15	.234
C2G_Model3	-487.4	1008.0	3.8	16	.010
C2G_Model	-493.8	1014.4	10.2	13	004
C2G_basemodel	-502.2	1029.1	25.0	12	<.001

Table A2.12.

Fixed-effects output for C2G_Model1 (the final model presented in the Chapter 3) using the Luke (Luke, 2017) method

Variable	**Estimate**	**S.E.**	**95% CI**	***t***	***Sig. (p)***

(Constant)***	-1.25	.36	[-1.61, -.88]	-3.43	<.001
Pain Threshold**	.00	.00	[.00, .00]	2.90	.004
Country	.35	.19	[.16, .54]	1.84	.070
*Pre v.s. Post Ritual****	.14	.05	[.10, .19]	3.09	< .001
*PANAS+****	.45	.10	[.35, .55]	4.41	< .001
*PANAS-****	-.20	.05	[-.24, -.15]	-4.32	< .001
Connection to God**	.14	.05	[.09, .19]	2.87	.004
Gender	.08	.10	[-.02, .18]	.82	.408
Age	.00	.00	[-.00, .01]	0.96	.34
Religiosity***	.19	.05	[.13, .24]	3.55	< .001
Country * PANAS+*	-.24	.11	[-.35, -.13]	-2.16	.031

S8. Measure of Behavioural synchrony issues

In study one, the plan had been to measure behavioural synchrony in some way. Computing methods, which assess image-based (video-recorded) data to analyse and assess the level of movement synchrony have been used in psychology research. 5 examples include the 2D In-Vivo Behavioural tracking (Halberstadt et al., 2016; Jackson et al., 2017), a 3D oriented-principal components method (Presti & La Cascia, 2016; Rahmani et al., 2014), a Cluster-Phase approach (Frank & Richardson, 2010; Richardson et al., 2012), a robotics method for automatic detection of entrainment (Iqbal et al., 2016; Iqbal & Riek, 2015a, 2015b; Rack et al., 2015) and coarse body-movement analysis (Alborno et al., 2018; Jakubowski et al., 2017). Of these, the first 3 require some extra equipment for participants to wear that we do not have direct access to for this experiment, and that we could not get ethical approval for. The 4th (robotics) method requires the Microsoft KINECT 2.0, which has since been discontinued and also does not have the depth of field needed to work in a church environment. The coarse body-movement analysis method (Alborno et al., 2018) would likely be the best option in terms of practical application. However, at the time of writing, the tools were not available.

I then thought to create a manual method of measuring behavioural synchrony. One method of doing so, was to use two raters to code the data using a combination of event and time sampling. Every 10 seconds of video would be coded for the presence of some form of movement (See table A2.13. for a list of the codes used). Once timestamped, a coder will rate each 10 second segment where there is some form of movement (any code that is not ‘S’ for stationary). They would do this by assigning a value rating between 0 and 10, where 0 indicates that all members of the congregation are completely out of time with each other, doing different behaviours and 10 indicates they are all perfectly in time with one another: These ratings are averaged across the church to give a single, average, synchrony value between 0 and 10 where 0 indicates that all members of the congregation are completely out of time with each other, doing different behaviours and 10 indicates they are all perfectly in time with one another: These ratings would have been averaged across the church to give a single, average, synchrony value between 0 and 10.

Table A2.13.

List of codes used for timestamping events

Code	Action
S	Stationary – Sitting or Standing
St	Moving by standing up or sitting down at
Sig	Singing/chanting/speaking while seated

Stg	Singing/chanting/speaking while standing
M	Movement not otherwise described
D	Dancing (but no singing
Msg	Movement while singing
Mo	Movement occurring, but outside view of camera

To check for inter-rater reliability, Gwet's AC1 (Gwet, 2001; Gwet, 2008) could have been used, because it can be used to measure interval data and because it is able to measure inter-rater reliability without the paradox that can be found in other reliability coefficient methods (Gwet, 2011; Wongpakaran et al., 2013).

This method of measurement ran into multiple issues:

1. The quality of video that came out of the Brazilian ritual sites endued up being of incredibly variable quality. It also included intermittent recording issues, and the camera moved in some instances. This made it impossible to provide such ratings for ritual sites in Brazil.
2. No objective set of items could be agreed upon for how to rate behavioural synchrony out of 10 (i.e., what was the difference between a 4 and 5, or a 5 and a 6 on the scale?).
3. No second rater could be found.

Consequently, only the event sampling method was used, using the codes listed in table A2.13. Where any non-stationary code was used deemed as a time where "synchrony" occurring.

Appendix 3 – Study 1 Pre-Regisrtation

Introduction

Background/Rationale

Religious rituals have been of interest to social scientists for at least the last 100 years (Cnaan & Heist, 2018; Durkheim, 1912; Freud, 1927/1961), in part because of their ubiquity across the globe (Norenzayan, 2010). The universal nature of religious rituals begs the question *why* religious rituals should be so ubiquitous. Evolutionary psychologists oft cite traits that appear universally across humanity and history as ones which likely confer an evolutionary advantage. In the last two to three decades, experimental cognitive science has also begun to systematically examine religion (Lawson & McCauley, 1993). One credible answer to the question of why they should be ubiquitous was brought forward by Dunbar (Dunbar, 2013) as an extension of both the 'brain-opioid theory of social attachment' (BOTSA; Machin & Dunbar, 2011; Panksepp et al., 1978) and the social brain hypothesis (Dunbar, 1998): Religious rituals are ubiquitous because they help encourage the formation and maintenance of social bonds in a way that is more effective and efficient than other mechanisms. Since this proposition, Dunbar (2017b) has highlighted that this question of why religious rituals are universal has yet to be fully investigated in the scientific study of religion and that new research ought to do so.

The Social Brain Hypothesis and BOTSA

The social brain hypothesis proposed by Dunbar (Barton & Dunbar, 1997; Dunbar, 1998), posits that primates' larger than average brains (for their size compared to other mammals; Jerison, 1982) is both caused by and contributes to their ability to socialise. As maintaining a large brain is incredibly energy-intensive, Dunbar argued that this size increase, especially that of the neocortex (Dunbar & Shultz, 2007), must confer an evolutionary advantage - specifically, that it allowed for primates to improve their ability to bond socially and manage these bonds by helping keep track of larger social networks and adapting an understanding of group members' social interactions (Dunbar, 1998; Dunbar & Shultz, 2007). Humans have the largest relative brain size of all primates (Jerison, 1982) and, under Dunbar's hypothesis, this is why humans have the greatest capacity for sociality (Dunbar, 1998). Over the years, this hypothesis has been the subject of much scrutiny (see Powell et al., 2017 for an overview), but there is much evidence to provide strong support for it (Oesch, 2018;

Powell et al., 2012). In humans, Powell et al. (2012) demonstrated that orbito-frontal cortex volume predicts social network size, serving as a within-species example of how neocortex size relates to social behaviour. More generally, Oesch (2018) conducted a wide-ranging literature review, covering primatology, social psychology, comparative animal behaviour, evolutionary anthropology, behavioural endocrinology, social cognitive neuroscience, developmental psychology, and psychopathology, and showed that in each field there was substantive evidence in support of the social brain hypothesis. This body of evidence suggests that sociality is, in some way, evolutionarily adaptive. Examples of evolutionary benefits of sociality include improving efficiency of child-rearing and food collection. While social bonds provide a benefit, maintaining bonds is difficult. Because of this difficulty, primates have created behaviours, such as one-on-one grooming, to foster and maintain these bonds (Matheson & Bernstein, 2000).

To explain how grooming, and similar behaviours, allow primates to foster social bonds, Dunbar re-proposed Panksepp's idea that endogenous opioids are the biochemical mechanism behind the bonding taking place (Machin & Dunbar, 2011; Panksepp, 1986; Panksepp, Bean, et al., 1980; Panksepp et al., 1978; Panksepp, Herman, et al., 1980). BOTSA mentions endogenous opioids in general but Dunbar's formulation of it places a large focus on mu-opioids (Machin & Dunbar, 2011). Support for mu-opioids playing a role in social bonding is mounting, with some major support from neurochemical research in animal models (Kelm-Nelson et al., 2013; Kobayashi et al., 2013; Parra-Gámez et al., 2013) as well as human adult social bonding (Burkett et al., 2011; Resendez et al., 2013). The human body's main mu-opioid receptor agonist (activator) is β-endorphin (βe; see Benarroch, 2012 for a full overview of endogenous opioids).

Much like grooming, Dunbar proposes that humans have developed further behaviours that encourage the release of βe in larger groups of people, thus encouraging bonding in these groups. This has an advantage over grooming behaviours, as they can affect larger groups as opposed to being one-on-one, making it a far more time-efficient way of encouraging bond formation and maintenance. The main behaviours that Dunbar and colleagues have suggested that foster social bonding are synchronised movement, sometimes in the form of music-making (Launay et al., 2016; Pearce et al., 2015; Tarr et al., 2015; Tarr et al., 2014), with other behaviours also being highlighted, such as modest alcohol consumption (Dunbar et al., 2017) and communal eating (Dunbar, 2017a; Jaremka et al., 2017).

Religious rituals, and the relation to BOTSA

To answer the question "why are religious rituals ubiquitous?" Dunbar (2013) has suggested that religious rituals reliably encourage the release of endogenous opioids, specifically βe, to foster the expansion and maintenance of larger social groups in humans. Dunbar (2013; 2017b) suggests that religious rituals foster the release of βe in two ways: (1) By including overtly painful experiences, such as fire walking (Xygalatas et al., 2011; Xygalatas et al., 2013), which encourages the release of βe via the natural pain response. (2) By encouraging the use of social technologies, such as group synchronised movement (Tarr et al., 2015; Tarr et al., 2016) and music making (Pearce et al., 2015; Pearce et al., 2016), which are hypothesised to be a proxy for one-on-one, βe-releasing primate grooming (Dunbar, 2017b, p. 350).

Religious rituals vary quite drastically both within and between religious traditions. The rituals can be as simple as a ritualised meal or a short prayer, such as the Passover Seder or the Shema both from the Jewish tradition, to painful acts such as fire-walking, self-flagellation as seen in the procession of Ashura, or extreme body piercing, as seen in the Thaipusam festival. Despite the wide-ranging behaviours observed in these rituals, both ritual participants and attendees often claim to feel a connection with others there (Fischer & Xygalatas, 2014; Fischer et al., 2014; Frecska & Kulcsar, 1989; Power, 2018; Xygalatas et al., 2011) including in children (Wen et al., 2016) albeit with participants experiencing it to different intensities or in different ways to attendees (Klement et al., 2017; Lee et al., 2016). The feeling of connectedness caused by these rituals may be the result of behaviours during the rituals, many of which have been shown to encourage feelings of bonding or social connection independently, such as eating (Jaremka et al., 2017), moderate levels of alcohol (Dunbar et al., 2017), synchronised movement (Bamford, 2017), music making (Tarr et al., 2014; Weinstein et al., 2016) or pain (Johnson & Dunbar, 2016). Religious rituals may have become ubiquitous by capitalising on these social technologies by integrating them into the rituals to promote social bonding within a meaningful context of joint goals (Wolf et al., 2016). Dunbar (2017b) suggests that this question has yet to be answered in the scientific study of religion and that new research should seek to do so.

Measuring Beta-Endorphin and field research

Whilst experimental evidence for the role of βe in social bonding is mounting (Loseth et al., 2014; Machin & Dunbar, 2011; Pellissier et al., 2018), and the links between music, singing, and synchronous movement – all behaviours that occur in religious rituals - and βe release are also established (Tarr et al., 2015; Tarr et al., 2016; Weinstein et al., 2016), no field research has been conducted to directly test the hypothesis that religious rituals foster social bonding via βe release. This research project seeks to explore the relationship between religious ritual, social bonding, and βe release.

The value of field research in understanding the role of neurotransmitter functions has recently been highlighted by Gangestad & Grebe (2017). Because of this, we believe field research is the next step required to test Dunbar's (2017b) proposed answers to the question of why religious rituals evolved as a human universal. Such field research remains rare (Gangestad & Grebe, 2017), as there is great difficulty in directly measuring βe levels in the field, due to their not passing the blood-brain barrier (Witt & Davis, 2006). However, as βe acts as a natural analgesic (Zubieta, Heitzeg, et al., 2003; Zubieta, Ketter, et al., 2003; Zubieta et al., 2001) pain threshold or pain tolerance have been used as proxy measures for βe release in experimental research (Cohen et al., 2010; Tarr et al., 2015; Tarr et al., 2016). This is especially relevant when not in laboratory settings, as pain threshold measures can be used in the field unlike direct measures of βe levels that require invasive procedures such as a spinal tap.

In the current research, we seek to better understand the psychobiological underpinnings of religious rituals and provide a test for the βe-social bonding hypothesis for the evolution of religious rituals proposed by Dunbar (2017b). We will do so by attending religious services in Christian churches in the United Kingdom, and measuring levels of social bonding and pain threshold as a proxy for βe before and after the services, and we will measure movement synchrony of congregations during the ritual. The measurement of movement synchrony is important as it is one of the key behaviours highlighted by Dunbar (Machin & Dunbar, 2011; Dunbar 2013; 2017b) that religious rituals utilise to act as a large-scale replacement of the one-on-one grooming that takes place in other primate species.

Aims and Hypotheses

The aims of this research are to examine if and how levels of social bonding as experienced by church-goers during religious rituals are linked to movement synchrony and beta-endorphins (as measured via the proxy-measure pain threshold).

Based on previous research, our experimental hypotheses are as follows:

1. Experiencing a religious service together (which will include moving and singing together) will increase both social bondedness measures and pain threshold levels in participants, as measured before and after the service.
2. Participants' ratings of social bonding will be correlated with their change in pain threshold from before to after the service.
3. Participants in church groups that move in higher levels of synchrony will show a greater increase in pain threshold and social bondedness measures after the service compared to before the service than those in churches with lower levels of synchrony.

4. When controlling for the change in pain threshold (i.e. the effect of beta-endorphins), there will no longer be a difference between those in high and low synchrony churches in social bondedness measures.

Method

Participants

Participants will be recruited from Christian churches in the UK as well as Brazil, with the aim to collect data from participants age 18 and over.

Pain threshold data will not be collected for those participants that have diagnoses of arthritis (Kosek & Ordeberg, 2000; Lee et al., 2011; Wessel, 1995), diabetes (Lee & McCarty, 1992; Themistocleous et al., 2016), ADD/ADHD (Stickley et al., 2016; Treister et al., 2015) due to a change in pain perception that is reported in those with those diagnoses. Moreover, questions asking about recent alcohol intake (Horn-Hofmann et al., 2015; Thompson et al., 2017) and pain medication will be used as exclusion criteria after data collection given to the effects alcohol and pain medications have on pain perception.

No effect size of the effect of pain threshold on social bonding could be found in the literature. However, a recent meta-analysis on the effects of synchronous movement by Mogan, et al. (2017) provided an effect size for the link between synchronous movement and perceived social bonding of r = 0.17, SE = 0.03 (95% CI [0.12, 0.23]. Based on the data analysis method, we are required to convert this into an f value to calculate effect size for our *a priori* power analysis. To do this we used the following equation from Cohen (1992, p. 157):

$$f^2 = \frac{R^2}{1 - R^2}$$

In this instance:

$$f = \sqrt{\frac{0.17^2}{1 - 0.17^2}}$$

$$f = 0.173\ (3.s.f)$$

Using an online effect-size conversion calculator to check this calculation (Lenhard & Lenhard, 2016), the same result is reached.

Using this effect size, we calculated the required sample size needed to have a properly-powered study using G*Power (Faul et al., 2007; version 3.1.9.2). A repeated-measures, between-factors MANOVA with an effect size of $f = 0.173$, $\alpha = 0.05$, Power ($1-\beta$) = 0.8 (this is the most commonly used power in biological sciences; McDonald, 2009, p. 34), two groups (low, and high levels of synchrony), 2 measurements (pre- and post- service) and a high level of correlation between the repeated measures (estimated to be 0.7), the calculated total sample size that is required is 226. We approximate that we will get 10-15 participants who volunteer per church visited, so aim to visit 20 churches in total.

Materials

Social Bonding questions

Social bonding will be measured using the Inclusions of Others in Self scale (IOS; Aron et al., 1992), a 7-point scale that uses Venn-diagrams to illustrate how connected one feels with others. The following questions, each measured on a 7-point Likert scale, will also be used:

- At this moment, how connected do you feel to the people in your congregation? (Please tick one).
- At this moment, how emotionally close do you feel to the other members of your congregation as a whole
- Thinking about everyone in your congregation now, how much do you trust the others in this group?
- How much do you like the people in your congregation overall?
- Thinking about everyone in your congregation now, do you feel you have a lot in common with others in this congregation?

A full example of the questionnaire can be found in the supplementary material on the OSF (https://osf.io/gnkp9/). Note, some questions in the questionnaire are a part of a different project being conducted simultaneously by one of the co-authors.

Pain-threshold measure

Pain threshold will be measured by slowly inflating a sphygmomanometer cuff on the participant's upper, non-dominant arm until the participant signifies that they are 'very uncomfortable'. The pressure (in mmHg) that is listed on the sphygmomanometer when a participant signals the experimenter to stop is noted. The pressure is taken before and after the service, with the difference in pressure taken as the change in threshold (ΔPT):

$$\Delta PT = Pressure\ Cuff\ Measure\ After\ Service\ - Pressure\ Cuff\ Measure\ Before\ Service$$

This method of testing will be used over other pain-threshold measurements methods as others tend to test pain tolerance (such as the cold-pressor method and the wall-sit method) rather than pain threshold, and other specific pain-threshold measurements use dolorimeters that are not appropriate for field research, due to their lack of portability. The current measure of pain threshold – the pressure cuff measure - has previously been used in other, similar studies (Cohen et al., 2010; Dunbar, Baron, et al., 2012; Dunbar, Kaskatis, et al., 2012).

The pain threshold measure will be conducted using a manual sphygmomanometer. The exact make and model of the sphygmomanometer being used in this experiment is the ICE Medical Aneroid Sphygmomanometer with 3 cuffs (Item No: IM-AS3). For most participants, the medium-sized cuff will be used. For the very large or small participants, the device is designed so that changing out the cuff is easy, and quick. The same researcher will perform the pressure cuff measure before the service and after the service, to reduce any kind of effect a researcher (e.g. slight individual variation in inflation speed) may have on pain threshold.

Recording Equipment

The church services will be recorded using both a camera and an audio recorder in order to monitor the movement and vocal synchrony of the church congregations. The audio recording device is the TASCAM DR-05 - Linear PCM Recorder, Version 2, and the camera used is a Besteker HDV-Z82, using an AmazonBasics 60-Inch Lightweight Tripod to keep the camera stable during recordings.

Procedure

In advance of the services, congregation members will have been made aware that we will be there, meaning that those who want to volunteer can arrive early to take part in this study. On the day of service, researchers will arrive early to set up video and audio recording devices as well as sphygmomanometers (see https://osf.io/9ebvr/ for the set-up protocol). As congregation members arrive for the service, they will be reminded of our attendance and asked if they would like to take part in our project. A full outline of this procedure can be found on the OSF (https://osf.io/6ndf7/). Once the congregant has agreed to take part and signed the consent form, they take part in the study.

Participants will first be asked to take part in the pressure cuff measure, where the sphygmomanometer will be attached to the participant’s upper non-dominant arm, with the pump line falling above the elbow. The researcher will double-check that the participant understands what to expect after having read about the measure in the participant information sheet. The researcher will then say “I will inflate the cuff slowly. Please, indicate when it becomes *very* uncomfortable by saying 'now'." Once the participant has confirmed they understand, the cuff will be inflated by 10mmHgs^{-1}. Once the participant says 'now', the measurement will be recorded, out of sight of the participant, and the participant will then fill out the pre-service section of the questionnaire. For the full cuff measure protocol please see the protocol on the OSF (https://osf.io/ndv3h/). The service will then take place and be recorded.

After the service, the participant will have the pressure cuff retaken by the same researcher who took it before the service (to keep extraneous variables for this measurement as consistent as possible), and then fill out the post-service section of the questionnaire. Participants will then be partly debriefed about the experiment. However, due to the interconnected nature of church congregations, we cannot fully reveal the purpose of the experiment to participants in case the aims are leaked to other congregations we intend to work with in future. A full debriefing will be sent out once we have finished data collection.

Data Analysis

Synchronous Movement Measurement

To measure level of synchronous movement, video data will be reviewed and coded by author SJC to code for time-sections where the congregation moves or sings. Two raters will then be asked to code these sections of time for level of synchronised movement on a scale of 1-9, where 1 is completely unsynchronised and 9 is perfectly synchronised. These sections will be combined into a single average for the church. An inter-rater reliability check will be performed using Gwet's AC1 (Gwet, 2001; Gwet, 2008), because it can be used to measure interval data and because it is able to measure inter-rater reliability without the paradox that can be found in other reliability coefficient methods (Gwet, 2011; Wongpakaran et al., 2013). If reliability is high, an average synchrony rating for each church will be calculated using each coder's ratings. Scores will be split into two halves, where the lower half will be described as 'low movement synchrony', and the upper half as 'high movement synchrony'. Participants' level of activity will also be noted as a possible confound. Alternative, computing methods of measuring synchrony were considered but ruled out for various reasons. These methods and reasons are listed below:

Computing methods, which assess image-based (video-recorded) data to analyse and assess the level of movement synchrony have been used in psychology research. 5 examples include the 2D In-Vivo Behavioural tracking (Halberstadt et al., 2016; Jackson et al., 2017), a 3D oriented-principal components method (Presti & La Cascia, 2016; Rahmani et al., 2014), a Cluster-Phase approach (Frank & Richardson, 2010; Richardson et al., 2012), a robotics method for automatic detection of entrainment (Iqbal et al., 2016; Iqbal & Riek, 2015a, 2015b; Rack et al., 2015) and coarse body-movement analysis (Alborno et al., 2018; Jakubowski et al., 2017). Of these, the first 3 require some extra equipment for participants to wear that we do not have direct access to for this experiment, and that we could not get ethical approval for. The 4th (robotics) method requires the Microsoft KINECT 2.0, which has since been discontinued and also does not have the depth of field needed to work in a church environment. The coarse body-movement analysis method (Alborno et al., 2018) would likely be the best option in terms of practical application. However, at the time of writing, the tools are not available to the researchers.

Pain Threshold

The sphygmomanometer being used has an upper bound of 300mmHG, which may cause some measurement issues should any participants have particularly high pain threshold for ischemic pain.

The stopping pressure will be measured in mmHg, due to this being the units given on the sphygmomanometer being used. For future studies that may seek to replicate this study using a different measuring tool that uses the international standard (SI) units, 1mmHg = 133.32Pa, such that the upper bound is 39,996.7Pa, or ~40kPa.

Analysis

The multiple questions from the questionnaire on social bonding will be used to create a single 'social bondedness' scale, provided that they reliably measure the same construct as suggested by an omega value (Dunn et al., 2014). An omega value will be used instead of Cronbach's Alpha because of Cronbach's Alpha's over-reliance on assumptions that are often violated in psychological research (Peters, 2014).

A repeated-measures, between-participant MANOVA will be conducted to examine if there is an effect of synchronous movement on pain threshold, and on subjective ratings of social bonding.

Follow-up analysis will be conducted to understand the role of possible covariates.

Conflicts of interest and sources of funding statement

There should be no notable conflicts of interest in the research group, as the team is made up of a mixture of believers, from atheists to practicing theists. The funding for this project comes from the Templeton Religion Trust, a charitable foundation that looks to explore the role of religion on human behaviour. This is a funding body that does not impose hypotheses on its researchers or seek to find specific conclusions from the research it funds.

Ethics Statement

This research was designed in accordance with the regulations of Coventry University, and has been reviewed and approved by the Coventry University Ethics Committee.

Study status statement

This study is part one of three experiments being conducted simultaneously, with extra data being collected for author JEB's research. As a result, some questions not related to this project appear in the questionnaire in the Appendices that are to be used for a separate research question and analysis.

Appendix 4 – Measuring Behavioural Synchrony

There are many ways that one can measure behavioural synchrony via video. Computing methods, which assess image-based (video-recorded) data to analyse and assess the level of synchrony have been used in psychology research in the past. Five examples include (1) the 2D In-Vivo Behavioural tracking (Halberstadt et al., 2016; Jackson et al., 2018), (2) a 3D oriented-principal components method (Presti & La Cascia, 2016; Rahmani et al., 2014), (3) a Cluster-Phase approach (Frank & Richardson, 2010; Richardson et al., 2012), (4) a robotics method for automatic detection of entrainment (Iqbal et al., 2016; Iqbal & Riek, 2015a, 2015b, 2017, 2019) and (5) coarse body-movement analysis (Alborno et al., 2018; Jakubowski et al., 2017). Of these, the first three require some extra equipment for participants to wear that would contravene the ethics board requirements of not interfering with the worship services, which meant I could not get ethical approval for their use. The fourth (robotics) method requires the Microsoft KINECT 2.0 camera, which has since been discontinued. The KINECT 1.0, which is still available, would not be able to conduct the same analysis. Moreover, upon discussion with Dr Iqbal (the creator of the fourth method), and upon analysing the *C++* code that he sent, it was found out that a specific depth of field is needed to work for this method, which is very likely not possible in a religious ritual environment.

Finally, the coarse body movement analysis method (Alborno et al., 2018; Jakubowski et al., 2017) would likely be the best option in terms of practical application due to not requiring wearable sensors nor requiring a specific camera. However, in their article, Jakubowski et al. (2017) note that there were "differences in movement tracking/quantification accuracy" between their datasets because of "differences in the video source material, such as lighting, camera angle, and distance of the performers from the camera." (p.9). In a ritual setting, the distance and the angle from the camera was slightly different for each individual within a ritual group, and was also varied across ritual sites – due to different floor-plans and the differences in sizes of each ritual site. Consequently, this method is likely not appropriate for field research. This issue is further highlighted as lighting differences naturally occur when people occupy different spaces in a room, which would undermine this computer-vision method. It should also be noted that, as with the Jakubowski et al. (2017) method, using a method where biomechanics software (software that can use point detection on a person in a video) to detect motion is used comes with its own issues of distance and angle from the camera, even if manually adding the points of interest. As such, automated methods of measuring group synchrony were not possible. Instead, a manual measure of behavioural synchrony was attempted.

To measure behavioural synchrony, a combination of event and time sampling was used, such that every 10 seconds of video recorded was coded for the presence of some form of movement. See Table A4.1. for a list of the codes used. Once timestamped, I coded each 10 second segment where there is some form of movement (any code that is not ‘S’ for stationary). A value for the level of synchronised behaviour for the group could be created for each ritual site by taking the proportion of time spent stationary as an inverse-proxy for synchronised behaviours.

Table A4.1.

List of codes used for timestamping events

Code	Action
S	Stationary – Sitting or Standing
St	Moving by standing up or sitting down at
Sig	Singing/chanting/speaking while seated
Stg	Singing/chanting/speaking while standing
M	Movement not otherwise described
D	Dancing (but no singing
Msg	Movement while singing
Mo	Movement occurring, but outside view of camera

Another option could be to assign a ‘synchrony value’ rating between 0 and 10, where 0 indicates that all members of the congregation are completely out of time with each other, doing different behaviours and 10 indicates they are all perfectly in time with one another for each 10 second clip: These ratings could then be averaged across the church to give a single, average, synchrony value between 0 and 10. As the video camera only records from behind, it may not be clear how synchronous attendees are when singing but not moving. To assess singing synchrony, I could use the level of 'chorus-reverb' (chorus minus reverb). This is a measure of how on-beat/in time the congregation are with the music and one another without letting the reverb (echo-effect of large spaces) interfere with the judgement. This is also rated on the same 0-10 scale, where 0 is completely out of time with the music/each other with a very large 'chorus-reverb' effect, and 10 denotes they are perfectly in time with very low 'chorus-reverb'. Of these two methods, the first was preferred due to it being far less subjective in nature compared with the 0-10 synchrony rating average score.

Unfortunately, due to technical issues outlined in section 3.1.5., none of the rituals in Brazil could be video coded, and some of the video files for the UK rituals became corrupted, causing the inability to assess video data for three of the UK churches. This left only 10 UK churches that could be assessed in this manner in any way (i.e., including Churches with loss of video data due to intermittent cutting out and early ending of recording), which would not have enough participants within them to conduct an appropriately powered analysis. As such behavioural synchrony was not included in any analyses for this study. Still, the 10 churches that could be coded using the video-coding method (assigned a % score for the amount of time spent stationary, as an inverse-proxy for behavioural synchrony).

Appendix 5 – Study 1 Questionnaire

Religion and the Social Brain survey

In this survey, please tick or circle the answer that applies. Please tick, cross, or circle only one answer per question, unless it is specifically indicated that multiple answers are possible.

Please feel free to ask the researcher(s) who is/are present if you have any questions at any point.

For researchers' use only:

Researcher taking measure:	
Pressure cuff measure before:	
Pressure cuff measure after:	

Before the service

Question 1

This scale consists of a number of words that describe feelings and emotions. Please tick for each feeling/emotion the box that represents the extent to which you feel this way at the moment.

		Not at all	A little	Somewhat	Moderately	Consider-ably	Very much
1.	Interested						
2.	Distressed						
3.	Excited						
4.	Upset						
5.	Strong						
6.	Guilty						
7.	Scared						
8.	Hostile						
9.	Enthusiastic						
10.	Proud						

Question 1 (continued)

This scale consists of a number of words that describe feelings and emotions. Please tick for each feeling/emotion the box that represents the extent to which you feel this way at the moment.

		Not at all	A little	Somewhat	Moderately	Consider-ably	Very much
11.	Irritable						
12.	Alert						
13.	Ashamed						
14.	Inspired						
15.	Nervous						
16.	Determined						
17.	Attentive						
18.	Jittery						
19.	Active						
20.	Afraid						

(The survey continues on the next page, please turn over)

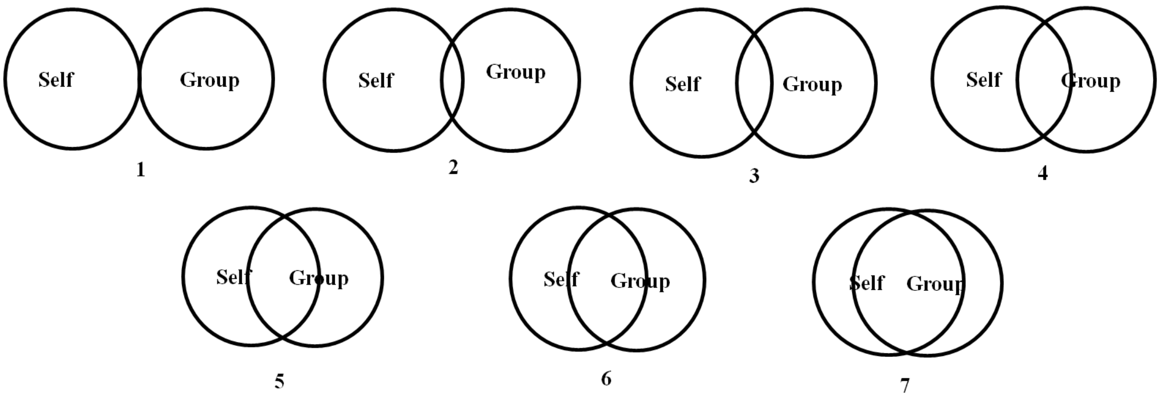
Question 2

<u>At this moment</u>, how connected do you feel to the people in your congregation? (Please tick one).

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 3

Please circle the diagram that best describes your current relationship to your congregation as a whole.



Question 4

At this moment, how emotionally close do you feel to the other members of your congregation as a whole? (Please tick one).

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 5

Thinking about everyone in your congregation now, how much do you trust the others in this group? (Please tick one).

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 6

How much do you like the people in your congregation overall? (Please tick one).

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 7

Thinking about everyone in your congregation now, do you feel you have a lot in common with others in this congregation? (Please tick one).

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 8

How long have you been going to this church for?

__________years_________months

Question 9

How often do you attend church or other religious meetings?

Never (1)	Once a year or less (2)	A few times a year (3)	A few times a month (4)	Once a week (5)	More than once a week (6)

Question 10

How often do you spend time in private religious activities, such as prayer or Bible study?

Rarely or never (1)	A few times a month (2)	Once a week (3)	Two or more times a week (4)	Daily (5)	More than once a day (6)

Question 11

The following section contains 3 statements about religious belief or experience. Please mark the extent to which each statement is true or not true for you.

	Definitely not true (1)	Tends not to be true (2)	Unsure (3)	Tends to be true (4)	Definitely true of me (5)
a. In my life, I experience the presence of the Divine (i.e., God).					
b. My religious beliefs are what really lie behind my whole approach to life.					
c. I try hard to carry my religion over into all other dealings in life					

Question 12

How religious do you consider yourself to be?

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 13

Approximately how many people in this church can you recognise by face?

____________________ person(s)

Question 14

Approximately how many people in this church do you know by name?

____________________ person(s)

Question 15

Are there people who you see at services in the church that you know or recognise?

No (1)	
Yes (2)	

Question 16

Please answer the following question honestly. This information –as all other answers in this survey- will not be linked to your name or identity, but we need this information to ensure our endurance test is appropriate for you as a participant.

	Yes	No or N/A
Are you currently pregnant?		
Do you have arthritis?		
Do you have diabetes?		
Do you have ADHD?		

END OF THE PRE-SERVICE SURVEY

Please let one of the researchers know you're done.

END OF THE PRE-SERVICE SURVEY

Please let one of the researchers know you’re done.

After the service

Question 17

This scale consists of a number of words that describe feelings and emotions. Please tick for each feeling/emotion the box that represents the extent to which you feel this way at the moment.

		Not at all	A little	Somewhat	Moderately	Consider-ably	Very much
1.	Interested						
2.	Distressed						
3.	Excited						
4.	Upset						
5.	Strong						
6.	Guilty						
7.	Scared						
8.	Hostile						
9.	Enthusiastic						
10.	Proud						

Question 17 (continued)

This scale consists of a number of words that describe feelings and emotions. Please tick for each feeling/emotion the box that represents the extent to which you feel this way at the moment.

		Not at all	A little	Somewhat	Moderately	Consider-ably	Very much
11.	Irritable						
12.	Alert						
13.	Ashamed						
14.	Inspired						
15.	Nervous						
16.	Determined						
17.	Attentive						
18.	Jittery						
19.	Active						
20.	Afraid						

Question 18

During today's service, did you feel connected to God, Jesus and/or the Holy Spirit?

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

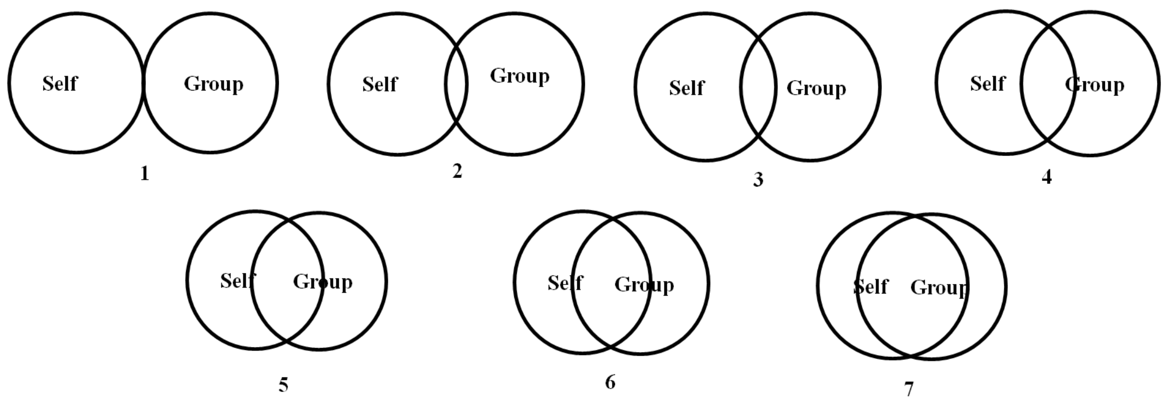
Question 19

At this moment, how connected do you feel to the people in your congregation? (Please tick one).

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 20

Please circle the diagram that best describes your current relationship to your congregation as a whole.



Question 21

At this moment, how emotionally close do you feel to the other members of your congregation as a whole? (Please tick one).

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 22

Thinking about everyone in your congregation now, how much do you trust the others in this group? (Please tick one).

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 23

How much do you like the people in your congregation overall? (Please tick one).

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 24

Thinking about everyone in your congregation now, do you feel you have a lot in common with others in this congregation? (Please tick one).

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 25

Approximately how many people that you know by <u>name</u> attended the service today?

0 persons	<5 persons	5-10 persons	10-20 persons	20-30 persons	30-40 persons	40-50 persons	>50 persons

Question 26

Approximately how many people that you know by <u>face</u> attended the service today?

0 persons	<5 persons	5-10 persons	10-20 persons	20-30 persons	30-40 persons	40-50 persons	>50 persons

Question 27

Approximately what proportion of your total friends go to the same church as you do?

None (0%)	A few (<10%)	Some (10-25%)	Almost half to a half (25-50%)	Half to most (50-75%)	Most to nearly all (75%-95%)	All (100%)

Question 28

What is your gender?

Male (1)	
Female (2)	

Question 29

How old are you?

____________________years

Question 30

How much have you exercised in the past 12 hours?

Not at all (1)	Very slightly (2)	A little (3)	Moderately (4)	Quite a bit (5)	Very much (6)	Extremely (7)

Question 31

How much alcohol have you drunk in past 6 hours (not including communion wine)?

Not at all (1)	A very slight amount (2)	A little (3)	A moderate amount (4)	Quite a bit (5)	Very much (6)	An extreme amount (7)

Question 32

Have you taken any pain medication in the past 12 hours? If yes, please specify in as much detail as possible, such as brand/type and quantity/grams.

No	**Yes** – *please specify as much as possible*

The next questions ask how you feel about your life, your identity, your quality of life and health. Please read each question, assess your feelings, and select the best answer for you.

.

Question 33

Please rate the importance of the following values as a life-guiding principle for you.

		Opposed to my principles	Not important	Important			Extremely important	Of supreme importance
		-1	0	1	2	3	4	5
1	POWER (social power, authority, wealth)							
2	ACHIEVEMENT (success, capability, ambition, influence on people and events)							
3	HEDONISM (gratification of desires, enjoyment in life, self-indulgence)							
4	STIMULATION (daring, a varied and							

	challenging life, an exciting life)							
5	SELF-DIRECTION (creativity, freedom, curiosity, independence, choosing one’s own goals)							

Question 33 (continued)

Please rate the importance of the following values as a life-guiding principle for you.

		Opposed to my principles	Not important	Important			Extremely important	Of supreme importance
		-1	0	1	2	3	4	5
6	UNIVERSALISM (broad-mindedness, beauty of nature and arts, social justice, a world at peace, equality, wisdom, unity with nature, environmental protection)							
7	BENEVOLENCE (helpfulness, honesty, forgiveness, loyalty, responsibility)							
8	TRADITION (respect for tradition, humbleness, accepting							

	one’s portion in life, devotion, modesty)							
9	CONFORMITY (obedience, honouring parents and elders, self-discipline, politeness)							
10	SECURITY (national security, family security, social order, cleanliness, reciprocation of favours)							

Question 34

How important are the following issues to you personally?

		Not at all important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)
1	A close relationship with God					
2	A strong sense of community					
3	Animal welfare and animal rights					
4	Being a good neighbour					
5	Being welcoming and inclusive					
6	Care for the environment					
7	Fair and equal treatment of all people					
8	Helping the poor					

9	Honesty					
10	Interventions in human reproduction					
11	Sexual morality					
12	Telling others about your beliefs					

Question 35

How would you rate your quality of life?

Very poor (1)	Poor (2)	Neither poor nor good (3)	Good (4)	Very good (5)

Question 36

How satisfied are you with your health?

Very dissatisfied (1)	Dissatisfied (2)	Neither satisfied nor dissatisfied (3)	Satisfied (4)	Very satisfied (5)

Question 37

The following questions ask about how much you have experienced certain things in the last two weeks.

		Not at all (1)	**A little (2)**	**A moderate amount (3)**	**Very much (4)**	**An extreme amount (5)**

1	To what extent do you feel that physical pain prevents you from doing what you need to do?					
2	How much do you need any medical treatment to function in your daily life?					
3	How much do you enjoy life?					
4	To what extent do you feel your life to be meaningful?					
5	How well are you able to concentrate?					
6	How safe do you feel in your daily life?					
7	How healthy is your physical environment?					

Question 38

The following questions ask about how you experience or were able to do certain things in the last two weeks.

		Not at all (1)	**A little (2)**	**Moderately (3)**	**Mostly (4)**	**Completely (5)**
1	Do you have enough energy for everyday life?					

2	Are you able to accept your bodily appearance?					
3	Have you enough money to meet your needs?					
4	How available to you is the information that you need in your day-to-day life?					
5	To what extent do you have the opportunity for leisure activities?					

Question 39

How well are you able to get around?

Very poorly (1)	Poorly (2)	Neither poorly nor well (3)	Well (4)	Very well (5)

Question 40

The following question refers to how often you have felt or experienced certain things in the last two weeks: How often do you have negative feelings such as blue mood, despair, anxiety, depression?

Never (1)	Seldom (2)	Quite often (3)	Very often (4)	Always (5)

Question 41

The following questions ask you to say how good or satisfied you have felt about various aspects of your life over the last two weeks.

		Very dis-satisfied (1)	Dis-satisfied (2)	Neither satisfied nor dis-satisfied (3)	Satisfied (4)	Very satisfied (5)
1	How satisfied are you with your sleep?					
2	How satisfied are you with your ability to perform your daily living activities?					
3	How satisfied are you with your capacity for work?					
4	How satisfied are you with yourself?					
5	How satisfied are you with your personal relationships?					
6	How satisfied are you with your sex life?					

7	How satisfied are you with the support you get from your friends?					
8	How satisfied are you with the conditions of your living place?					
9	How satisfied are you with your access to health services?					
10	How satisfied are you with your transport?					

Question 42

How similar do you think that your moral values are to the values of others in your church congregation?

Very dissimilar (1)	Somewhat dissimilar (2)	Neither similar nor dissimilar (3)	Somewhat similar (4)	Very similar (5)

Question 43

Please indicate from the following the highest educational level you have attained:

No qualifications	
GCSE/O-level or equivalent	
A-Level/high school diploma or equivalent	
Technical/vocational qualification	
Foundation Degree/Associate's Degree or equivalent	
Bachelor's Degree	
Master's Degree	
Doctorate	

END OF THE SURVEY

Please let one of the researchers know you're done.

Appendix 6 – Pain Measure Evaluations

A6.1. Why study 1 used pain threshold

Pain is linked to opioid activation, which is shown across a robust literature on pain (see Fillingim et al., 2005; Hagelberg et al 2012; Huang et al., 2008; Kialka et al., 2016; Nickel et al., 2018). In their articles, Fillingim et al. (2005) and Huang et al (2008) demonstrate that pressure pain threshold is related to variations in the human mu-opioid gene OPRM1. This provides direct evidence of the relationship between pain threshold and mu-opioid expression. Kialka et al. (2016) showed that pressure pain threshold and serum beta-endorphin (the most abundant endogenous mu-opioid agonist) levels were both elevated in pregnant PCOS women. They conclude that circulating plasma β- endorphins concentration can increase pressure pain threshold. Hagelberg et al. (2012) used PET scanning to demonstrate that pain threshold was related to striatal mu-opioid receptor availability. Finally, Nickel et al. (2018) demonstrated that pain threshold is related to use of opioids for pain relief (suggesting a link between pain threshold and opioid activation). In their article, Nickel et al. (2018) used a very similar technique to that used in study 1, wherein they slowly increased pressure and stopped only when the participant said to stop. Moreover. there is ample evidence that opioid receptor activation leads to analgesia (see Sun et al., 2020, Lau et al., 2020 and Stein, 2020 for examples published within the last year, let alone the previous several decades worth of literature showing the same). As such, the pain experience has been used as a proxy measure for central opioid receptor activation for over a decade (Cohen et al., 2010). This comes in two main forms: Pain tolerance (Johnson & Dunbar, 2016) and pain threshold (Dunbar, Baron, et al., 2012).

Pain threshold marks the onset of the pain experience. Pain tolerance is one's ability to withstand pain over time. Examples of pain threshold measures are varied. It can include anything from inflating a sphygmomanometer slowly, as used in this thesis, or slowly increasing a heat stimulus until it is deemed painful to using a dolorimeter to explicitly measure the onset of pain using pressure. Pain tolerance can be measured using a wall-sit test, as in this thesis, or using the cold-pressor method. Tolerance can be measured in many ways by providing any known painful stimulus (heat, cold, electricity, pressure), and determine either how long one can sustain (tolerate) the pain for, or the upper limit one is willing to take the stimulus.

In a religious ritual environment, there are various issues with using each of the pain tolerance methods:

- Wall-sit

  - Different ritual sites will have different configurations. If there is no location to have an appropriate amount of space for someone to complete the wall-sit, or if the walls of a church are not completely flat, this will cause issues in taking the measure.
  - The wall-sit is very demanding on the hips and knee joints of those who do it. As participants at religious rituals are older than the average population (especially in the UK), this population is more likely to suffer with some kind of hip or joint issue, making the measure automatically exclude potential participants
- Cold-Pressor method
  - Using an ice bath to test pain tolerance, while a well-known method, comes with major issues outside of controlled conditions. In fieldwork, the temperature of the ice bath would be at its highest before the ritual (making it a more extreme noxious stimulus), compared to after an hour of ritual. It is not possible that one could ensure the ice bath maintains a consistent temperature in all ritual locations, making the measure unreliable in such settings.
  - As many ritual sites in both the UK and Brazil do not have any kind of central heating or air conditioning system, the ambient temperature of the room may affect one's perception of the cold-pressor stimuli: If, at the start of the service at 8:30am there was an ambient temperature of 8°C (e.g., in Winter), but after the ritual, close to 9:30 or 10:00am, it had become warmer, say 12°C, this would mean that, even if the issue listed above could be addressed, that the relative temperature of the participant to the ice bath would not be the same, making the measure unreliable
- Heat-based pain.
  - Sustained use of a hot stimulus may lead to the potential for burning, especially in older participants.

It is for these reasons, among others, that pain tolerance measures were not used in the religious ritual setting.

A6.2. Why might there be a difference in study 1 and study 3 results.

One of the major reasons that there may be a difference between the results of study 1 (using pain threshold) and study 3 (using pain tolerance) could be that there is a clear distinction between pain tolerance and pain threshold in the pain literature (see Gelfand, 1964 for research showing this as early as the 1960s). As such, there may be different mechanisms at play, or the opioid activation needed to make a difference in pain threshold may be different to that needed for pain tolerance.

While past research has found a link between pain tolerance and social bonding (Johnson & Dunbar, 2016), the vast majority of the work linking pain to social bonding uses pain threshold (Dunbar, Baron, et al., 2012; Dunbar et al., 2016; Lewis & Sullivan, 2018; Tarr et al., 2015; Weinstein et al., 2016). As much of the work linking pain to μ-opioids comes from measures of pain threshold (see Fillingim et al., 2005; Hagelberg et al 2012; Huang et al., 2008; Kialka et al., 2016; Nickel et al., 2018), not pain tolerance, it is possible that pain threshold is a more appropriate measure to assess the role of μ-opioids activation on social bonding outcomes.

Appendix 7 – Pressure Cuff Protocol

Steps for protocol:

1. Exclusion procedure:
    a. Give participants the exclusion list.
    b. Ask if they would answer 'yes' once or more to any of the questions.
    c. If 'yes', DO NOT do the pressure cuff measure.
    d. If 'no', proceed.
2. Preparation:
    a. Ask the participant to sit down.
    b. Ask them to remove any thick jersey/coat, so that their upper arm is bare.
    c. Tell them you will be putting on the cuff so they are not alarmed by you touching them.
3. Placing the cuff:
    a. Place the cuff on their upper non-dominant arm, DIRECTLY ONTO THEIR SKIN.
    b. The participant's arm should be resting on the table, with their hand upturned, at a relaxed natural angle (i.e. the elbow should be bent, on the table).
    c. Make sure that the cuff is two fingers above the crease at the elbow joint in the inside of their arm.
    d. Make sure that the cuff is snug – you shouldn't be able to put a finger between the cuff and the participant's arm.
    e. Make sure that the two tubes are going along their forearm, in the middle.
    f. Make sure that you can see the gage, but the participant can't.
    g. Once the cuff is strapped on check that the valve is closed.
4. Inflating the cuff:
    a. Tell them: "**I will inflate the cuff slowly/gently. Please, indicate when it becomes *<u>very</u>* uncomfortable by saying 'now'.**"*
    b. Then inflate the cuff gently at 10mg at a time (not too much at once!).

c. Keep the time between each inflation of the cuff constant.

d. Watch the gage constantly.

e. Make sure that you can see the gage, but the participant can't.

f. When they say 'now' or you reach 300mg, the highest amount possible on the gage, note the value on the gage in your head and release the valve.

5. Ask the participant to unstrap the cuff while you discretely record the value.

   a. The participant should unstrap the cuff, as this reduced the amount of time an RA is in contact with a participant, reducing health and safety issues.

Notes:

- We are calling it the pressure cuff test. Please stick to exactly this phrasing at all points.

- Sometimes the participant requests more information, e.g. by asking what we mean by 'very uncomfortable'. If they do so, merely repeat the instructions, emphasising that it is up to them to assess when it becomes very uncomfortable for them.

- Note that we are not measuring their blood pressure, and if they ask we can tell them we measure "when it becomes very uncomfortable" (We should refrain from saying we measure 'comfort' as we don't want them to stop when it becomes slightly uncomfortable, which they then may think is the goal).

Appendix 8 – Study 1 Participant Information Sheet

Thank you for your interest in our research. Participating in this study will involve completing a number of questionnaires on connectedness to others and positive and negative emotions, and a pressure cuff test. The aim of this study is to increase our understanding of religious rituals, and its role in religious communities.

This project is being carried out by a team of researchers at the Centre for Advances in Behavioural Science at Coventry University, in collaboration with the University of Oxford. This team consists out of Dr Valerie van Mulukom, Sarah Charles, Rev. Jennifer Brown, and Principal Investigator Dr Miguel Farias. The research team at the University of Oxford consists out of Dr Joseph Watts and Professor Robin Dunbar. Thank you for taking the time to read this information sheet.

It is important to read this page carefully so that you can make an informed decision about whether you would like to participate.

Purpose of the research: We are interested in studying religious rituals and their effects. We are investigating several aspects of religious rituals and communities, including emotions, social relations, and morality. This study will allow us to better understand the role of rituals in religious communities.

Your rights as a participant: Participation in this study is entirely voluntary. Even if you choose to participate, you can change your mind at any time without giving a reason and without any negative consequences. After your participation is completed you will still have the right to request that your data be withdrawn from the study for up to two weeks after your participation. If you have any questions about the research you would like to clarify before participating you can ask us now or send us a letter or e-mail later (details below).

Procedure: Immediately before and after your religious activity, you will answer a few questions about your feelings of connectedness to others in your congregation, levels of emotions you may be experiencing, your standpoint on several moral values, as well as a few additional demographic questions. In addition, you will complete a pressure cuff test (please see below).

Risks and discomforts: In this study, you will be completing a questionnaire, which should not cause any discomfort. You will also be completing a pressure cuff test. In the test, a blood pressure cuff will be placed on your non-dominant arm, above the elbow, to induce ischaemic discomfort, to measure endurance. Pressure will be increased at a rate of 10 mm Hg s-1 by gentle pumping and you will be asked to indicate the point at which you feel discomfort by saying ‘now’. The cuff will then be deflated immediately.

While this task involves discomfort, you may stop the test as soon as you decide you do not want to endure any discomfort any longer. After a small break you should experience no further discomfort, and there are no lasting effects of this task.

Confidentiality, anonymity and data storage: Nobody except for authorised researchers will be allowed to see your answers, and all data collected will be stored in a secure database. Furthermore, the personal details supplied when providing consent will not be used to identify your data. The data will be used in various publications, but any personal details will be removed. All anonymous data, including computer files, will be kept for a minimum of five years to allow for publication and future re-analysis.

Results: The answers that you provide will be anonymised and will only be available to researchers on this project. The results may be published as journal articles or other published work and may also be used in conference presentations. The use of the data from this study will not allow any of the participants to be individually identified.

Ethics approval: This research was designed in accordance with the regulations of Coventry University, and has been reviewed and approved by the Coventry University Ethics Committee. If you have a concern about any aspect of this project, please contact us using the details provided, and we will do our best to answer your query.

Researcher contact details: We appreciate the time you have taken to read this invitation. If you have any further queries, please ask us now, or contact us by e-mail or mail:

Dr Valerie van Mulukom

Coventry University

Faculty of Health and Life Sciences

Centre for Advances in Behavioural Science

Richard Crossman Building

Gosford Street

Coventry CV1 2HF

United Kingdom

E-mail: ac2492@coventry.ac.uk

Appendix 9 – Study 1 Consent Form

Informed Consent Form

Please select YES or NO for each of the following statements to indicate your consent to participating in this study:

I am currently 18 years old or over.	Yes / No
I have read and understood the participant information sheet of this study, and have had the opportunity to ask questions.	Yes / No
I take part in this study voluntarily, and understand I have the right to not take part at any time, and/or withdraw or remove my data from the study (for up to two weeks after the study finishes).	Yes / No
I understand that any information I provide will remain confidential, and will not be used to identify responses.	Yes / No
I agree to voluntarily take part in the research project.	Yes / No

Name: ____________________________________ Date:___________________

Signature:_________________________________

Appendix 10 – Study 1 Recruitment Script and Letter

A10.1. – Phone Script

Hi, 'I'm Sarah Charles, calling on behalf of the Brain, Belief, and Behaviour *group* at Coventry University. Am I talking to [X]?

[response]

[*the following section should be said slowly so that they can follow easily*]

Excellent. I am calling as we (Coventry University) are conducting research in collaboration with the University of Oxford exploring the positive effects of religious services on church members, and we are wondering if your Church would be interested in collaborating. Could I tell you a bit more about the research and the research team?

[response]

This research investigates how *bonded* or *connected* members of the congregation feel with other members of the congregation before and after religious services. Previous research has shown that activities such as religious services may facilitate these feelings of connection.

Our research team, which consist of five researchers from Coventry University and the University of Oxford, would like to come along to one of your church services, to conduct the following study:

- We would like to audio- and video-record the church service
- We would like to give volunteers in the congregation a survey and an endurance test.

[*The phrase 'endurance test' may cause alarm. Allow time for questions/response and put them at ease to ensure they understand that it is not a strenuous activity – this is an opportunity to build rapport*]

Let me explain these aspects to you in a bit more detail.

We would like to video, and audio record the church service. The video recording will be used to investigate how the congregation members interact with one another. We will also place an audio-recording device at the front of the church to record the sermon and hymns of that day.

We will set up the camera at the back of the church so that only the back of the heads of church members will be recorded, to preserve the church members' privacy. Note that, regardless, the recordings will only be shown to the members of our research team, and footage will never be shown to people other than researchers. Similarly, the audio recording will only be listened to by authorised researchers of our team.

[*emphasise*] Importantly, please note that our research aims to not interrupt the service in any way; we merely wish to record the service. We will ensure that there will be sections that are not captured on video, should people wish to not be filmed.

We would also like to ask for volunteers among the church members to complete a short questionnaire both before and after the service.

No one is obliged to volunteer. Even if the church agrees to participate in our study, on the day participation by any single congregation member will still be completely voluntary.

The survey aims to gather some of the important information about your church members' perceptions of their emotions and social connections before and after the service. All of this information is anonymous – no names will be written on the surveys - so that no one can be identified in any way from the surveys.

Finally, we will conduct a short endurance test before and after the service with the volunteer, which should take no more than a few minutes. Based on previous research, we think that levels of endurance may be improved by religious services.

a. Explain what: For the endurance test, we will use a pressure cuff, much like one to take blood pressure, to record a pressure value.
b. If asked re pay: We will not be paying church members for volunteering.

This is a highly ambitious project that will look at hundreds of individuals across different religious groups and different countries, and we would like to ask your collaboration to undertake part of this research within your religious community.

[At this stage they will probably ask questions regarding the nature of the research, the aims of the research etc.]

The aim of the research is to better understand how it is that religious rituals have a positive effect on the congregation.

[At this stage they may ask questions.]

All the data will be anonymous and all findings will be made available to your church once published if your church is interested in this - you could make use of this to demonstrate the benefits of religious services. There will be an opportunity to express this interest.

I understand that talking on the phone is not a very practical way to arrange anything like this. Could we perhaps organise a meeting to discuss this further, where we can provide more detailed information?

[Answer any questions]

If they say yes:

Fantastic, I will send a short information sheet in the post/via email [whichever they prefer] in advance of our meeting, with the information from today's phone call, as well as contact information.

Note that participation is not binding in any way - you are free at any point to say that your Church would rather not participate.

Thank you for your time.

A10.2. – Letter to Churches

We are undertaking research into the positive effects of religious activities. This is an ambitious world-leading project that will look at thousands of individuals across different religious groups and countries, in collaboration with the University of Oxford.

We would like to ask your collaboration to undertake research within your religious community. For our project, a group of five of our researchers would like to come along to one of your religious activities, such as a church service, and to video record it. In addition, we would like to provide those church members who are interested in participating with a brief questionnaire with questions about how close they feel to other members and the emotions they are feeling. Finally, we would also ask those volunteers to participate in a brief endurance test. Participation is entirely voluntary – no one has to participate if they do not want to - and individuals are free to stop their participation at any time, without giving a reason.

In very practical terms, we are asking your consent to allow us do (i) an audio and video recording of a church service, (ii) and to approach church members before the service to ask if they would like to participate in our study (i.e., questionnaire and endurance test).

The audio and video recorders will be set up at the back of the church, so that the faces of church members will not be visible (except for the ministers presiding to the service). Moreover, we will leave dedicated spaces outside of the view of the camera where church members who wish to not be recorded may sit. We will announce where these spaces will be in advance, and designate them with small signs on the day of the recording.

The recordings will be used for research purposes only, and will not be viewed by anyone other than our research team. To be clear: these recordings will not be used to identify any individuals, or to evaluate church or service leaders, but rather to observe patterns of group behaviours - only. The audio and video recorders will be set up in such a way that they will not interfere with the church service.

Your participation in our project will increase our understanding of the role of religion in creating a sense of social belonging and well-being. We also hope that it will be an interesting and engaging experience for your church members, which will allow them to reflect upon and value their role in their religious community.

We very much hope you will consider being part of our research project. We will provide copies of the final published report of the study to all participating churches.

If you have any questions please do not hesitate to contact us by e-mail or mail.

Yours sincerely,

Dr Valerie van Mulukom, Sarah Charles, and Dr Miguel Farias

Coventry University

Faculty of Health and Life Sciences

Centre for Advances in Behavioural Science

Richard Crossman Building, Gosford Street, Coventry CV1 2HF

E-mail: valerie.vanmulukom@coventry.ac.uk

Study information

Purpose of the research: We are interested in studying religious rituals and their effects. We are investigating several aspects of religious rituals and communities, including emotions and social relations. This study will allow us to better understand the role of rituals in religious communities.

Rights of the participants: We hope that some church members will participate in our questionnaire before and after the service. Participation is entirely voluntary. Even if a church member chooses to participate, they can change their mind at any time without giving a reason and without any negative consequences. After their participation is completed they will still have the right to request that their data be withdrawn from the study for up to two weeks after the study finishes.

Procedure: Immediately before and after the religious service, the participant will answer a few questions about their feelings of connectedness to others in their congregation as well as a few additional demographic questions. In addition, they will rate levels of emotions they may be experiencing, and complete an endurance test.

Risks and discomforts: In this study, the participants will be completing a questionnaire and an endurance test. The questionnaire should not cause any discomfort. In the endurance test, a blood pressure cuff will be placed on the participant's non-dominant arm, above the elbow, to induce ischaemic discomfort, to measure endurance. Pressure will be increased at a rate of 10 mm Hg s^{-1} by gentle pumping and participants will be instructed to indicate the point at which they feel discomfort by saying 'now'. The cuff will then be deflated immediately. While this task involves discomfort, the participant may stop the test as soon as they decide they do not want to endure any discomfort any longer. There are no lasting effects of this task, and after a small break they should experience no further discomfort.

Confidentiality, anonymity and data storage: Nobody except for authorized researchers will be allowed to see the participants' answers, and all data collected will be stored in a secure database. The data will be used in various publications but any personal details will be removed. All anonymous data, including computer files, will be kept for a minimum of five years to allow for publication and future re-analysis. The consent forms will be kept in a separate, secure storage space, and any personal details supplied when providing consent will not be used in the research, nor to identify any participant's data.

Ethics approval: This research was designed in accordance with the regulations of Coventry University, and has been reviewed and approved by the Coventry University Ethics Committee. If the participant or church or service leader has a concern about any aspect of this project, please contact us using the details provided, and we will do our best to answer the query.

Disclosure. This project is funded by the Templeton Religious Trust (grant TRT0153).

Appendix 11 – Visual Representation of Ritual Site Recruitment

This appendix provides a visual flow-chart of the ritual site recruitment process. Figure A11.1. Shows the full process. However, the resolution on the flow diagram is low, and so figures A11.2 and A11.3 show the process broken up into the first half (the first six columns) and the second half (the second seven columns)

Figure A11.1. A visual representation, in the form of a flow-chart, of the ritual site recruitment process used for Study 1. (The word ‘churche’ was used instead of ‘ritual site’ in the figure for space-saving purposes)

Figure A11.2. The first six columns of the flow-chart shown in figure A11.1. This shows the first attempts at contacting ritual sites (the word churches was used for space-saving purposes in the figure).

Figure A11.3. The last seven columns of the flow-chart shown in figure A11.1. This shows the process after successfully making initial contact with ritual sites (the word churches was used for space-saving purposes in the figure)

Appendix 12 – Study 1 Set Up Protocol

Set-up before the service and surveys:

6. Camera:
    a. Place the camera in the back and the centre of the church.
    b. Check with the pastor/church contact if this placement of the camera is alright.
    c. If possible, use an elevated position for the camera, so it will have a better field of view
    d. Ensure the tripod legs are fully extended and secure and check for the field of view on the camera to make sure nothing is obscuring the view of the pews.
7. Dictaphone:
    a. Place the Dictaphone in an appropriate location near the pulpit.
    b. Ensure it has the batteries in (they are removed at the end of each session).
8. Table(s):
    a. We will be bringing at least 1 portable table with us. The church may provide other tables. Set these up in a different room to the main service, if possible.
    b. Where not possible, have this table set up to the side and back of the congregation hall, to ensure it is not in the way.
9. Questionnaires.
    a. Place questionnaires on the table, along with pens, ready to be filled out by congregants.
    b. A set of questionnaires should be prepared in advance of congregants' arrival onto clipboards to be filled out, in case space on the table(s) is limited.
10. Items
    a. Give all research team members their <u>name badge</u>.
    b. Keep <u>participant numbers</u> within reach of all present researchers.
    c. Have <u>post-its</u> within reach of research team members.

After set-up but before surveys and service:

1. Take photos:
    a. Of the church (before members arrive)
    b. Of the camera position (from different sides)
    c. Of the Dictaphone position
    d. Of the survey table position
2. Take a still shot with the camera (its view before members arrive)

After/during surveys, just before the service:

1. Turn on the Dictaphone
2. Turn on the camera

Directly after service but before surveys:

1. Turn off the camera
2. Turn off the Dictaphone

After each service:

1. Download files and back-up in multiple locations:
    a. Video file (camera)
    b. Audio file (Dictaphone)
2. Input data from questionnaires into password protected file and send round to the research team.

Appendix 13 – Study 1 participant interaction protocol

Steps for pre-service protocol:

11. Approaching Congregants:
    a. When approaching congregants, do so with a smile and say
    "Hi, I'm "***XYZ***" from Coventry University. Would you be able to take a few minutes before and after the service to take part in our research?"
    b. They will likely ask further questions. When answering these, it is often best to tell them that we are "looking at the effects of religious worship on congregation members" and nothing more.
    c. If they then ask for more information, mention that there is an information sheet with further information and guide them towards the table with information sheets/consent forms/questionnaires on them, so they can read these should they want more information before taking part.
        i. This subtle motion towards the table will allow for a slightly faster initiation of the research, which will save us valuable time.
    d. Ensure all participants you ask are aged 18 or over.
12. Once congregant sits down:
    a. Explain in a bit more detail what the research entails
        i. Pre- and post-service questionnaires
        ii. Pre- and post-service "**Pressure cuff measure**" (Use this exact wording)
            1. *Avoid any mention of '**Pain**' or '**Threshold**'.*
    b. Do ***NOT*** proceed until the congregant has completed the entire consent form.

i. Ensure all the sections are circled with 'YES'
ii. Ensure it has been named and signed

13. Once congregant signs consent form:
    a. 'Congregant' now becomes 'participant'
    b. Provide them with a participant number
    c. Write he participant number on their information sheet, along with the church number (e.g. XX01)
    d. Mention that they should keep the information sheet.
    e. Follow pressure cuff protocol.

Steps for in-service protocol:

1. Do not sit in the centre of the pews
    a. This is to ensure we are out of camera shot
2. Do not act in an unusual manner
    a. Jen (and possibly Miguel) have experience in churches, and so them taking part in the services is normal.
    b. However, those who are not used to the service (e.g. Sarah) should attempt to remain respectful and inconspicuous.
    c. Do not use phones or make too much noise during the service, else you may disturb congregants.
3. Fill in Researcher Checklist
    a. Sarah + either Valerie or Miguel will fill in their researcher checklist during the service.

Steps for post-service protocol:

1. Approaching participants.
    a. As the service ends, ensure you take note of where all participants you used the pressure cuff on are.
    b. Approach these participants and explain that we need to conduct the 2nd half of the research.
    c. Try to do this before participants are able to have post-service caffeine. (In the form of tea/coffee)
    d. Find all your participants and sit them down before continuing with the post-measures with any participant.
        i. This lowers the likelihood of any participants leaving before we have a chance to take post- measures
2. If participant asks about debrief/follow-up
    a. Explain to participant that we are going to provide anonymised versions of the data to our contact in their church.
    b. This may require elaboration that it could take close to a year for us to collect all the data and have a manuscript written for the church to have access to.
    c. Further debriefing is not possible due to the possibility for the participants to talk to members of other congregations that may take part in our research.
        i. We do not want the aims of our research to be known by other congregations in advance.

Appendix 14 – Study 1 Cuff measure exclusion questions

We need a little information to ensure our pressure cuff measure is appropriate for you as a participant.

Please read the following questions carefully.

No need to indicate which question, but would you say **YES** to **one or more** of the following questions?

Are you currently pregnant?

Do you have arthritis?

Do you have diabetes?

Do you have ADHD?

Appendix 15 – Study 1 R Script

```
### Testing BOTSA in the Field ###

rm(list=ls())

library("MASS",character.only=TRUE)
library(lme4)
library(MBESS)
library(dplyr)
library(MASS)
library(apaTables)
library(lavaan)
library(psychometric)
require(foreign)
require(magrittr)
require(lmerTest)
require(ggplot2)
require(ggpubr)
require(lattice)
require(reshape2)
require(nlme)
require(MuMIn)
require(PairedData)
require(gridExtra)
require(ggfortify)
require(multilevel)
require(robumeta)
require(psych)
```

```
require(GPArotation)

require(lm.beta)



### Import Data ###


data <- read.csv("RSB - Study 1 - WIDE.csv", header=TRUE)

SB_CV <- read.csv("SB_Construct_Validity.csv", header=TRUE) # Social Bonding construct validity


{## Centring and standardising variables ====



  data <-
    data %>%
    mutate(CuffC = (Cuff_Change - mean(Cuff_Change, na.rm=T))) %>%  #grand-mean centred
    mutate(PANASPZ = (PANASP_Change - mean(PANASP_Change, na.rm=T))/sd(PANASP_Change,
na.rm=T)) %>% #grand-mean centred and standardised
    mutate(PANASNZ = (PANASN_Change - mean(PANASN_Change, na.rm=T))/sd(PANASN_Change,
na.rm=T)) %>% #grand-mean centred and standardised
    mutate(Social_BondingZ = (SB_Change - mean(SB_Change, na.rm=T))/sd(SB_Change, na.rm=T)) %>%
#grand-mean centred and standardised
    mutate(AgeC = (Age - mean(Age, na.rm=T)))%>%   #grand-mean centred
    mutate(RelZ = (Religiosity_SR - mean(Religiosity_SR, na.rm=T))/sd(Religiosity_SR, na.rm=T)) #grand-
mean centred and standardised



  data_EnChr <- data[data$DataCategory==0,] # UK Churches Only


  data_EnSA <- data[data$DataCategory==1,] # UK Sunday Assemblies - seperate data
```

```
  data_BrChr <- data[data$DataCategory==2,] # Brazil Churches


  data_Chr <- data[data$DataCategory==0 |data$DataCategory == 2,] # All churches - both UK and Brazil



  ##Variables:##
  ##___C = Centred around the grand mean ##
  ##___Z = converted to z-score/standardised ##
  ##PANASP = PANAS Positive ##
  ##PANASN = PANAS Negative ##
  ##SB = Average score created for Social Bonding ##
  ##Cuff = Pressure cuff measure



}
# Basic Information
#Participants ages:
mean(data_Chr$Age) #42.3
sd(data_Chr$Age) #15.45
count(data_Chr, Gender) #85m, 180f, 1 NA

#UK only
mean(data_EnChr$Age) #54.6
sd(data_EnChr$Age) #17.18
count(data_EnChr, Gender) #23m, 47F

mean(data_EnChr$PANASP_Pre) #54.6
sd(data_EnChr$Age) #17.18
count(data_EnChr, Gender) #23m, 47F
```

```
#Brazil only

mean(data_BrChr$Age) #37.9

sd(data_BrChr$Age) #12.13

count(data_BrChr, Gender) #62m, 133F, 1NA


### Social Bonding Measure - Factor Analysis and Reliability ----




{## Factor Analysis of SB5 ####


    IOS_Pre <- SB_CV$IOS_Pre

    SB5_Pre <- SB_CV$SB5_Pre


    #Factor Analysis:

    SB5_Cor_Prea <- SB_CV[,2:6]

    SB5_Cor_Pre <- round(cor(SB5_Cor_Prea),2)

    SB5_Cor_Pre


    SB5_Cor_Posta <- SB_CV[,9:13]

    SB5_Cor_Post <- round(cor(SB5_Cor_Posta),2)

    SB5_Cor_Post

#Factor analysis of the pre-service SB5 data

  factors_SB5_Pre <- fa(r = SB5_Cor_Pre, fm = "pa")

  #Getting the factor loadings and model analysis

  factors_SB5_Pre

  scree(SB5_Cor_Pre) # scree plot suggests 1 factor

  #Factor Analysis using method =  principal axis (pa)

  #Default is oblimin - an oblique rotation

  # factor analysis shows that 1 factor is sufficient.

  #Mean item complexity = 1
```

```
  #Factor analysis of the post-service SB5 data

  factors_SB5_Post <- fa(r = SB5_Cor_Post, fm = "pa")

  #Getting the factor loadings and model analysis

  factors_SB5_Post

  scree(SB5_Cor_Post) # scree plot suggests 1 factor

  #Factor Analysis using method =  principal axis (pa)

  #Default is oblimin - an oblique rotation

  # factor analysis shows that 1 factor is sufficient.

  #Mean item complexity = 1



  }
{## Validity check of SB5 and IOS (similar Constructs?) ####


  IOS_Post <- SB_CV$IOS_Post

  SB5_Post <- SB_CV$SB5_Post


  Pre_CV <- cor.test(IOS_Pre,SB5_Pre, method = "pearson", conf.level = 0.95) # Pre-service construct validity

  Pre_CV

  Post_CV <- cor.test(IOS_Post,SB5_Post, method = "pearson", conf.level = 0.95) # post-service construct
validity

  Post_CV


  ## non-parametric ##

  Pre_CVSR <- cor.test(IOS_Pre,SB5_Pre, method = "spearman", conf.level = 0.95) # Pre-service construct
validity

  Pre_CVSR
```

```
  Post_CVSR <- cor.test(IOS_Post,SB5_Post, method = "spearman", conf.level = 0.95) # post-service construct
validity
  Post_CVSR
}
  {## Factor Analysis of SB6 ####
  #Factor Analysis:
  SB6_Cor_Prea <- select(SB_CV, Connected_Pre, EmoClose_Pre, Trust_Pre, Like_Pre, InCommon_Pre,
IOS_Pre)
  head(SB6_Cor_Prea)
  SB6_Cor_Pre <- round(cor(SB6_Cor_Prea),2)
  SB6_Cor_Pre

  SB6_Cor_Posta <- select(SB_CV, Connected_Post, EmoClose_Post, Trust_Post, Like_Post, InCommon_Post,
IOS_Post)
  SB6_Cor_Post <- round(cor(SB6_Cor_Posta),2)
  SB6_Cor_Post

  #Factor analysis of the pre-service SB5 data
  factors_SB6_Pre <- fa(r = SB6_Cor_Pre, fm = "pa")
  #Getting the factor loadings and model analysis
  factors_SB6_Pre
  scree(SB6_Cor_Pre) # scree plot suggests 1 factor
  #Factor Analysis using method =  principal axis (pa)
  #Default is oblimin - an oblique rotation
  # factor analysis shows that 1 factor is sufficient.
  #Mean item complexity = 1

  #Factor analysis of the post-service SB5 data
  factors_SB6_Post <- fa(r = SB6_Cor_Post, fm = "pa")
  #Getting the factor loadings and model analysis
```

```
  factors_SB6_Post

  scree(SB6_Cor_Post) # scree plot suggests 1 factor

  #Factor Analysis using method =  principal axis (pa)

  #Default is oblimin - an oblique rotation

  # factor analysis shows that 1 factor is sufficient.

  #Mean item complexity = 1


  # Factor Diagrams, showing loadings for the single factor.

  fa.diagram(factors_SB5_Pre, sort = TRUE)

  fa.diagram(factors_SB5_Post, sort = TRUE)

  fa.diagram(factors_SB6_Pre, sort = TRUE)

  fa.diagram(factors_SB6_Post, sort = TRUE)

}

{## McDonald's Omega values ####

  SB5_pre_omega <- ci.reliability(SB5_Cor_Prea, type = "omega", conf.level = 0.95, B=1000)

  SB5_pre_omega # SB5_Pre  omega = .85[.82, .88]

  SB5_post_omega <- ci.reliability(SB5_Cor_Posta, type = "omega", conf.level = 0.95, B=1000)

  SB5_post_omega# SB5_post omega = .90[.87, .93]

  SB6_pre_omega <- ci.reliability(SB6_Cor_Prea, type = "omega", conf.level = 0.95, B=1000)

  SB6_pre_omega # SB6_Pre  omega = .87[.85, .89]

  SB6_post_omega <- ci.reliability(SB6_Cor_Posta, type = "omega", conf.level = 0.95, B=1000)

  SB6_post_omega# SB6_post omega = .90[.88, .93]


#Alpha comparison

  SB5_pre_alpha <- psych::alpha(SB5_Cor_Prea)

  SB5_pre_alpha # SB5_Pre  omega = .84[.82, .87]

  SB5_post_alpha <- psych::alpha(SB5_Cor_Posta)

  SB5_post_alpha # SB5_Pre  omega = .90[.88, .92]

  SB6_pre_alpha <-psych::alpha(SB6_Cor_Prea)

  SB6_pre_alpha # SB6_Pre  omega = .87[.84, .89]
```

```
  SB6_post_alpha <- psych::alpha(SB6_Cor_Posta)

  SB6_post_alpha # SB6_post omega = .90[.88, .92]


}


### ----------------------------- ###

### Data Assumptions - Normality  ----

### ----------------------------- ###


## ------------- ##

{## Density Plots  ====

  ## ------------- ##


  # -------------- #

  {# Social Bonding ####

    # -------------- #


    ggdensity(data_Chr$SB6_Pre,

              main = "Density plot of Pre-Service Social Bonding Measure",

              xlab = "Pre-Service Social Bonding")


    # definitely doesn't look normal


    ggdensity(data_Chr$SB6_Post,

              main = "Density plot of Post-Service Social Bonding Measure",

              xlab = "Post-Service Social Bonding")


    # definitely doesn't look normal


    ggdensity(data_Chr$SB_Change,
```

```
          main = "Density plot of change in Social Bonding Measure",
          xlab = "Social Bonding Change")


  # Looks more normal
 }
 # ---- #
 {# Cuff ####
  # ---- #
  ggdensity(data_Chr$Cuff_Pre,
          main = "Density plot of change in cuff measure",
          xlab = "Pre-Service Cuff")


  # definitely doesn't look normal


  ggdensity(data_Chr$Cuff_Post,
          main = "Density plot of change in cuff measure",
          xlab = "Post-Service Cuff")


  # definitely doesn't look normal


  ggdensity(data_Chr$Cuff_Change,
          main = "Density plot of change in cuff measure",
          xlab = "Cuff Change")


  # Looks more normal
 }
 # ------ #
 {# PANAS+ ####
  # ------ #
  ggdensity(data_Chr$PANASP_Pre,
```

```
            main = "Density plot of change in PANAS+",

            xlab = "Pre-Service PANAS+")


    # definitely doesn't look normal


    ggdensity(data_Chr$PANASP_Post,

            main = "Density plot of change in PANAS+",

            xlab = "Post-Service PANAS+")


    # definitely doesn't look normal


    ggdensity(data_Chr$PANASP_Change,

            main = "Density plot of change in PANAS+",

            xlab = "PANAS+ Change")


    # Looks a little more normal, though high kurtosis.

  }

  # ------ #

  {# PANAS- ####

    # ------ #

    ggdensity(data_Chr$PANASP_Pre,

            main = "Density plot of change in PANAS-",

            xlab = "Pre-Service PANAS-")


    # definitely doesn't look normal


    ggdensity(data_Chr$PANASP_Post,

            main = "Density plot of change in PANAS-",

            xlab = "Post-Service PANAS-")
```

```
    # definitely doesn't look normal


    ggdensity(data_Chr$PANASP_Change,
              main = "Density plot of change in PANAS-",
              xlab = "PANAS- Change")


    # Looks a little more normal, though high kurtosis.
  }}
## --------- ##
{## Q-Q Plots ====
  ## --------- ##


  # -------------- #
  {# Social Bonding ####
    # -------------- #
    ggqqplot(data_Chr$SB6_Pre)
    ggqqplot(data_Chr$SB6_Post)
    ggqqplot(data_Chr$SB_Change)
  }
  # ---- #
  {# Cuff ####
    # ---- #
    ggqqplot(data_Chr$Cuff_Pre)
    ggqqplot(data_Chr$Cuff_Post)
    ggqqplot(data_Chr$Cuff_Change)
  }
  # ------ #
  {# PANAS+ ####
    # ------ #
    ggqqplot(data_Chr$PANASP_Pre)
```

```
    ggqqplot(data_Chr$PANASP_Post)

    ggqqplot(data_Chr$PANASP_Change)

  }

  # ------ #

  {# PANAS- ####

    # ------ #

    ggqqplot(data_Chr$PANASN_Pre)

    ggqqplot(data_Chr$PANASN_Post)

    ggqqplot(data_Chr$PANASN_Change)

  }}

## ----------------- ##

{## Shaprio-Wilk Test ====

  ## ----------------- ##


  # -------------- #

  {# Social Bonding ####

    # -------------- #

    shapiro.test(data_Chr$SB6_Pre) # W = .965 - stat. sig. dif. from normal

    shapiro.test(data_Chr$SB6_Post) # W = .932 - stat. sig. dif. from normal

    shapiro.test(data_Chr$SB_Change) # W = .973 - stat. sig. dif. from normal

  }

  # ---- #

  {# Cuff ####

    # ---- #

    shapiro.test(data_Chr$Cuff_Pre) # W = .973 - stat. sig. dif. from normal

    shapiro.test(data_Chr$Cuff_Post) # W = .974 - stat. sig. dif. from normal

    shapiro.test(data_Chr$Cuff_Change) # W = .984 - stat. sig. dif. from normal

  }

  # ------ #

  {# PANAS+ ####
```

```
    # ------ #
    shapiro.test(data_Chr$PANASP_Pre) # W = .962 - stat. sig. dif. from normal
    shapiro.test(data_Chr$PANASP_Post) # W = .967 - stat. sig. dif. from normal
    shapiro.test(data_Chr$PANASP_Change) # W = .978 - stat. sig. dif. from normal
  }
  # ------ #
  {# PANAS- ####
    # ------ #
    shapiro.test(data_Chr$PANASN_Pre) # W = .930 - stat. sig. dif. from normal
    shapiro.test(data_Chr$PANASN_Post) # W = .863 - stat. sig. dif. from normal
    shapiro.test(data_Chr$PANASN_Change) # W = .861 - stat. sig. dif. from normal
  }
}

### ------------------------------------------------ ###
### Hypothesis 1: Change from Before to After Service ----------------------

{## Wilcoxon Signed Ranks ====

  {# Social Bonding ####


    # descriptives #


    length(data_Chr$SB6_Pre) # 266
    mean(data_Chr$SB6_Pre) # 5.41
    sd(data_Chr$SB6_Pre)  # 0.942
    median(data_Chr$SB6_Pre) # 5.5

    length(data_Chr$SB6_Post) #266
```

```
mean(data_Chr$SB6_Post) # 5.70

sd(data_Chr$SB6_Post) # 0.922

median(data_Chr$SB6_Post) # 6.0


# non-parametric test #

Wilcox_SB <- wilcox.test(data_Chr$SB6_Pre, data_Chr$SB6_Post, paired = TRUE)

Wilcox_SB #output result

SB_diff <- c(data_Chr$SB6_Pre- data_Chr$SB6_Post) #create the differences

SB_diff <- SB_diff[ SB_diff!=0 ] #delete all differences equal to zero

SB_diff_rank <- rank(abs(SB_diff)) #check the ranks of the differences, taken in absolute

SB_diff_rank_sign <- SB_diff_rank * sign(SB_diff) #check the sign to the ranks, recalling the signs of the values of the differences

SB_ranks_P <- sum(SB_diff_rank_sign[SB_diff_rank_sign > 0]) #calculating the sum of ranks assigned to the differences as a positive, ie greater than zero

SB_ranks_N <- -sum(SB_diff_rank_sign[SB_diff_rank_sign < 0]) #calculating the sum of ranks assigned to the differences as a negative, ie less than zero


SB_ranks_P # used in effect size calculation (Kerby)

SB_ranks_N # used in effect size calculation (Kerby)


# effect size #

Zstat_SB<-qnorm(Wilcox_SB$p.value/2) #Z score

Zstat_SB #print the Z-score

SB_Bf_pval <- Wilcox_SB$p.value

SB_Bf_pval

SB_rR <- abs(Zstat_SB)/sqrt(266*2)

# Effect size (Rosenthal) - more conservative effect size.

SB_rR # r = 0.30

SB_rK <- ((SB_ranks_P/(SB_ranks_P+SB_ranks_N))-(SB_ranks_N/(SB_ranks_P+SB_ranks_N)))

# Effect size (Kerby) - Less conservative.
```

```
abs(SB_rK) # r= 0.52

}

{# Cuff ####



# descriptives #

length(data_Chr$Cuff_Pre) # 266

mean(data_Chr$Cuff_Pre) # 157.90

sd(data_Chr$Cuff_Pre) # 54.45

median(data_Chr$Cuff_Pre) # 150.0


length(data_Chr$Cuff_Post) # 266

mean(data_Chr$Cuff_Post) # 178.63

sd(data_Chr$Cuff_Post) # 60.35

median(data_Chr$Cuff_Post) # 170.0


# Non-Directional non-parametric test #

Wilcox_Cuff <- wilcox.test(data_Chr$Cuff_Post, data_Chr$Cuff_Pre, paired = TRUE)

Wilcox_Cuff #output result

Cuff_diff <- c(data_Chr$Cuff_Pre- data_Chr$Cuff_Post) #create the differences

Cuff_diff <- Cuff_diff[ Cuff_diff!=0 ] #delete all differences equal to zero

Cuff_diff_rank <- rank(abs(Cuff_diff)) #check the ranks of the differences, taken in absolute

Cuff_diff_rank_sign <- Cuff_diff_rank * sign(Cuff_diff) #check the sign to the ranks, recalling the signs of the values of the differences

Cuff_ranks_P <- sum(Cuff_diff_rank_sign[Cuff_diff_rank_sign > 0]) #calculating the sum of ranks assigned to the differences as a positive, ie greater than zero

Cuff_ranks_N <- -sum(Cuff_diff_rank_sign[Cuff_diff_rank_sign < 0]) #calculating the sum of ranks assigned to the differences as a negative, ie less than zero


Cuff_ranks_P # used in effect size calculation (Kerby)
```

```
Cuff_ranks_N # used in effect size calculation (Kerby)


# effect size #

Zstat_Cuff<-qnorm(Wilcox_Cuff$p.value/2) #Z score

Zstat_Cuff #print the Z-score

Cuff_Bf_pval <- Wilcox_Cuff$p.value

Cuff_Bf_pval

Cuff_rR <- abs(Zstat_Cuff)/sqrt(266*2)

# Effect size (Rosenthal) - more conservative effect size.

Cuff_rR # r = 0.27

Cuff_rK <- ((Cuff_ranks_P/(Cuff_ranks_P+Cuff_ranks_N))-(Cuff_ranks_N/(Cuff_ranks_P+Cuff_ranks_N)))

# Effect size (Kerby) - Less conservative.

abs(Cuff_rK) # r = 0.47


# Directional non-parametric test #

Wilcox_CuffDirect <- wilcox.test(data_Chr$Cuff_Post, data_Chr$Cuff_Pre, paired = TRUE, alternative = "greater")

Wilcox_CuffDirect #output result

Cuff_diffDirect <- c(data_Chr$Cuff_Pre- data_Chr$Cuff_Post) #create the differences

Cuff_diffDirect <- Cuff_diffDirect[ Cuff_diffDirect!=0 ] #delete all differences equal to zero

Cuff_diff_rankDirect <- rank(abs(Cuff_diffDirect)) #check the ranks of the differences, taken in absolute

Cuff_diff_rank_signDirect <- Cuff_diff_rankDirect * sign(Cuff_diffDirect) #check the sign to the ranks, recalling the signs of the values of the differences

Cuff_ranks_PDirect <- sum(Cuff_diff_rank_signDirect[Cuff_diff_rank_signDirect > 0]) #calculating the sum of ranks assigned to the differences as a positive, ie greater than zero

Cuff_ranks_NDirect <- -sum(Cuff_diff_rank_signDirect[Cuff_diff_rank_signDirect < 0]) #calculating the sum of ranks assigned to the differences as a negative, ie less than zero


Cuff_ranks_PDirect # used in effect size calculation (Kerby)

Cuff_ranks_NDirect # used in effect size calculation (Kerby)
```

```
    # effect size #
    Zstat_CuffDirect<-qnorm(Wilcox_Cuff$p.value/2) #Z score
    Zstat_CuffDirect #print the Z-score
    Cuff_Bf_pvalDirect <- Wilcox_CuffDirect$p.value
    Cuff_Bf_pvalDirect
    Cuff_rRDirect <- abs(Zstat_CuffDirect)/sqrt(266*2)
    # Effect size (Rosenthal) - more conservative effect size.
    Cuff_rRDirect # r = 0.27
    Cuff_rKDirect <- ((Cuff_ranks_PDirect/(Cuff_ranks_PDirect+Cuff_ranks_NDirect))-
(Cuff_ranks_NDirect/(Cuff_ranks_PDirect+Cuff_ranks_NDirect)))
    # Effect size (Kerby) - Less conservative.
    abs(Cuff_rKDirect) # r = 0.47

  }
  {# PANAS+ ####

    # descriptives #
    mean(data_Chr$PANASP_Pre) #38.71
    sd(data_Chr$PANASP_Pre) #11.90
    median(data_Chr$PANASP_Pre) #41.5

    mean(data_Chr$PANASP_Post) #39.78
    sd(data_Chr$PANASP_Post) #12.12
    median(data_Chr$PANASP_Post) #42

    # test #
    Wilcox_PANASP <- wilcox.test(data_Chr$PANASP_Pre, data_Chr$PANASP_Post, paired = TRUE)
```

```
    Wilcox_PANASP #output result

    PANASP_diff <- c(data_Chr$PANASP_Pre - data_Chr$PANASP_Post) #create the differences

    PANASP_diff <- PANASP_diff[ PANASP_diff!=0 ] #delete all differences equal to zero

    PANASP_diff_rank <- rank(abs(PANASP_diff))  # create difference ranks

    PANASP_diff_rank_sign <- PANASP_diff_rank * sign(PANASP_diff) # give difference correct sign

    PANASP_ranks_P <- sum(PANASP_diff_rank_sign[PANASP_diff_rank_sign > 0])  # sum positive ranks

    PANASP_ranks_N <- -sum(PANASP_diff_rank_sign[PANASP_diff_rank_sign < 0]) # sum negative ranks


    PANASP_ranks_P # used in effect size calculation (Kerby)

    PANASP_ranks_N # used in effect size calculation (Kerby)


    # effect size #

    Zstat_PANASP<-qnorm(Wilcox_PANASP$p.value/2) #Z score

    Zstat_PANASP #print the Z-score

    PANASP_Bf_pval <- Wilcox_PANASP$p.value

    PANASP_Bf_pval

    PANASP_rR <- abs(Zstat_PANASP)/sqrt(265*2)

    # Effect size (Rosenthal) - more conservative effect size.

    PANASP_rR

    PANASP_rK <- ((PANASP_ranks_P/(PANASP_ranks_P+PANASP_ranks_N))-

(PANASP_ranks_N/(PANASP_ranks_P+PANASP_ranks_N)))

    # Effect size (Kerby) - Less conservative.

    abs(PANASP_rK)

  }

  {# PANAS- ####


    # descriptives #

    mean(data_Chr$PANASN_Pre)

    sd(data_Chr$PANASN_Pre)

    median(data_Chr$PANASN_Pre)
```

```
mean(data_Chr$PANASN_Post)

sd(data_Chr$PANASN_Post)

median(data_Chr$PANASN_Post)


# test #

Wilcox_PANASN <- wilcox.test(data_Chr$PANASN_Pre, data_Chr$PANASN_Post, paired = TRUE)

Wilcox_PANASN #output result

PANASN_diff <- c(data_Chr$PANASN_Pre - data_Chr$PANASN_Post) #create the differences

PANASN_diff <- PANASN_diff[ PANASN_diff!=0 ] #delete all differences equal to zero

PANASN_diff_rank <- rank(abs(PANASN_diff))  # create difference ranks

PANASN_diff_rank_sign <- PANASN_diff_rank * sign(PANASN_diff) # give difference correct sign

PANASN_ranks_P <- sum(PANASN_diff_rank_sign[PANASN_diff_rank_sign > 0])  # sum positive ranks

PANASN_ranks_N <- -sum(PANASN_diff_rank_sign[PANASN_diff_rank_sign < 0]) # sum negative ranks


PANASN_ranks_P # used in effect size calculation (Kerby)

PANASN_ranks_N # used in effect size calculation (Kerby)


# effect size #

Zstat_PANASN<-qnorm(Wilcox_PANASN$p.value/2) #Z score

Zstat_PANASN #print the Z-score

PANASN_Bf_pval <- Wilcox_PANASN$p.value

PANASN_Bf_pval

PANASN_rR <- abs(Zstat_PANASN)/sqrt(265*2)

# Effect size (Rosenthal) - more conservative effect size.

PANASN_rR

PANASN_rK <- ((PANASN_ranks_P/(PANASN_ranks_P+PANASN_ranks_N))-
(PANASN_ranks_N/(PANASN_ranks_P+PANASN_ranks_N)))

# Effect size (Kerby) - Less conservative.

abs(PANASN_rK)
```

```
  }}

### Hypothesis 1: Difference Between Countries: UK churches only ####

{## Wilcoxon Signed Ranks ====

  {# Social Bonding ####

    # descriptives #

    length(data_EnChr$SB6_Pre) # 70
    mean(data_EnChr$SB6_Pre) # 5.07
    sd(data_EnChr$SB6_Pre)  # 0.945
    median(data_EnChr$SB6_Pre) # 5.17

    length(data_EnChr$SB6_Post) #70
    mean(data_EnChr$SB6_Post) # 5.36
    sd(data_EnChr$SB6_Post) # 0.933
    median(data_EnChr$SB6_Post) # = 5.5

    # non-parametric test #
    Wilcox_SBEn <- wilcox.test(data_EnChr$SB6_Pre, data_EnChr$SB6_Post, paired = TRUE)
    Wilcox_SBEn #output result
    SB_diffEn <- c(data_EnChr$SB6_Pre- data_EnChr$SB6_Post) #create the differences
    SB_diffEn <- SB_diffEn[ SB_diffEn!=0 ] #delete all differences equal to zero
    SB_diff_rankEn <- rank(abs(SB_diffEn)) #check the ranks of the differences, taken in absolute
    SB_diff_rank_signEn <- SB_diff_rankEn * sign(SB_diffEn) #check the sign to the ranks, recalling the signs
of the values of the differences
```

SB_ranks_PEn <- sum(SB_diff_rank_signEn[SB_diff_rank_signEn > 0]) #calculating the sum of ranks assigned to the differences as a positive, ie greater than zero

SB_ranks_NEn <- -sum(SB_diff_rank_signEn[SB_diff_rank_signEn < 0]) #calculating the sum of ranks assigned to the differences as a negative, ie less than zero

SB_ranks_PEn # used in effect size calculation (Kerby)

SB_ranks_NEn # used in effect size calculation (Kerby)

effect size

Zstat_SBEn<-qnorm(Wilcox_SBEn$p.value/2) #Z score

Zstat_SBEn #print the Z-score

SBEn_Bf_pval <- Wilcox_SBEn$p.value

SBEn_Bf_pval

SBEn_rR <- abs(Zstat_SBEn)/sqrt(70*2)

Effect size (Rosenthal) - more conservative effect size.

SBEn_rR # r = 0.34

SBEn_rK <- ((SB_ranks_PEn/(SB_ranks_PEn+SB_ranks_NEn))-(SB_ranks_NEn/(SB_ranks_PEn+SB_ranks_NEn)))

Effect size (Kerby) - Less conservative.

abs(SBEn_rK) # r= 0.62

}

{# Cuff ####

descriptives

length(data_EnChr$Cuff_Pre) # 70

mean(data_EnChr$Cuff_Pre) # 168.89

sd(data_EnChr$Cuff_Pre) # 59.10

median(data_EnChr$Cuff_Pre) # 160.0

```
length(data_EnChr$Cuff_Post) # 70

mean(data_EnChr$Cuff_Post) # 179.81

sd(data_EnChr$Cuff_Post) # 65.61

median(data_EnChr$Cuff_Post) # 185.0


# non-parametric test #

Wilcox_CuffEn <- wilcox.test(data_EnChr$Cuff_Pre, data_EnChr$Cuff_Post, paired = TRUE)

Wilcox_CuffEn #output result

Cuff_diffEn <- c(data_EnChr$Cuff_Pre- data_EnChr$Cuff_Post) #create the differences

Cuff_diffEn <- Cuff_diffEn[ Cuff_diffEn!=0 ] #delete all differences equal to zero

Cuff_diff_rankEn <- rank(abs(Cuff_diffEn)) #check the ranks of the differences, taken in absolute

Cuff_diff_rank_signEn <- Cuff_diff_rankEn * sign(Cuff_diffEn) #check the sign to the ranks, recalling the signs of the values of the differences

Cuff_ranks_PEn <- sum(Cuff_diff_rank_signEn[Cuff_diff_rank_signEn > 0]) #calculating the sum of ranks assigned to the differences as a positive, ie greater than zero

Cuff_ranks_NEn <- -sum(Cuff_diff_rank_signEn[Cuff_diff_rank_signEn < 0]) #calculating the sum of ranks assigned to the differences as a negative, ie less than zero


Cuff_ranks_PEn # used in effect size calculation (Kerby)

Cuff_ranks_NEn # used in effect size calculation (Kerby)


# effect size #

Zstat_CuffEn<-qnorm(Wilcox_CuffEn$p.value/2) #Z score

Zstat_CuffEn #print the Z-score

CuffEn_Bf_pval <- Wilcox_CuffEn$p.value

CuffEn_Bf_pval

CuffEn_rR <- abs(Zstat_CuffEn)/sqrt(70*2)

# Effect size (Rosenthal) - more conservative effect size.

CuffEn_rR # r = 0.16
```

```
    CuffEn_rK <- ((Cuff_ranks_PEn/(Cuff_ranks_PEn+Cuff_ranks_NEn))-
(Cuff_ranks_NEn/(Cuff_ranks_PEn+Cuff_ranks_NEn)))
    # Effect size (Kerby) - Less conservative.
    abs(CuffEn_rK) # r = 0.27


  }
  {# PANAS+ ####




    # descriptives #
    mean(data_EnChr$PANASP_Pre) #27.69
    sd(data_EnChr$PANASP_Pre) # 9.44
    median(data_EnChr$PANASP_Pre) # 27

    mean(data_EnChr$PANASP_Post) # 31.66
    sd(data_EnChr$PANASP_Post) # 10.54
    median(data_EnChr$PANASP_Post) # 32

    # test #
    Wilcox_PANASPEn <- wilcox.test(data_EnChr$PANASP_Pre, data_EnChr$PANASP_Post, paired =
TRUE)
    Wilcox_PANASPEn #output result
    PANASP_diffEn <- c(data_EnChr$PANASP_Pre - data_EnChr$PANASP_Post) #create the differences
    PANASP_diffEn <- PANASP_diffEn[ PANASP_diffEn!=0 ] #delete all differences equal to zero
    PANASP_diff_rankEn <- rank(abs(PANASP_diffEn))  # create difference ranks
    PANASP_diff_rank_signEn <- PANASP_diff_rankEn * sign(PANASP_diffEn) # give difference correct sign
    PANASP_ranks_PEn <- sum(PANASP_diff_rank_signEn[PANASP_diff_rank_signEn > 0])  # sum positive
ranks
```

```
    PANASP_ranks_NEn <- -sum(PANASP_diff_rank_signEn[PANASP_diff_rank_signEn < 0]) # sum negative
ranks

    PANASP_ranks_PEn # used in effect size calculation (Kerby)
    PANASP_ranks_NEn # used in effect size calculation (Kerby)

    # effect size #
    Zstat_PANASPEn<-qnorm(Wilcox_PANASPEN$p.value/2) #Z score
    Zstat_PANASPEn #print the Z-score
    PANASPEn_Bf_pval <- Wilcox_PANASPEn$p.value
    PANASPEn_Bf_pval
    PANASPEn_rR <- abs(Zstat_PANASPEn)/sqrt(70*2)
    # Effect size (Rosenthal) - more conservative effect size.
    PANASPEn_rR # rR = 0.23
    PANASPEn_rK <- ((PANASP_ranks_PEn/(PANASP_ranks_PEn+PANASP_ranks_NEn))-
(PANASP_ranks_NEn/(PANASP_ranks_PEn+PANASP_ranks_NEn)))
    # Effect size (Kerby) - Less conservative.
    abs(PANASPEn_rK) # rK =  0.76
  }
  {# PANAS- ####

    # descriptives #
    mean(data_EnChr$PANASN_Pre) # 2.93
    sd(data_EnChr$PANASN_Pre) # 3.78
    median(data_EnChr$PANASN_Pre) # 2

    mean(data_EnChr$PANASN_Post) # 1.5
    sd(data_EnChr$PANASN_Post) # 3.34
    median(data_EnChr$PANASN_Post) # 0
```

```
# test #
Wilcox_PANASNEn <- wilcox.test(data_EnChr$PANASN_Pre, data_EnChr$PANASN_Post, paired =
TRUE)
Wilcox_PANASNEn #output result
PANASN_diffEn <- c(data_EnChr$PANASN_Pre - data_EnChr$PANASN_Post) #create the differences
PANASN_diffEn <- PANASN_diffEn[ PANASN_diffEn!=0 ] #delete all differences equal to zero
PANASN_diff_rankEn <- rank(abs(PANASN_diffEn))  # create difference ranks
PANASN_diff_rank_signEn <- PANASN_diff_rankEn * sign(PANASN_diffEn) # give difference correct
sign
PANASN_ranks_PEn <- sum(PANASN_diff_rank_signEn[PANASN_diff_rank_signEn > 0])  # sum positive
ranks
PANASN_ranks_NEn <- -sum(PANASN_diff_rank_signEn[PANASN_diff_rank_signEn < 0]) # sum
negative ranks

PANASN_ranks_PEn # used in effect size calculation (Kerby)
PANASN_ranks_NEn # used in effect size calculation (Kerby)

# effect size #
Zstat_PANASNEn<-qnorm(Wilcox_PANASNEn$p.value/2) #Z score
Zstat_PANASNEn #print the Z-score
PANASNEn_Bf_pval <- Wilcox_PANASNEn$p.value
PANASNEn_Bf_pval
PANASNEn_rR <- abs(Zstat_PANASNEn)/sqrt(70*2)
# Effect size (Rosenthal) - more conservative effect size.
PANASNEn_rR # rR = 0.21
PANASNEn_rK <- ((PANASN_ranks_PEn/(PANASN_ranks_PEn+PANASN_ranks_NEn))-
(PANASN_ranks_NEn/(PANASN_ranks_PEn+PANASN_ranks_NEn)))
# Effect size (Kerby) - Less conservative.
abs(PANASNEn_rK) # rK = 0.81
```

```
  }}

### Hypothesis 1: Difference Between Countries: Brazil churches only ####


{## Wilcoxon Signed Ranks ====


  {# Social Bonding ####




    # descriptives #


    length(data_BrChr$SB6_Pre) # 196

    mean(data_BrChr$SB6_Pre) # 5.53

    sd(data_BrChr$SB6_Pre)  # 0.914

    median(data_BrChr$SB6_Pre) # 5.67


    length(data_BrChr$SB6_Post) #196

    mean(data_BrChr$SB6_Post) # 5.83

    sd(data_BrChr$SB6_Post) # 0.888

    median(data_BrChr$SB6_Post) # = 6


    # non-parametric test #

    Wilcox_SBBr <- wilcox.test(data_BrChr$SB6_Pre, data_BrChr$SB6_Post, paired = TRUE)

    Wilcox_SBBr #output result

    SB_diffBr <- c(data_BrChr$SB6_Pre- data_BrChr$SB6_Post) #create the differences

    SB_diffBr <- SB_diffBr[ SB_diffBr!=0 ] #delete all differences equal to zero

    SB_diff_rankBr <- rank(abs(SB_diffBr)) #check the ranks of the differences, taken in absolute

    SB_diff_rank_signBr <- SB_diff_rankBr * sign(SB_diffBr) #check the sign to the ranks, recalling the signs
of the values of the differences

    SB_ranks_PBr <- sum(SB_diff_rank_signBr[SB_diff_rank_signBr > 0]) #calculating the sum of ranks
assigned to the differences as a positive, ie greater than zero
```

```
  SB_ranks_NBr <- -sum(SB_diff_rank_signBr[SB_diff_rank_signBr < 0]) #calculating the sum of ranks
assigned to the differences as a negative, ie less than zero


  SB_ranks_PBr # used in effect size calculation (Kerby)
  SB_ranks_NBr # used in effect size calculation (Kerby)


  # effect size #
  Zstat_SBBr<-qnorm(Wilcox_SBBr$p.value/2) #Z score
  Zstat_SBBr #print the Z-score
  SBBr_Bf_pval <- Wilcox_SBBr$p.value
  SBBr_Bf_pval
  SBBr_rR <- abs(Zstat_SBBr)/sqrt(195*2)
  # Effect size (Rosenthal) - more conservative effect size.
  SBBr_rR # r = 0.29
  SBBr_rK <- ((SB_ranks_PBr/(SB_ranks_P+SB_ranks_NBr))-
(SB_ranks_NBr/(SB_ranks_PBr+SB_ranks_NBr)))
  # Effect size (Kerby) - Less conservative.
  abs(SBBr_rK) # r= 0.52
 }
 {# Cuff ####



  # descriptives #
  length(data_BrChr$Cuff_Pre) # 196
  mean(data_BrChr$Cuff_Pre) # 153.98
  sd(data_BrChr$Cuff_Pre) # 52.29
  median(data_BrChr$Cuff_Pre) # 140.0

  length(data_BrChr$Cuff_Post) # 196
  mean(data_BrChr$Cuff_Post) # 178.20
```

```
sd(data_BrChr$Cuff_Post) # 58.53

median(data_BrChr$Cuff_Post) # 170.0


# non-parametric test #

Wilcox_CuffBr <- wilcox.test(data_BrChr$Cuff_Pre, data_BrChr$Cuff_Post, paired = TRUE)

Wilcox_CuffBr #output result

Cuff_diffBr <- c(data_BrChr$Cuff_Pre- data_BrChr$Cuff_Post) #create the differences

Cuff_diffBr <- Cuff_diffBr[ Cuff_diffBr!=0 ] #delete all differences equal to zero

Cuff_diff_rankBr <- rank(abs(Cuff_diffBr)) #check the ranks of the differences, taken in absolute

Cuff_diff_rank_signBr <- Cuff_diff_rankBr * sign(Cuff_diffBr) #check the sign to the ranks, recalling the
signs of the values of the differences

Cuff_ranks_PBr <- sum(Cuff_diff_rank_signBr[Cuff_diff_rank_signBr > 0]) #calculating the sum of ranks
assigned to the differences as a positive, ie greater than zero

Cuff_ranks_NBr <- -sum(Cuff_diff_rank_signBr[Cuff_diff_rank_signBr < 0]) #calculating the sum of ranks
assigned to the differences as a negative, ie less than zero


Cuff_ranks_PBr # used in effect size calculation (Kerby)

Cuff_ranks_NBr # used in effect size calculation (Kerby)


# effect size #

Zstat_CuffBr<-qnorm(Wilcox_CuffBr$p.value/2) #Z score

Zstat_CuffBr #print the Z-score

CuffBr_Bf_pval <- Wilcox_CuffBr$p.value

CuffBr_Bf_pval

CuffBr_rR <- abs(Zstat_CuffBr)/sqrt(195*2)

# Effect size (Rosenthal) - more conservative effect size.

CuffBr_rR # r = 0.31

CuffBr_rK <- ((Cuff_ranks_PBr/(Cuff_ranks_PBr+Cuff_ranks_NBr))-
(Cuff_ranks_NBr/(Cuff_ranks_PBr+Cuff_ranks_NBr)))

# Effect size (Kerby) - Less conservative.
```

```
abs(CuffBr_rK) # r = 0.53


}

{# PANAS+ ####




# descriptives #

mean(data_BrChr$PANASP_Pre) #42.65

sd(data_BrChr$PANASP_Pre) # 10.09

median(data_BrChr$PANASP_Pre) # 45


mean(data_BrChr$PANASP_Post) # 42.69

sd(data_BrChr$PANASP_Post) # 11.33

median(data_BrChr$PANASP_Post) # 45


# test #

Wilcox_PANASPBr <- wilcox.test(data_BrChr$PANASP_Pre, data_BrChr$PANASP_Post, paired = TRUE)

Wilcox_PANASPBr #output result NOT SIGNIFICANT

PANASP_diffBr <- c(data_BrChr$PANASP_Pre - data_BrChr$PANASP_Post) #create the differences

PANASP_diffBr <- PANASP_diffBr[ PANASP_diffBr!=0 ] #delete all differences equal to zero

PANASP_diff_rankBr <- rank(abs(PANASP_diffBr))  # create difference ranks

PANASP_diff_rank_signBr <- PANASP_diff_rankBr * sign(PANASP_diffBr) # give difference correct sign

PANASP_ranks_PBr <- sum(PANASP_diff_rank_signBr[PANASP_diff_rank_signBr > 0])  # sum positive
ranks

PANASP_ranks_NBr <- -sum(PANASP_diff_rank_signBr[PANASP_diff_rank_signBr < 0]) # sum negative
ranks


PANASP_ranks_PBr # used in effect size calculation (Kerby)

PANASP_ranks_NBr # used in effect size calculation (Kerby)
```

```
    # effect size #
    Zstat_PANASPBr<-qnorm(Wilcox_PANASPBr$p.value/2) #Z score
    Zstat_PANASPBr #print the Z-score
    PANASPBr_Bf_pval <- Wilcox_PANASPBr$p.value
    PANASPBr_Bf_pval # p has an upper-bound of 1, report p = 1
    PANASPBr_rR <- abs(Zstat_PANASPBr)/sqrt(195*2)
    # Effect size (Rosenthal) - more conservative effect size.
    PANASPBr_rR # rR = 0.02
    PANASPBr_rK <- ((PANASP_ranks_PBr/(PANASP_ranks_PBr+PANASP_ranks_NBr))-
(PANASP_ranks_NBr/(PANASP_ranks_PBr+PANASP_ranks_NBr)))
    # Effect size (Kerby) - Less conservative.
    abs(PANASPBr_rK) # rK =  0.03
  }
  {# PANAS- ####

    # descriptives #
    mean(data_BrChr$PANASN_Pre) # 14.21
    sd(data_BrChr$PANASN_Pre) # 5.87
    median(data_BrChr$PANASN_Pre) # 12.5

    mean(data_BrChr$PANASN_Post) # 11.51
    sd(data_BrChr$PANASN_Post) # 3.41
    median(data_BrChr$PANASN_Post) # 10

    # test #
    Wilcox_PANASNBr <- wilcox.test(data_BrChr$PANASN_Pre, data_BrChr$PANASN_Post, paired =
TRUE)
    Wilcox_PANASNBr #output result
    PANASN_diffBr <- c(data_BrChr$PANASN_Pre - data_BrChr$PANASN_Post) #create the differences
```

```
   PANASN_diffBr <- PANASN_diffBr[ PANASN_diffBr!=0 ] #delete all differences equal to zero
   PANASN_diff_rankBr <- rank(abs(PANASN_diffBr))  # create difference ranks
   PANASN_diff_rank_signBr <- PANASN_diff_rankBr * sign(PANASN_diffBr) # give difference correct
sign
   PANASN_ranks_PBr <- sum(PANASN_diff_rank_signBr[PANASN_diff_rank_signBr > 0])  # sum positive
ranks
   PANASN_ranks_NBr <- -sum(PANASN_diff_rank_signBr[PANASN_diff_rank_signBr < 0]) # sum
negative ranks


   PANASN_ranks_PBr # used in effect size calculation (Kerby)
   PANASN_ranks_NBr # used in effect size calculation (Kerby)


   # effect size #
   Zstat_PANASNBr<-qnorm(Wilcox_PANASNBr$p.value/2) #Z score
   Zstat_PANASNBr #print the Z-score
   PANASNBr_Bf_pval <- Wilcox_PANASNBr$p.value
   PANASNBr_Bf_pval
   PANASNBr_rR <- abs(Zstat_PANASNBr)/sqrt(195*2)
   # Effect size (Rosenthal) - more conservative effect size.
   PANASNBr_rR # rR = 0.32
   PANASNBr_rK <- ((PANASN_ranks_PBr/(PANASN_ranks_PBr+PANASN_ranks_NBr))-
(PANASN_ranks_NBr/(PANASN_ranks_PBr+PANASN_ranks_NBr)))
   # Effect size (Kerby) - Less conservative.
   abs(PANASNBr_rK) # rK = 0.60



{###Table 1 p-values ----
  library(FSA)


# using the Benjamini-Hochberg multiple test correction.
```

```
  BH_all <- c(SB_Bf_pval, Cuff_Bf_pval,PANASP_Bf_pval,PANASN_Bf_pval)

BH_cor_All <- p.adjust(BH_all, method = "BH")

BH_cor_All4dp <- round(BH_cor_All,4)

BH_cor_All4dp


BH_En <- c(SBEn_Bf_pval, CuffEn_Bf_pval, PANASPEn_Bf_pval, PANASNEn_Bf_pval)

BH_cor_En <- p.adjust(BH_En, method = "BH")

BH_cor_En4dp <- round(BH_cor_En,4)

BH_cor_En4dp


BH_Br <- c(SBBr_Bf_pval,CuffBr_Bf_pval,PANASPBr_Bf_pval,PANASNBr_Bf_pval)

BH_cor_Br <- p.adjust(BH_Br, method = "BH")

BH_cor_Br4dp <- round(BH_cor_Br,4)

BH_cor_Br4dp



    }

  }}

### Hypothesis 2 - Relationship between social bonding and pain threshold ----



{## Pain Threshold and Bonding only ====



  ## plot scatterplot to visualise data

  plot(data_Chr$Cuff_Change,data_Chr$SB_Change, main = "Relationship Between Pain Threshold and Social
Bonding",

      xlab = "Change in Pressure Cuff Measurea (Pain Threshold)", ylab = "Change in Social Bonding Measure")

  abline(lm(data_Chr$SB_Change~data_Chr$Cuff_Change), col="red") # regression line (y~x)
```

```
## plot scatterplot to visualise data using standardised/centred values
plot(data_Chr$CuffC,data_Chr$Social_BondingZ, main = "Relationship Between Pain Threshold and Social Bonding",
     xlab = "Change in Pressure Cuff Measurea (Pain Threshold)", ylab = "Change in Social Bonding Measure")
abline(lm(data_Chr$SB_Change~data_Chr$Cuff_Change), col="red") # regression line (y~x)


## Include confidence interval of regression line
ggplot(data = data_Chr, aes(x = Cuff_Change, y = SB_Change)) + geom_point(size = 1, shape = 1) +
  geom_smooth(data = data_Chr, method = lm, color = "black",
              fill = "darkgrey", se= TRUE, level =0.95, formula = y ~ x)+
  labs(title="Relationship Between Pain Threshold and Social Bonding",
       x = "Change in Pressure Cuff Measure (Pain Threshold)",
       y = "Change in Social Bonding Measure")


#using standardised/centred values
ggplot(data = data_Chr, aes(x = CuffC, y = Social_BondingZ)) + geom_point(size = 1, shape = 1) +
  geom_smooth(data = data_Chr, method = lm, color = "black",
              fill = "darkgrey", se= TRUE, level =0.95, formula = y ~ x)+
  labs(title="Relationship Between Pain Threshold and Social Bonding",
       x = "Change in Pressure Cuff Measure (Pain Threshold)",
       y = "Change in Social Bonding Measure")+
 theme(panel.grid.major=element_blank(),
       panel.grid.minor=element_blank(),
       panel.border=element_blank(),
       text=element_text(family='Times'))
```

```
##Model 1: Just pain threshold##
model1 <- lm(Social_BondingZ ~ CuffC, data = data_Chr)
summary(model1) # F(1,264) = 4.846 - 265 participants
confint(model1)
apa.reg.table(model1)



##Assumptions##
## A:Mean of residuals is close to 0
mean(model1$residuals) # this assumption holds
## A: Homoscedacisity and Normality
autoplot(model1)
# Resid v.s. Fitted shows assumption holds
# Q-Q Plot (top right) appears close to Normal.
# 74 and 240 appear as outliers in plots 1 and 2.
# 74, 202 and 240 appear as outlier on plot 3
# 213, 240 and 256 appear as outliers on plot 4
## A: The X variable and residuals are uncorrelated
cor.test (data_Chr$CuffC, model1$residuals) # assumption holds

## A: Durbin Watson (Autocorrelation)
require(lmtest)
dwtest(model1) # DW = 2.15, p = 0.88. Data not auto-correlated. Assumption holds

## A: Positive variability
var(data_Chr$CuffC) #assumption holds

## A: No multicolineatrity
```

```
  # Only 1 predictor - no multicolinearity possible.


}


{## Other predictors and Bonding ====



  ##Model 2 with PANASx2##


  model2 = lm(Social_BondingZ ~ CuffC + PANASPZ + PANASNZ, data = data_Chr)

  summary(model2) # F(3,262) = 9.167 - 265 participants

  confint(model2)

  apa.reg.table(model2)




  #Assumptions of Model2#



  ## A:Mean of residuals is close to 0

  mean(model2$residuals) # this assumption holds


  ## A: Homoscedacisity and Normality

  autoplot(model2)

  # Resid v.s. Fitted shows assumption holds

  # Q-Q Plot (top right) appears close to Normal.


  # 74 and 152 appear as outliers on each graph.

  # 81 appears as an outlier in graphs 1-3, 103 in graph 4
```

```
## A: The X variable and residuals are uncorrelated
cor.test (data_Chr$CuffC, model2$residuals) # assumption holds
cor.test (data_Chr$PANASPZ, model2$residuals) # assumption holds
cor.test (data_Chr$PANASNZ, model2$residuals) # assumption holds

## A: Durbin Watson (Autocorrelation)
 dwtest(model2) # DW = 2.23, p = 0.97. Data not auto-correlated. Assumption holds

## A: Positive variability
var(data_Chr$CuffC) #assumption holds
var(data_Chr$PANASPZ) #assumption holds
var(data_Chr$PANASNZ) #assumption holds

## A: No multicolineatrity
require(car)
vif(model2)
# low VIF. No multi-colinearity.


anova(model1,model2)
# Including PANAS as explanatory variables improves model fit significantly


#Exploratory model accounting for RelZ, Years attended service, gender, Age and country
model3 = lm(Social_BondingZ ~  CuffC + PANASPZ + PANASNZ + factor(DataCategory) + ConnectedGod
+ AgeC + ServiceAttend_Yrs + factor(Gender) + RelZ,
        data = data_Chr) #explore the connectedness to god
summary(model3) #F(9,233) = 4.47 - 242 participants answered all related questions
#can't be compared with previous models due to different number of participants
```

```
  confint(model3)

  apa.reg.table(model3)

  #Cuff, PANAS+, PANAS- and Connectedness to God are significant predictors #R^2 = .147 [.05, .20]

lm.beta(model3)


## Assumptions Model 3 ##


## A:Mean of residuals is close to 0

mean(model3$residuals) # this assumption holds


## A: Homoscedacisity and Normality

autoplot(model3)

# Resid v.s. Fitted shows assumption holds

# Q-Q Plot (top right) appears close to Normal.


# 202, 213 and 240 appear as outliers on graph 1-3.

# 103 appears as outlier in graph 4


## A: The X variables and residuals are uncorrelated

# due to missing values, cannot be tested.


## A: Durbin Watson (Autocorrelation)

dwtest(model3) # DW = 2.24, p = 0.96. Data not auto-correlated. Assumption holds


## A: Positive variability

var(data_Chr$CuffC) #assumption holds

var(data_Chr$PANASPZ) #assumption holds

var(data_Chr$PANASNZ) #assumption holds

var(data_Chr$DataCategory) #assumption holds

var(data_Chr$Gender) #NA
```

```
var(data_Chr$AgeC) #assumption holds

var(data_Chr$RelZ) #assumption holds

var(data_Chr$ConnectedGod) #NA

var(data_Chr$ServiceAttend_Yrs) #NA


## A: No multicolineatrity

require(car)

vif(model3)

# low VIF (all under 2). Little multi-colinearity.



}



### Predictor of Pain threshold ####


model4 = lm(CuffC ~ PANASPZ + PANASNZ+ AgeC + factor(Gender),

        data = data_Chr) #explore the connectedness to god

summary(model4) #F(4,260) = 0.62, p = .646


confint(model4)

apa.reg.table(model4)

lm.beta(model4)



#### Follow-Up Analysis: Multi-Level Modelling ####


data_long <- read.csv("RSB - Study 1 - LONG.csv", header=TRUE)


data_long <- data_long[data_long$ChurchID!="?",]
```

```
data_long <-
  data_long %>%
  mutate(CuffC = (Cuff - mean(Cuff, na.rm=T))) %>%  #grand-mean centred
  mutate(PANASPZ = (PANASP - mean(PANASP, na.rm=T))/sd(PANASP, na.rm=T)) %>% #grand-mean
centred and standardised
  mutate(PANASNZ = (PANASN - mean(PANASN, na.rm=T))/sd(PANASN, na.rm=T)) %>% #grand-mean
centred and standardised
  mutate(SB6Z = (Social_Bonding - mean(Social_Bonding, na.rm=T))/sd(Social_Bonding, na.rm=T)) %>%
#grand-mean centred and standardised
  mutate(AgeC = (Age - mean(Age, na.rm=T)))%>%   #grand-mean centred
  mutate(RelZ = (Religiosity_SR - mean(Religiosity_SR, na.rm=T))/sd(Religiosity_SR, na.rm=T)) #grand-mean
centred and standardised




{#### H1: Social Bonding v.s. Measurement Occasion ####

basemodel <- lm(SB6Z~1 , data = data_long)
MuMIn::AICc(basemodel)

Model <- lme4::lmer(SB6Z ~ 1+
                    (1|ParticipantID), data=data_long, REML = F) # Allow variance within participants
MuMIn::AICc(Model)

Model1 <- lme4::lmer(SB6Z ~ Occasion + #fixed effect of pre v.s. post
                     (1|ParticipantID), data=data_long, REML = F)
MuMIn::AICc(Model1)
```

```
Model2 <- lme4::lmer(SB6Z ~ Occasion +
            (1|ChurchID/ParticipantID), data=data_long, REML = F) # vary participant within ritual site
MuMIn::AICc(Model2)


Model3 <- lme4::lmer(SB6Z ~ Occasion +
            (1|ParticipantID/ChurchID), data=data_long, REML = F)
MuMIn::AICc(Model3)






require(bbmle)
bbmle::AICctab(basemodel, Model, Model1, Model2, Model3,
    logLik=T, weights = T, base = T) #basemodel appears to be far worse than other models.


anova(Model, Model3, Model1, Model2)
# best model here is Model2, allowing variance to change within ParticipantID, within ChurchID.


SB_PrePost_Test <- lmerTest::lmer(SB6Z ~ Occasion +
                  (1|ChurchID/ParticipantID), data=data_long, REML = T)
summary(SB_PrePost_Test)


#Significant effect of measurement occasion on Social bonding.


{## Covariates for H1 ----


Covdata_long <- data_long[!is.na(data_long$Age),]


  CovbaseModel <- lme4::lmer(SB6Z ~ Occasion +
             (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
```

```
  MuMIn::AICc(CovbaseModel)



  CovModel <- lme4::lmer(SB6Z ~ Occasion + Gender +
                       (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(CovModel)

  CovModel1 <- lme4::lmer(SB6Z ~ Occasion + Gender + AgeC +
                        (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(CovModel1)

  CovModel2 <- lme4::lmer(SB6Z ~ Occasion * Gender + AgeC + # check for interaction between gender and
occasion
                        (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(CovModel2)

  CovModel3 <- lme4::lmer(SB6Z ~ Occasion * Gender * AgeC + # check for interaction between gender,
occasion and age
                        (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(CovModel3)



  CovModel4 <- lme4::lmer(SB6Z ~ Occasion + Gender + AgeC + DataCategory + # check for effect of country
                        (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(CovModel4)



  CovModel5 <- lme4::lmer(SB6Z ~ Occasion * Gender * AgeC * DataCategory + # check for interactions
                        (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(CovModel5)
```

```
  CovModel6 <- lme4::lmer(SB6Z ~ Occasion * DataCategory + Gender + AgeC  + # check for interaction
between only country and occasion
                         (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(CovModel6)




  bbmle::AICctab(CovbaseModel, CovModel, CovModel1, CovModel2, CovModel3, CovModel4, CovModel5,
CovModel6,
                 logLik=T, weights = T, base = T) #CovModel4 (no interactions) is the lowest AICc model for
covariates

  anova(CovModel5,  CovModel3, CovModel2, CovModel1, CovModel, CovbaseModel, CovModel6,
CovModel4)
  anova(CovbaseModel, CovModel6, CovModel4)
  # best model here is CovModel4,

  CovSB_Test <- lmerTest::lmer(SB6Z ~ Occasion + Gender + AgeC + DataCategory +
                                 (1|ChurchID/ParticipantID), data=Covdata_long, REML = T)
  summary(CovSB_Test)

  # Significant effect of measurement occasion and country.



}}
{#### H2: Pain Threshold and Social Bonding ####

  PT_basemodel <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory +
                         (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
```

```
  MuMIn::AICc(PT_basemodel)


  PT_Model <- lme4::lmer(SB6Z ~ CuffC * Occasion + Gender + AgeC + DataCategory +
                         (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(PT_Model)


  PT_Model1 <- lme4::lmer(SB6Z ~ CuffC * Occasion + Gender + AgeC + DataCategory *CuffC +
                        (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(PT_Model1)


  PT_Model2 <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory *Occasion +
                        (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(PT_Model2)


  bbmle::AICctab(CovModel4, PT_basemodel, PT_Model, PT_Model1, PT_Model2,
                logLik=T, weights = T, base = T) #PT_basemodel has lower AICc


  anova(CovModel4, PT_basemodel, PT_Model)



  PT_SB_Test <- lmerTest::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory +
                           (1|ChurchID/ParticipantID), data=Covdata_long,  REML = T)
  summary(PT_SB_Test)
  }




{#### Follow-up: The role of Affect ####
```

```
  PANAS_basemodel1 <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory + 
PANASPZ+ # Only Positive Affect
                          (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(PANAS_basemodel1)


  PANAS_basemodel2 <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory + 
PANASNZ+ # Only Negative Affect
                             (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(PANAS_basemodel2)


  PANAS_basemodel3 <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory + 
PANASPZ + PANASNZ+ # Both PANAS subscales
                             (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(PANAS_basemodel3)



  bbmle::AICctab(PT_basemodel, PANAS_basemodel1, PANAS_basemodel2, PANAS_basemodel3,
               logLik=T, weights = T, base = T) #PANAS_basemodel3 has lowest AICc
  anova(PT_basemodel, PANAS_basemodel1, PANAS_basemodel2, PANAS_basemodel3)
  # including both PANAS subscales is best model fit.



  PANAS_Model <- lme4::lmer(SB6Z ~ CuffC + Occasion + Gender + AgeC + DataCategory + 
PANASPZ*PANASNZ+ # check for PANAS interacton
                            (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(PANAS_Model)


  PANAS_Model1 <- lme4::lmer(SB6Z ~ CuffC * PANASPZ * PANASNZ+ Occasion + Gender + AgeC + 
DataCategory +  # check for PANAS interaction with cuff
                         (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
```

```
  MuMIn::AICc(PANAS_Model1)



  PANAS_Model2 <- lme4::lmer(SB6Z ~ CuffC +  DataCategory * PANASPZ + PANASNZ + Occasion +
Gender + AgeC  +  # check for PANAS+ interaction with country
                           (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(PANAS_Model2)

  PANAS_Model3 <- lme4::lmer(SB6Z ~ CuffC +   PANASPZ  + PANASNZ * DataCategory + Occasion +
Gender + AgeC  +  # check for PANAS- interaction with country
                           (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(PANAS_Model3)

  PANAS_Model4 <- lme4::lmer(SB6Z ~ CuffC +  DataCategory + PANASPZ + (PANASPZ * DataCategory)
+ PANASNZ + (PANASNZ * DataCategory) + Occasion + Gender + AgeC  +  # check for PANAS+/-
interaction with country
                           (1|ChurchID/ParticipantID), data=Covdata_long, REML = F)
  MuMIn::AICc(PANAS_Model4)

  bbmle::AICctab(PANAS_basemodel3, PANAS_Model,PANAS_Model1, PANAS_Model2,
PANAS_Model3,PANAS_Model4,
               logLik=T, weights = T, base = T)

  anova(PANAS_basemodel3, PANAS_Model,PANAS_Model1,
PANAS_Model2,PANAS_Model3,PANAS_Model4)
  anova(PANAS_Model2,PANAS_Model4)
# adding multiple interactions does not improve model fi over just PANASP*country interaction
```

```
  PANAS_SB_Test <- lmerTest::lmer(SB6Z ~ CuffC +  DataCategory * PANASPZ + PANASNZ + Occasion +
Gender + AgeC  +  # check for PANAS interaction with cuff
                                  (1|ChurchID/ParticipantID), data=Covdata_long, REML = T)
  summary(PANAS_SB_Test)
}



{# Connection to something bigger ----
  C2G_Data <-  Covdata_long [!is.na(Covdata_long$ConnectedGod),]
  C2G_Data <-  C2G_Data [!is.na(C2G_Data$RelZ),]
  C2G_Data <-  C2G_Data [!is.na(C2G_Data$ServiceAttend_Yrs),]

  C2G_basemodel <- lme4::lmer(SB6Z ~ CuffC +  DataCategory * PANASPZ + PANASNZ + Occasion +
Gender + AgeC +
                             (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
  MuMIn::AICc(C2G_basemodel)

  C2G_Model <- lme4::lmer(SB6Z ~  CuffC + ConnectedGod + DataCategory * PANASPZ + PANASNZ +
Occasion + Gender + AgeC +
                              (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
  MuMIn::AICc(C2G_Model)

  C2G_Model1 <- lme4::lmer(SB6Z ~  CuffC + ConnectedGod + RelZ + DataCategory * PANASPZ +
PANASNZ + Occasion + Gender + AgeC +
                          (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
  MuMIn::AICc(C2G_Model)

  C2G_Model2 <- lme4::lmer(SB6Z ~  CuffC +  ConnectedGod + RelZ + ServiceAttend_Yrs + DataCategory *
PANASPZ + PANASNZ + Occasion + Gender + AgeC +
                          (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
```

```
  MuMIn::AICc(C2G_Model2)


  C2G_Model3 <- lme4::lmer(SB6Z ~  CuffC +  ConnectedGod * RelZ + ServiceAttend_Yrs + DataCategory *
PANASPZ + PANASNZ + Occasion + Gender + AgeC +
                          (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
  MuMIn::AICc(C2G_Model3)


  bbmle::AICctab(C2G_basemodel,C2G_Model, C2G_Model1, C2G_Model2,  C2G_Model3,
               logLik=T, weights = T, base = T)
  # including both connection to god and self-rated religiosity in the model is lowest AICc


  anova(C2G_basemodel,C2G_Model, C2G_Model1, C2G_Model2,C2G_Model3)
# C2G_Model1 (no interaction between religiosity and connection to something bigger) is the model with the
best fit.


  C2G_SB_Test <- lmerTest::lmer(SB6Z ~ Occasion + CuffC + DataCategory * PANASPZ + PANASNZ +
ConnectedGod + Gender + AgeC + RelZ +
                              (1|ChurchID/ParticipantID), data= C2G_Data, REML = T)
  summary(C2G_SB_Test)


  # Pain Threshold (cuff), Connection to God, Self-rated religiosity, positive & negative affect and measurement
occasion all significantly predict Bonding.


}




### Predictor of Pain threshold ####


Predict_PT_base <- lme4::lmer(CuffC ~ 1+
                          (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
```

```
MuMIn::AICc(Predict_PT_base)



Predict_PT_Model <- lme4::lmer(CuffC ~ Occasion +
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model)

Predict_PT_Model1 <- lme4::lmer(CuffC ~ Occasion + SB6Z +
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model1)

Predict_PT_Model2 <- lme4::lmer(CuffC ~ Occasion * SB6Z +
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model2)

Predict_PT_Model3 <- lme4::lmer(CuffC ~ Occasion * SB6Z + DataCategory+
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model3)

Predict_PT_Model4 <- lme4::lmer(CuffC ~ Occasion * SB6Z + DataCategory+ ConnectedGod +
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model4)

Predict_PT_Model5 <- lme4::lmer(CuffC ~ Occasion * SB6Z + DataCategory+ Gender +
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model5)

Predict_PT_Model6 <- lme4::lmer(CuffC ~ Occasion * SB6Z * DataCategory + Gender +
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model6)
```

```
Predict_PT_Model7 <- lme4::lmer(CuffC ~ Occasion * SB6Z * Gender + DataCategory  +
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model7)

Predict_PT_Model8 <- lme4::lmer(CuffC ~ Occasion * SB6Z + Gender + DataCategory  + RelZ +
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model8)

Predict_PT_Model9 <- lme4::lmer(CuffC ~ Occasion * SB6Z + Gender + DataCategory  + RelZ +
ConnectedGod +
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model9)

Predict_PT_Model10 <- lme4::lmer(CuffC ~ Occasion * SB6Z + Gender + DataCategory  + RelZ  + PANASPZ
+ PANASNZ +
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model10)

Predict_PT_Model11 <- lme4::lmer(CuffC ~ Occasion * SB6Z + Gender + DataCategory  + RelZ  + PANASPZ
+ PANASNZ + ConnectedGod+
                         (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model11)



bbmle::AICctab(Predict_PT_base, Predict_PT_Model, Predict_PT_Model1, Predict_PT_Model2,
Predict_PT_Model3,
        Predict_PT_Model4, Predict_PT_Model5, Predict_PT_Model6, Predict_PT_Model7,
        Predict_PT_Model8, Predict_PT_Model9, Predict_PT_Model10, Predict_PT_Model11,
        logLik=T, weights = T, base = T)
```

```
# Predict_PT_Model8 is most parsimonious model for predicting PT.


anova(Predict_PT_Model8, Predict_PT_Model9, Predict_PT_Model10, Predict_PT_Model11)


# models based on Predict_PT_Model8


Predict_PT_Model12 <- lme4::lmer(CuffC ~ Occasion * SB6Z + RelZ * Occasion + Gender + DataCategory  +
                                 (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model12)


Predict_PT_Model13 <- lme4::lmer(CuffC ~ Occasion * SB6Z +  Gender * Occasion + RelZ + DataCategory  +
                                 (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model13)


Predict_PT_Model14 <- lme4::lmer(CuffC ~ Occasion * SB6Z + DataCategory * Occasion + Gender + RelZ  +
                                 (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model14)


bbmle::AICctab(Predict_PT_Model8, Predict_PT_Model12, Predict_PT_Model13,Predict_PT_Model14,
               logLik=T, weights = T, base = T)


# Predict_PT_Model13 is  most parsimonious model for predicting PT.


Predict_PT_Model15 <- lme4::lmer(CuffC ~ Occasion * SB6Z +  Gender * Occasion + RelZ + DataCategory *
Occasion  +
                                 (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)
MuMIn::AICc(Predict_PT_Model15)


Predict_PT_Model16 <- lme4::lmer(CuffC ~ Occasion * SB6Z +  Gender * Occasion + RelZ * Occasion +
DataCategory   +
```

```
                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = F)

MuMIn::AICc(Predict_PT_Model16)


bbmle::AICctab(Predict_PT_Model13, Predict_PT_Model15, Predict_PT_Model16,

          logLik=T, weights = T, base = T)


# Predict_PT_Model13 is still most parsimonious model for predicting PT.


Predict_PT_Test <- lmerTest::lmer(CuffC ~ Occasion * SB6Z + Gender *Occasion + DataCategory  + RelZ +

                        (1|ChurchID/ParticipantID), data= C2G_Data, REML = T)

summary(Predict_PT_Test)



#                  Estimate Std. Error   df    t-value  Pr(>|t|)

# (Intercept)       29.869     15.531 164.384   1.923  0.05618 .

# Occasion          39.137     11.911 238.882   3.286  0.00117 **

# SB6Z               5.427      3.553 466.924   1.528  0.12730

# Gender           -16.695      7.418 330.179  -2.251  0.02507 *

# DataCategory     -16.005     11.070  22.757  -1.446  0.16187

# RelZ             -10.066      3.362 245.540  -2.994  0.00303 **

# Occasion:SB6Z      6.520      3.533 254.188   1.846  0.06611 .

# Occasion:Gender  -12.061      6.846 237.023  -1.762  0.07940 .


# Measurement occasion, Gender and religiosity predict pain threshold.
```

Appendix 16 – Study 2 R Script

```
#### Social Bonding at Sunday Assembly Rituals ####

#load packages

rm(list=ls())

library("MASS",character.only=TRUE)

library(lme4)

library(MBESS)

library(dplyr)

library(MASS)

library(apaTables)

library(psychometric)

require(foreign)

require(magrittr)

require(ggplot2)

require(ggpubr)

require(lattice)

require(reshape2)

require(nlme)

require(MuMIn)

require(PairedData)
```

```
require(gridExtra)

require(ggfortify)

require(multilevel)

require(robumeta)

require(psych)

require(GPArotation)

require(lm.beta)

require(lmtest)

require(car)

require(nparLD)

require(WRS2)

require(npsm)

require(exactRankTests)


## Can't recall  which of these libraries are needed as I've used different ones at different times, so just load all##


### Import Data ###


data <- read.csv("Church and SA data - Wide.csv", header = TRUE) # includes participants otherwise excluded by cuff.

length(data$SB6_Pre) # N = 99
```

```
SB_CV <- read.csv("Social Bonding Factor Analysis.csv", header=TRUE) # Social Bonding construct validity (Sunday Assembly participants only)

data_Chr <- data[data$SA_Ctrl==0,] # Churches Only

data_SA <- data[data$SA_Ctrl==1,] # SA Only

# Basic Information

#Participants ages/gender:

mean(data$Age) #48.2

sd(data$Age) #18.21

count(data, "Gender") #32 Male, 66 Female, 1 Non-Binary

# Churches

mean(data_Chr$Age) #57.8

sd(data_Chr$Age) #18.08

count(data_Chr, "Gender") #16 Male, 34 Female

#Sunday Assemblies

mean(data_SA$Age) #38.4
```

sd(data_SA$Age) #12.21

count(data_SA, Gender) #16 Male, 32 Female, 1 Non-Binary

#Participants' overall Religiosity:

mean(data$Religiosity) #3.56 (out of 7)

sd(data$Religiosity) # 2.25

#Church

mean(data_Chr$Religiosity) #5.41 (out of 7)

sd(data_Chr$Religiosity) # 1.36

#SA

mean(data_SA$Religiosity) #1.63 (out of 7)

sd(data_SA$Religiosity) # 1.05

Social Bonding Measure (SB6) - Factor Analysis and Reliability -----------------------------------

Here we conducted a factor analysis first of the 5 verbal social bonding questions. (lines 87-123)

We then saught to see if it had some construct by correlating it with the IOS (Aron et al., 1992) (lines 124-165)

It did have validity, and we incorporated IOS into the measure, and did a second factor analysis. (lines 166-249)

For factor diagrams, see lines 203-207. For reliability see lines 208-247

First only Sunday Assembly (SA) social bonding was measured, then Church data, then a combination, for completeness.

```
{## Factor Analysis of SB5 ####


  #Factor Analysis:

  SB5_Cor_Prea <- SB_CV[,2:6]

  SB5_Cor_Pre <- round(cor(SB5_Cor_Prea),2)

  SB5_Cor_Pre


  SB5_Cor_Posta <- SB_CV[,10:14]

  SB5_Cor_Post <- round(cor(SB5_Cor_Posta),2)

  SB5_Cor_Post

  #Factor analysis of the pre-service SB5 data

  factors_SB5_Pre <- fa(r = SB5_Cor_Pre, fm = "pa")

  #Getting the factor loadings and model analysis

  factors_SB5_Pre

  scree(SB5_Cor_Pre) # scree plot suggests 1 factor

  # Factor Analysis using method =  principal axis (pa)

  # Default is oblimin - an oblique rotation

  # factor analysis shows that 1 factor is sufficient.

  # Mean item complexity = 1

  # Variance explained = .72
```

```
  # RMSR = 0.04

  # df corrected RMSR = 0.06



  #Factor analysis of the post-service SB5 data

  factors_SB5_Post <- fa(r = SB5_Cor_Post, fm = "pa")

  #Getting the factor loadings and model analysis

  factors_SB5_Post

  scree(SB5_Cor_Post) # scree plot suggests 1 factor

  #Factor Analysis using method =  principal axis (pa)

  #Default is oblimin - an oblique rotation

  # factor analysis shows that 1 factor is sufficient.

  #Mean item complexity = 1

  # Variance explained = .75

  # RMSR = 0.06

  # df corrected RMSR = 0.08



}

{## Validity check of SB5 and IOS (similar Constructs?) ####



  IOS_Pre <- SB_CV$IOS_Pre

  SB5_Pre <- SB_CV$SB5_Pre

  IOS_Post <- SB_CV$IOS_Post

  SB5_Post <- SB_CV$SB5_Post
```

```
ggdensity(SB5_Pre,
          main = "Density plot of Pre-Service SB5",
          xlab = "Pre-Service SB5")
ggdensity(SB5_Post,
          main = "Density plot of Post-Service SB5",
          xlab = "Post-Service SB5")
ggdensity(IOS_Pre,
          main = "Density plot of Pre-Service IOS",
          xlab = "Pre-Service IOS")
ggdensity(IOS_Post,
          main = "Density plot of Post-Service IOS",
          xlab = "Post-Service IOS")


shapiro.test(SB5_Pre) # W = .967 - Not stat. sig. dif. from normal(p = .189)
shapiro.test(IOS_Pre) # W = .918 - stat. sig. dif. from normal (p = .002)
shapiro.test(SB5_Post) # W = .951 - stat. sig. dif. from normal (p = .039)
shapiro.test(IOS_Post) # W = .939 - stat. sig. dif. from normal (p = .013)

# Non-parametric tests needed for construct validity

## non-parametric ##
```

```
  Pre_CVSR <- cor.test(IOS_Pre,SB5_Pre, method = "spearman", conf.level = 0.95) # Pre-service construct validity

  Pre_CVSR # rho = .774, p < .001

  Post_CVSR <- cor.test(IOS_Post,SB5_Post, method = "spearman", conf.level = 0.95) # post-service construct validity

  Post_CVSR # rho = .722, p < .001



  # (Parametric versions, For completeness)

  Pre_CV <- cor.test(IOS_Pre,SB5_Pre, method = "pearson", conf.level = 0.95) # Pre-service construct validity

  Pre_CV # r = .760, p < .001

  Post_CV <- cor.test(IOS_Post,SB5_Post, method = "pearson", conf.level = 0.95) # post-service construct validity

  Post_CV # r = .733, p < .001




}

{## Factor Analysis of SB6 ####

  #Factor Analysis:

  SB6_Cor_Prea <- select(SB_CV, Connected_Pre, Emo_Close_Pre, Trust_Pre, Like_Pre, Common_Pre, IOS_Pre)

  head(SB6_Cor_Prea)

  SB6_Cor_Pre <- round(cor(SB6_Cor_Prea),2)

  SB6_Cor_Pre
```

```
SB6_Cor_Posta <- select(SB_CV, Connected_Post, Emo_Close_Post, Trust_Post, Like_Post, Common_Post,
IOS_Post)

SB6_Cor_Post <- round(cor(SB6_Cor_Posta),2)

SB6_Cor_Post



#Factor analysis of the pre-service SB5 data

factors_SB6_Pre <- fa(r = SB6_Cor_Pre, fm = "pa")

#Getting the factor loadings and model analysis

factors_SB6_Pre

scree(SB6_Cor_Pre) # scree plot suggests 1 factor

#Factor Analysis using method =  principal axis (pa)

#Default is oblimin - an oblique rotation

# factor analysis shows that 1 factor is sufficient.

#Mean item complexity = 1

# Var explained 0.7

# RMSR = 0.05

# df corrected RMSR = 0.06



#Factor analysis of the post-service SB5 data

factors_SB6_Post <- fa(r = SB6_Cor_Post, fm = "pa")

#Getting the factor loadings and model analysis

factors_SB6_Post

scree(SB6_Cor_Post) # scree plot suggests 1 factor
```

```
  # Factor Analysis using method =  principal axis (pa)

  # Default is oblimin - an oblique rotation

  # factor analysis shows that 1 factor is sufficient.

  # Mean item complexity = 1

  # RMSR = 0.05

  # df corrected RMSR = 0.07



  # Factor Diagrams, showing loadings for the single factor.

  fa.diagram(factors_SB5_Pre, sort = TRUE) # factor loadings average > .7, Likely essentially tau-equivalent
(alpha ~ omega)

  fa.diagram(factors_SB5_Post, sort = TRUE) # factor loadings average > .7, Likely essentially tau-equivalent
(alpha ~ omega)

  fa.diagram(factors_SB6_Pre, sort = TRUE) # factor loadings average > .7, Likely essentially tau-equivalent
(alpha ~ omega)

  fa.diagram(factors_SB6_Post, sort = TRUE) # factor loadings average > .7, Likely essentially tau-equivalent
(alpha ~ omega)

}

{## SB Scale Reliability ####

  SASB5_pre_omega <- ci.reliability(SB5_Cor_Prea, type = "omega", conf.level = 0.95, B=1000)

  SASB5_pre_omega # SB5_Pre  omega = .93[.90, .96]

    SASB5_post_omega <- ci.reliability(SB5_Cor_Posta, type = "omega", conf.level = 0.95, B=1000)

  SASB5_post_omega# SB5_post omega = .94[.90, .97]



  SASB6_pre_omega <- ci.reliability(SB6_Cor_Prea, type = "omega", conf.level = 0.95, B=1000)
```

```
SASB6_pre_omega # SB6_Pre  omega = .93[.91, .96]

SASB6_post_omega <- ci.reliability(SB6_Cor_Posta, type = "omega", conf.level = 0.95, B=1000)

sASB6_post_omega# SB6_post omega = .93[.90, .96]



SASB6_Pre_Alpha <- alpha(SB6_Cor_Prea)

SASB6_Pre_Alpha # SB6_Pre  alpha = .93[.90, .96]

SASB6_Post_Alpha <- alpha(SB6_Cor_Posta)

SASB6_Post_Alpha # SB6_Post  alpha = .93[.90, .96]

# (as can be seen here, alpha ~ omega, so either value is fine to use)



Chr_SB6_Cor_Pre <- select(data_Chr, SBpre_Connected, SBpre_Emo_close, SBpre_trust, SBpre_like,
SBpre_common, SBpre_IOS)

Chr_SB6_Cor_Post <- select(data_Chr, SBpost_Connected, SBpost_Emo_close, SBpost_trust, SBpost_like,
SBpost_common, SBpost_IOS)



ChrSB6_pre_omega <- ci.reliability(Chr_SB6_Cor_Pre, type = "omega", conf.level = 0.95, B=1000)

ChrSB6_pre_omega # Church SB6 Pre omega = .94[.90, .97]

ChrSB6_pre_alpha <- alpha(Chr_SB6_Cor_Pre)

ChrSB6_pre_alpha  # Church SB6 Pre  alpha = .94[.91, .96]

ChrSB6_post_omega <- ci.reliability(Chr_SB6_Cor_Post, type = "omega", conf.level = 0.95, B=1000)

ChrSB6_post_omega# Church SB6 Post omega = .88[.81, .95]

ChrSB6_post_alpha <- alpha(Chr_SB6_Cor_Post)

ChrSB6_post_alpha  # Church SB6 Post  alpha = .89[.84, .93]
```

```
  All_SB6_Cor_Pre <- select(data, SBpre_Connected, SBpre_Emo_close, SBpre_trust, SBpre_like,
SBpre_common, SBpre_IOS)
  All_SB6_Cor_Post <- select(data, SBpost_Connected, SBpost_Emo_close, SBpost_trust, SBpost_like,
SBpost_common, SBpost_IOS)


  All_SB6_Pre_Alpha <- alpha(All_SB6_Cor_Pre)
  All_SB6_Pre_Alpha # All SB6 Pre alpha = .93 [.91, .95]
  All_SB6_Post_Alpha <- alpha(All_SB6_Cor_Post)
  All_SB6_Post_Alpha # All SB6 Pre alpha = .91 [.88, .94]
  AllSB6_pre_omega <- ci.reliability(All_SB6_Cor_Pre, type = "omega", interval.type = "perc", conf.level =
0.95, B=500)
  AllSB6_pre_omega # SB6_Pre  omega = .93 [.91, .96]
  AllSB6_post_omega <- ci.reliability(All_SB6_Cor_Post, type = "omega", interval.type = "perc", conf.level =
0.95, B=1000)
  AllSB6_post_omega# SB6_post omega = .90 [.87, .94]


}
{# PANASP Scale Reliablity  ####
  #SA
  SA_PANASP_Pre <-  select(data_SA, PANAS1_interested,
                        PANAS1_excited,
                        PANAS1_Strong,
                        PANAS1_Enthusiastic,
```

```
                    PANAS1_Proud,

                    PANAS1_Alert,

                    PANAS1_Inspired,

                    PANAS1_Determined,

                    PANAS1_Attentive,

                    PANAS1_Active)

scree(SA_PANASP_Pre)

factors_PANASP_Pre <- fa(r = SA_PANASP_Pre, fm = "pa")

fa.diagram(factors_PANASP_Pre) # Not tau-equivalent

SAPANASP_pre_omega <- ci.reliability(SA_PANASP_Pre, type = "omega", conf.level = 0.95, B=1000)

SAPANASP_pre_omega # .90 [.85, .95]

SAPANASP_Pre_Alpha <- alpha(SA_PANASP_Pre)

SAPANASP_Pre_Alpha # .90 [.85, .94]



SA_PANASP_Post <-  select(data_SA, PANAS2_interested,

                    PANAS2_excited,

                    PANAS2_Strong,

                    PANAS2_Enthusiastic,

                    PANAS2_Proud,

                    PANAS2_Alert,

                    PANAS2_Inspired,

                    PANAS2_Determined,

                    PANAS2_Attentive,
```

```
                 PANAS2_Active)

scree(SA_PANASP_Post)

factors_PANASP_Post <- fa(r = SA_PANASP_Post, fm = "pa")

fa.diagram(factors_PANASP_Post) # tau-equivalent

SAPANASP_post_omega <- ci.reliability(SA_PANASP_Post, type = "omega", conf.level = 0.95, B=1000)

SAPANASP_post_omega # .96 [.94, .98]

SAPANASP_Post_Alpha <- alpha(SA_PANASP_Post)

SAPANASP_Post_Alpha # .96 [.94, .97]



#Churches

Chr_PANASP_Pre <-  select(data_Chr, PANAS1_interested,

                 PANAS1_excited,

                 PANAS1_Strong,

                 PANAS1_Enthusiastic,

                 PANAS1_Proud,

                 PANAS1_Alert,

                 PANAS1_Inspired,

                 PANAS1_Determined,

                 PANAS1_Attentive,

                 PANAS1_Active)

scree(Chr_PANASP_Pre)

factors_PANASP_Pre <- fa(r = Chr_PANASP_Pre, fm = "pa")

fa.diagram(factors_PANASP_Pre) # Not tau-equivalent
```

```
ChrPANASP_pre_omega <- ci.reliability(Chr_PANASP_Pre, type = "omega", conf.level = 0.95, B=1000)

ChrPANASP_pre_omega # .90 [.86, .95]

ChrPANASP_Pre_Alpha <- alpha(Chr_PANASP_Pre)

ChrPANASP_Pre_Alpha # .90 [.86, .94]



Chr_PANASP_Post <-  select(data_Chr, PANAS2_interested,

                    PANAS2_excited,

                    PANAS2_Strong,

                    PANAS2_Enthusiastic,

                    PANAS2_Proud,

                    PANAS2_Alert,

                    PANAS2_Inspired,

                    PANAS2_Determined,

                    PANAS2_Attentive,

                    PANAS2_Active)

scree(Chr_PANASP_Post)

factors_PANASP_Post <- fa(r = Chr_PANASP_Post, fm = "pa")

fa.diagram(factors_PANASP_Post) # Not tau-equivalent

ChrPANASP_post_omega <- ci.reliability(Chr_PANASP_Post, type = "omega", conf.level = 0.95, B=1000)

ChrPANASP_post_omega # .94 [.91, .96]

ChrPANASP_Post_Alpha <- alpha(Chr_PANASP_Post)

ChrPANASP_Post_Alpha # .93 [.91, .96]
```

```
# all#

ALL_PANASP_Pre <-  select(data, PANAS1_interested,

                      PANAS1_excited,

                      PANAS1_Strong,

                      PANAS1_Enthusiastic,

                      PANAS1_Proud,

                      PANAS1_Alert,

                      PANAS1_Inspired,

                      PANAS1_Determined,

                      PANAS1_Attentive,

                      PANAS1_Active)

scree(ALL_PANASP_Pre)

factors_PANASP_Pre <- fa(r = ALL_PANASP_Pre, fm = "pa")

fa.diagram(factors_PANASP_Pre) # Not tau-equivalent

ALLPANASP_pre_omega <- ci.reliability(ALL_PANASP_Pre, type = "omega", conf.level = 0.95, B=1000)

ALLPANASP_pre_omega # .90 [.86, .93]

ALLPANASP_Pre_Alpha <- alpha(ALL_PANASP_Pre)

ALLPANASP_Pre_Alpha # .90 [.86, .93]



ALL_PANASP_Post <-  select(data, PANAS2_interested,

                      PANAS2_excited,

                      PANAS2_Strong,

                      PANAS2_Enthusiastic,
```

```
                    PANAS2_Proud,
                    PANAS2_Alert,
                    PANAS2_Inspired,
                    PANAS2_Determined,
                    PANAS2_Attentive,
                    PANAS2_Active)
  scree(ALL_PANASP_Post)
  factors_PANASP_Post <- fa(r = ALL_PANASP_Post, fm = "pa")
  fa.diagram(factors_PANASP_Post) # Not tau-equivalent
  ALLPANASP_post_omega <- ci.reliability(ALL_PANASP_Post, type = "omega", conf.level = 0.95, B=1000)
  ALLPANASP_post_omega # .94 [.93, .96]
  ALLPANASP_Post_Alpha <- alpha(ALL_PANASP_Post)
  ALLPANASP_Post_Alpha # .94 [.93, .96]


}


{# PANASN Scale Reliability ####
  ## PANASN ##
  #SA


  SA_PANASN_Pre <-  select(data_SA, PANAS1_distressed,
                   PANAS1_Upset,
                   PANAS1_Guilty,
```

```
                PANAS1_Scared,
                PANAS1_Hostile,
                PANAS1_Irritable,
                PANAS1_Ashamed,
                PANAS1_Nervous,
                PANAS1_Jittery,
                PANAS1_Afraid)
scree(SA_PANASN_Pre)
factors_PANASN_Pre <- fa(r = SA_PANASN_Pre, fm = "pa")
fa.diagram(factors_PANASN_Pre) # Not tau-equivalent
SAPANASN_pre_omega <- ci.reliability(SA_PANASN_Pre, type = "omega", conf.level = 0.95, B=1000)
SAPANASN_pre_omega # .81 [.70, .93]
SAPANASN_Pre_Alpha <- alpha(SA_PANASN_Pre)
SAPANASN_Pre_Alpha # .79 [.70, .87]


SA_PANASN_Post <-  select(data_SA, PANAS2_distressed,
                PANAS2_Upset,
                PANAS2_Guilty,
                PANAS2_Scared,
                PANAS2_Hostile,
                PANAS2_Irritable,
                PANAS2_Ashamed,
                PANAS2_Nervous,
```

```
                PANAS2_Jittery,
                PANAS2_Afraid)
scree(SA_PANASN_Post)
factors_PANASN_Post <- fa(r = SA_PANASN_Post, fm = "pa")
fa.diagram(factors_PANASN_Post) # Not tau-equivalent
SAPANASN_post_omega <- ci.reliability(SA_PANASN_Post, type = "omega", conf.level = 0.95, B=1000)
SAPANASN_post_omega # .79 [.59, .99]
SAPANASN_Post_Alpha <- alpha(SA_PANASN_Post)
SAPANASN_Post_Alpha # .82 [.75, .89]



#Churches
Chr_PANASN_Pre <-  select(data_Chr, PANAS1_distressed,
                PANAS1_Upset,
                PANAS1_Guilty,
                PANAS1_Scared,
                PANAS1_Hostile,
                PANAS1_Irritable,
                PANAS1_Ashamed,
                PANAS1_Nervous,
                PANAS1_Jittery,
                PANAS1_Afraid)
scree(Chr_PANASN_Pre)
```

```
factors_PANASN_Pre <- fa(r = Chr_PANASN_Pre, fm = "pa")

fa.diagram(factors_PANASN_Pre) # Not tau-equivalent

ChrPANASN_pre_omega <- ci.reliability(Chr_PANASN_Pre, type = "omega", conf.level = 0.95, B=1000)

ChrPANASN_pre_omega # .88 [.82, .94]

ChrPANASN_Pre_Alpha <- alpha(Chr_PANASN_Pre)

ChrPANASN_Pre_Alpha # .86 [.81, .91]



Chr_PANASN_Post <-  select(data_Chr, PANAS2_distressed,

                  PANAS2_Upset,

                  PANAS2_Guilty,

                  PANAS2_Scared,

                  PANAS2_Hostile,

                  PANAS2_Irritable,

                  PANAS2_Ashamed,

                  PANAS2_Nervous,

                  PANAS2_Jittery,

                  PANAS2_Afraid)

scree(Chr_PANASN_Post)

factors_PANASN_Post <- fa(r = Chr_PANASN_Post, fm = "pa")

fa.diagram(factors_PANASN_Post) # Not tau-equivalent

ChrPANASN_post_omega <- ci.reliability(Chr_PANASN_Post, type = "omega", conf.level = 0.95, B=1000)

ChrPANASN_post_omega # .94 [.85, .99]

ChrPANASN_Post_Alpha <- alpha(Chr_PANASN_Post)
```

```
ChrPANASN_Post_Alpha # .92 [.89, .95]


#All


ALL_PANASN_Pre <-  select(data, PANAS1_distressed,
                   PANAS1_Upset,
                   PANAS1_Guilty,
                   PANAS1_Scared,
                   PANAS1_Hostile,
                   PANAS1_Irritable,
                   PANAS1_Ashamed,
                   PANAS1_Nervous,
                   PANAS1_Jittery,
                   PANAS1_Afraid)
scree(ALL_PANASN_Pre)
factors_PANASN_Pre <- fa(r = ALL_PANASN_Pre, fm = "pa")
fa.diagram(factors_PANASN_Pre) # Not tau-equivalent
ALLPANASN_pre_omega <- ci.reliability(ALL_PANASN_Pre, type = "omega", conf.level = 0.95, B=1000)
ALLPANASN_pre_omega # .85 [.80, .90]
ALLPANASN_Pre_Alpha <- alpha(ALL_PANASN_Pre)
ALLPANASN_Pre_Alpha # .82 [.78, .87]


ALL_PANASN_Post <-  select(data, PANAS2_distressed,
```

```
                        PANAS2_Upset,

                        PANAS2_Guilty,

                        PANAS2_Scared,

                        PANAS2_Hostile,

                        PANAS2_Irritable,

                        PANAS2_Ashamed,

                        PANAS2_Nervous,

                        PANAS2_Jittery,

                        PANAS2_Afraid)

  scree(ALL_PANASN_Post)

  factors_PANASN_Post <- fa(r = ALL_PANASN_Post, fm = "pa")

  fa.diagram(factors_PANASN_Post) # Not tau-equivalent

  ALLPANASN_post_omega <- ci.reliability(ALL_PANASN_Post, type = "omega", conf.level = 0.95,
B=1000)

  ALLPANASN_post_omega # .86 [.77, .96]

  ALLPANASN_Post_Alpha <- alpha(ALL_PANASN_Post)

  ALLPANASN_Post_Alpha # .86 [.82, .90]

  }



### -----------------------------  ###

###    Main Hypothesis Tests      ####

### -----------------------------  ###
```

```
### ----------------------------------  ###

###    Hypothesis 1 - Data Assumptions  ####

### ----------------------------------  ###



  ## ------------- ##

  {## Density Plots  ====

    ## ------------- ##



    ggdensity(data_SA$SB6_Pre,

              main = "Density plot of Pre-Service Social Bonding Measure",

              xlab = "Pre-Service Social Bonding")



    # Doesn't look very normal



    ggdensity(data_SA$SB6_Post,

              main = "Density plot of Post-Service Social Bonding Measure",

              xlab = "Post-Service Social Bonding")



    # Looks somewhat normal



    ggdensity(data_SA$SB6_Change,

              main = "Density plot of change in Social Bonding Measure",

              xlab = "Social Bonding Change")
```

```
    # Does not look normal

  }

  ## --------- ##

  {## Q-Q Plots ====

    ## --------- ##

    ggqqplot(data_SA$SB6_Pre)

    ggqqplot(data_SA$SB6_Post)

    ggqqplot(data_SA$SB6_Change)

  }

  ## ----------------- ##

  {## Shaprio-Wilk Test ====

    ## ----------------- ##

    shapiro.test(data_SA$SB6_Pre) # W = .977, p = .433 - Not stat. sig. dif. from normal

    shapiro.test(data_SA$SB6_Post) # W = .952, p = .047 - stat. sig. dif. from normal

    shapiro.test(data_SA$SB6_Change) # W = .816, p = < .001  - stat. sig. dif. from normal

  }

### ------------------------------------------------------------------------------- ###
```

```
### Hypothesis 1: Change from Before to After Sunday Assembly ----------------------- ####

### ---------------------------------------------------------------------------------- ###

{## Wilcoxon Signed Ranks ====

  {# Social Bonding ####

    # descriptives #

    length(data_SA$SB6_Pre) # 49

    mean(data_SA$SB6_Pre) # 4.27

    sd(data_SA$SB6_Pre)  # 1.26

    median(data_SA$SB6_Pre) # 4.33

    length(data_SA$SB6_Post) #49

    mean(data_SA$SB6_Post) # 4.96

    sd(data_SA$SB6_Post) # 1.16

    median(data_SA$SB6_Post) # 5.17

    # non-parametric test #

    Wilcox_SB <- wilcox.test(data_SA$SB6_Pre, data$SB6_Post, paired = TRUE, exact = TRUE, alternative =
"less")

    Wilcox_SB #output result
```

```
# V = 89.5, p = < .001

SB_diff <- c(data_SA$SB6_Pre- data_SA$SB6_Post) #create the differences

SB_diff <- SB_diff[ SB_diff!=0 ] #delete all differences equal to zero

SB_diff_rank <- rank(abs(SB_diff)) #check the ranks of the differences, taken in absolute

SB_diff_rank_sign <- SB_diff_rank * sign(SB_diff) #check the sign to the ranks, recalling the signs of the values of the differences

SB_ranks_P <- sum(SB_diff_rank_sign[SB_diff_rank_sign > 0]) #calculating the sum of ranks assigned to the differences as a positive, ie greater than zero

SB_ranks_N <- -sum(SB_diff_rank_sign[SB_diff_rank_sign < 0]) #calculating the sum of ranks assigned to the differences as a negative, ie less than zero


SB_ranks_P # used in effect size calculation (Kerby)

SB_ranks_N # used in effect size calculation (Kerby)


# effect size #

Zstat_SB<-qnorm(Wilcox_SB$p.value/2) #Z score

Zstat_SB #print the Z-score = -5.02

SB_Bf_pval <- Wilcox_SB$p.value * 3 # Bonferroni correction (should it be needed)

SB_Bf_pval

SB_rR <- abs(Zstat_SB)/sqrt(49*2)

# Effect size (Rosenthal, 1994) - more conservative effect size.

SB_rR # r = 0.51

SB_rK <- ((SB_ranks_P/(SB_ranks_P+SB_ranks_N))-(SB_ranks_N/(SB_ranks_P+SB_ranks_N)))
```

```
    # Effect size (Kerby, 2014) - Less conservative.

    abs(SB_rK) # r= 0.84



    # two-tailed

    Wilcox_SB <- wilcox.test(data_SA$SB6_Pre, data_SA$SB6_Post, paired = TRUE, exact = TRUE)

    Wilcox_SB #  V = 89.5, p = < .001

  }

}



### ---------------------------------  ###

###    Hypothesis 2 - Power Analysis  ####

### ---------------------------------  ###

#based on Charles et . (2020)

effect_size_rR <- .34

effect_size_rK <- .62



#convert r -> f



#f = sqrt(R^2/ (1-R^2))

conservative_f <-sqrt(.34^2/ (1-.34^2)) # f = .3615...

simpledif_to_f <- sqrt(.62^2/ (1-.62^2)) # f = .7902...



cor(data$SB6_Pre,data$SB6_Post, method = "pearson")
```

```
# 0.753...

#though, data may not be normally distributed.

shapiro.test(data$SB6_Pre)

#W = 0.96781, p-value = 0.01506

shapiro.test(data$SB6_Post)

#W = 0.94679, p-value = 0.0005132

cor(data$SB6_Pre,data$SB6_Post, method = "spearman")

# 0.799...

### -----------------------------------  ###

###    Hypothesis 2 - Data assumptions  ####

### -----------------------------------  ###

shapiro.test(data_SA$SB6_Pre)

#W = 0.97663, p-value = 0.4334

shapiro.test(data_SA$SB6_Post)

#W = 0.95264, p-value = 0.04727
```

```
shapiro.test(data_Chr$SB6_Pre)

#W = 0.92674, p-value = 0.003742



shapiro.test(data_Chr$SB6_Post)

#W = 0.93877, p-value = 0.01097



# Assumption of normality not met. Non-parametric ANOVA required.



data_long <- read.csv("Church and SA data - LONG.csv", header = TRUE)



data_long$FactRT <- factor(data_long$SA_Ctrl) # Ritual type - SA  or Control (churches) as a factor

data_long$FactPP <- factor(data_long$Pre_Post) # Measurement Occasion as a factor

require(plyr)

data_long$FactPP <- revalue(data_long$FactPP, c("Pre"="Pre-Ritual","Post"="Post-Ritual"))




require(car)

  leveneTest(SB6 ~ FactRT,data_long)

  # Levene's Test for Homogeneity of Variance (center = median)

  #     Df F value Pr(>F)

  # group   1  2.7988 0.09593

  # 196

# Homogeneity of Variances assumtion not violated
```

```
### ---------------------------------------------------  ###

###    Hypothesis 2 - Difference Between SA and Church   ####

### ---------------------------------------------------  ###


require(nparLD) # non-parametric ANOVA package


  ex.f1f1np <- nparLD(SB6 ~ FactRT * FactPP, data = data_long, subject = "Participant_Code", description =
FALSE)

  plot(ex.f1f1np)


  summary(ex.f1f1np)


  nonpar_ANOVA <- f1.ld.f1(data_long$SB6, data_long$FactPP, data_long$FactRT,
data_long$Participant_Code)


  nonpar_ANOVA$RTE

  # RTE < .5 means there is less than 50% chance of randomly choosing a participant from this sample with a
higher than average SB6.

  # RTE > .5 means there is greater than 50% chance of randomly choosing a participant from this sample with a
higher than average SB6.


  nonpar_ANOVA$case2x2

  #            Statistic  p-value(N)       df  p-value(T)
```

```
  # Group       2.093185 3.633265e-02 95.98559 3.896964e-02

  # Time       -7.215408 5.377263e-13 94.83816 1.312904e-10

  # Group:Time  1.942023 5.213437e-02 94.83816 5.510160e-02



  nonpar_ANOVA$ANOVA.test

#             Statistic  df     p-value

#  Group       4.381423  1 3.633265e-02

#  Time       52.062108  1 5.377263e-13

#  Group:Time  3.771452  1 5.213437e-02



  # Significant Main Effect Measurement Occasion (p < .001) and Group (p = .036)

  # No Significant interaction effect (p = .052)



  nonpar_ANOVA$ANOVA.test.mod.Box  # Whole model.

  #        Statistic     df1      df2     p-value

  # Group  4.381423       1    95.98559  0.03896964




  ## Feys (2016) suggest that in a non-parametric, Mixed-ANOVA design with only 2 time points (pre-post
test),

  ## a non-parametric ANCOVA could be used instead (p. 373-374). reccomends a few options:



##Feys (2016) non-parametric ANOVA Follow-Up ####
```

```
# The onecovahomog function from npsm

# 'yuen', 'Kruskal-Wallis' and ' Exact Wilcoxon-Mann-Whitney'from WRS2


## NPSM ANCOVA results:  ###

library("npsm")

ANCOVAdata=data[,c('SB6_Post','SA_Ctrl')] ## Data for ANOVA - Post-SB6 column 1 and Group in column 2

xcov<-cbind(data['SB6_Pre']) # Covariate - in this case pre-SB6

onecovahomog(2,ANCOVAdata,xcov,print.table=TRUE) # 2 levels, Post-SB6 by Group, with Pre-SB6 as Covariates

# There is not a significant effect of group on post-SB6 response after controlling for pre-SB6 response. F(1,98) = 1.81, p = .18 (i.e. no interaction effect)


## WRS2 Yuen

library("WRS2")

yuen(SB6_Change ~ SA_Ctrl, data = data)

# Two-tailed Yuen-Welch Test (timmed-mean difference) t(58.3) = 2.20, p = .0317,

# TMD = -.32312 95%CI [-.617, -.0293], d =  0.33

# significant effect of group, where those at SA had a greater change in social bonding score by .323 compared to Sunday Assembly.


## KW Test

kruskal.test(SB6_Change ~ SA_Ctrl, data = data)
```

```
# chi-squared = 4.90, p = .027 - significant difference between the groups, where SB change is higher in SA than in Church.


## Exact Wilcoxon-Mann-Whitney

library("exactRankTests")

wilcox.exact(SB6_Change ~ SA_Ctrl, data = data, conf.int = TRUE, conf.level = 0.95)

## W=910, p = .027. Estimated difference of Church v.s. Sunday Assembly = -.333 95% CI [-,500, -.000]

# Majority of tests suggest a significant effect.


## Feys (2016). Nonparametric Tests for the Interaction in Two-way Factorial Designs Using R,

## The R Journal Volume 8(1):367-378

## DOI: 10.32614/RJ-2016-027


# Figure 2 - Social Bonding Interaction Plot ####

# Interaction Box Plot  (Figure 2 in paper)

SB6Int <- ddply(data_long,.(FactPP,SA_Ctrl),summarise, val = mean(SB6))

ggplot(data_long, aes(x = FactPP, y = SB6, colour = SA_Ctrl)) +

  geom_boxplot(position=position_dodge(1), notch = "TRUE", outlier.shape = NA) +

  geom_point(data = SB6Int, aes(y = val)) +

  geom_line(data = SB6Int, aes(y = val, group = SA_Ctrl)) +

  theme_bw()  +

  scale_x_discrete(limits=c("Pre-Ritual", "Post-Ritual")) +

  xlab("Measurement Occasion") +
```

```
  ylab("Social Bonding score") +
  labs(colour = "Ritual Group") +
  theme(panel.border = element_blank(), panel.grid.major = element_blank(),panel.grid.minor =
element_blank(),
    axis.line = element_line(colour = "black"))+
  theme(axis.text=element_text(size=12),
    axis.title=element_text(size=12),
    legend.text = element_text(size=12),
    legend.title = element_text(size=12))
```

```
# Interaction Violin Plot - for those who prefer violin plots to notched box plots
SB6Int <- ddply(data_long,.(Pre_Post,SA_Ctrl),summarise, val = mean(SB6))
ggplot(data_long, aes(x = factor(Pre_Post), y = SB6, colour = SA_Ctrl)) +
  geom_violin(position=position_dodge(1)) +
  geom_point(data = SB6Int, aes(y = val)) +
  geom_line(data = SB6Int, aes(y = val, group = SA_Ctrl)) +
  theme_bw()  +
  scale_x_discrete(limits=c("Pre", "Post"))+
  xlab("Measurement Occasion (pre- v.s. post- ritual)") +
  ylab("Social Bonding Score (SB6, 0-7)") +
```

```
    labs(title ="Social Bonding Change from before to after ritual for both Sunday Assembly and Church groups",
         colour = "Ritual Group")

### Exploratory Analysis Data assumptions  ----

  dataPANAS <- data[complete.cases(data), ] # Exclude NAs
  length(dataPANAS$PANASP_Pre) # N = 95

  dataPANAS_Chr <- dataPANAS[dataPANAS$SA_Ctrl==0,] # Churches Only, only participants who have no NA in PANAS
  dataPANAS_SA <- dataPANAS[dataPANAS$SA_Ctrl==1,] # SA Only, only participants who have no NA in PANAS

{# PANAS+ ####

 shapiro.test(dataPANAS_SA$PANASP_Pre) # W = .976, p = .445 - Not stat. sig. dif. from normal
 shapiro.test(dataPANAS_SA$PANASP_Post) # W = .939, p = .017 - stat. sig. dif. from normal
 shapiro.test(dataPANAS_SA$PANASP_Change) # W = .972, p = .323  - stat. sig. dif. from normal
 # Non-parametric test to be carried out.
```

```
# descriptives #

mean(dataPANAS_SA$PANASP_Pre) #26.21
sd(dataPANAS_SA$PANASP_Pre) #9.23
median(dataPANAS_SA$PANASP_Pre) #24.0

mean(dataPANAS_SA$PANASP_Post) #31.68
sd(dataPANAS_SA$PANASP_Post) #11.57
median(dataPANAS_SA$PANASP_Post) #32.0

# test #
Wilcox_PANASP <- wilcox.test(dataPANAS_SA$PANASP_Pre, dataPANAS_SA$PANASP_Post, paired =
TRUE)
Wilcox_PANASP #output result
PANASP_diff <- c(dataPANAS_SA$PANASP_Pre - dataPANAS_SA$PANASP_Post) #create the differences
PANASP_diff <- PANASP_diff[ PANASP_diff!=0 ] #delete all differences equal to zero
PANASP_diff_rank <- rank(abs(PANASP_diff))  # create difference ranks
PANASP_diff_rank_sign <- PANASP_diff_rank * sign(PANASP_diff) # give difference correct sign
PANASP_ranks_P <- sum(PANASP_diff_rank_sign[PANASP_diff_rank_sign > 0])  # sum positive ranks
PANASP_ranks_N <- -sum(PANASP_diff_rank_sign[PANASP_diff_rank_sign < 0]) # sum negative ranks

PANASP_ranks_P # used in effect size calculation (Kerby)
PANASP_ranks_N # used in effect size calculation (Kerby)
```

```
  # effect size #

  Zstat_PANASP<-qnorm(Wilcox_PANASP$p.value/2) #Z score

  Zstat_PANASP # Z = -3.90

  PANASP_Bf_pval <- Wilcox_PANASP$p.value * 3 # Bonferroni correction

  PANASP_Bf_pval # p < .001

  PANASP_rR <- abs(Zstat_PANASP)/sqrt(47*2)

  # Effect size (Rosenthal) - more conservative effect size.

  PANASP_rR # .40

  PANASP_rK <- ((PANASP_ranks_P/(PANASP_ranks_P+PANASP_ranks_N))-
(PANASP_ranks_N/(PANASP_ranks_P+PANASP_ranks_N)))

  # Effect size (Kerby) - Less conservative.

  abs(PANASP_rK) # .68

}

{# PANAS- ####



  shapiro.test(dataPANAS_SA$PANASN_Pre) # W = .861, p < .001 - stat. sig. dif. from normal

  shapiro.test(dataPANAS_SA$PANASN_Post) # W = .738, p < .001 - stat. sig. dif. from normal

  shapiro.test(dataPANAS_SA$PANASN_Change) # W = .976, p = = .435  - stat. sig. dif. from normal



  # non parametric test to be carried out.



  # descriptives #
```

```
mean(dataPANAS_SA$PANASN_Pre) # 5.00

sd(dataPANAS_SA$PANASN_Pre) # 4.10

median(dataPANAS_SA$PANASN_Pre) # 4.0



mean(dataPANAS_SA$PANASN_Post) # 3.30

sd(dataPANAS_SA$PANASN_Post) # 4.23

median(dataPANAS_SA$PANASN_Post) # 2.0


# test #

Wilcox_PANASN <- wilcox.test(dataPANAS_SA$PANASN_Pre, dataPANAS_SA$PANASN_Post, paired =
TRUE)

Wilcox_PANASN #output result

PANASN_diff <- c(dataPANAS_SA$PANASN_Pre - dataPANAS_SA$PANASN_Post) #create the
differences

PANASN_diff <- PANASN_diff[ PANASN_diff!=0 ] #delete all differences equal to zero

PANASN_diff_rank <- rank(abs(PANASN_diff))  # create difference ranks

PANASN_diff_rank_sign <- PANASN_diff_rank * sign(PANASN_diff) # give difference correct sign

PANASN_ranks_P <- sum(PANASN_diff_rank_sign[PANASN_diff_rank_sign > 0])  # sum positive ranks

PANASN_ranks_N <- -sum(PANASN_diff_rank_sign[PANASN_diff_rank_sign < 0]) # sum negative ranks


PANASN_ranks_P # used in effect size calculation (Kerby)
```

```
  PANASN_ranks_N # used in effect size calculation (Kerby)



  # effect size #

  Zstat_PANASN<-qnorm(Wilcox_PANASN$p.value/2) #Z score

  Zstat_PANASN #print the Z-score

  PANASN_Bf_pval <- Wilcox_PANASN$p.value * 3 # Bonferroni correction

  PANASN_Bf_pval  # p = .047

  PANASN_rR <- abs(Zstat_PANASN)/sqrt(47*2)

  # Effect size (Rosenthal) - more conservative effect size.

  PANASN_rR # .25

  PANASN_rK <- ((PANASN_ranks_P/(PANASN_ranks_P+PANASN_ranks_N))-
(PANASN_ranks_N/(PANASN_ranks_P+PANASN_ranks_N)))

  # Effect size (Kerby) - Less conservative.

  abs(PANASN_rK) # .44

}



    # PANAS ANOVA ####



    # PANAS+

    require(nparLD)

    PANASdata_long <- data_long[complete.cases(data_long),]

    ANOVAPANASdata_long <- subset(PANASdata_long, ave(Participant_Code, Participant_Code, FUN =
length) > 1)
```

```
PANASP.f1f1np <- nparLD(PANASP ~ FactRT * FactPP, data = ANOVAPANASdata_long, subject = "Participant_Code", description = FALSE)

plot(PANASP.f1f1np)

summary(PANASP.f1f1np)

PANASP_ANOVA <- f1.ld.f1(ANOVAPANASdata_long$PANASP, ANOVAPANASdata_long$FactPP, ANOVAPANASdata_long$FactRT, ANOVAPANASdata_long$Participant_Code)

PANASP_ANOVA$RTE

# RTE < .5 means there is less than 50% chance of randomly choosing a participant from this sample with a higher than average PANAS+.

# RTE > .5 means there is greater than 50% chance of randomly choosing a participant from this sample with a higher than average PANAS+.

PANASP_ANOVA$case2x2

#            Statistic  p-value(N)      df   p-value(T)

# Group      -0.3869925 6.987618e-01 93.92600 6.996372e-01    No sig effect of group

# Time       -6.0316593 1.622846e-09 92.42517 3.311585e-08    Sig effect of time

# Group:Time   1.942023  5.213437e-02 94.83816 5.510160e-02    No sig interaction effect

PANASP_ANOVA$ANOVA.test

#            Statistic  df     p-value

# Group      0.1497632   1 6.987618e-01
```

Time 36.3809140 1 1.622846e-09

Group:Time 1.3027492 1 2.537117e-01

Significant Main Effect Measurement Occasion (p < .001) but not group Group (p = .700)

No Significant interaction effect (p = .055)

PANASP_ANOVA$ANOVA.test.mod.Box # Whole model.

Statistic df1 df2 p-value

Group 0.1497632 1 95.98559 0.6996372

The onecovahomog function from npsm

'yuen', 'Kruskal-Wallis' and ' Exact Wilcoxon-Mann-Whitney'from WRS2

NPSM ANCOVA results:

library("npsm")

ANCOVAdata=data[,c('SB6_Post','SA_Ctrl')] ## Data for ANOVA - Post-SB6 column 1 and Group in column 2

xcov<-cbind(data['SB6_Pre']) # Covariate - in this case pre-SB6

onecovahomog(2,ANCOVAdata,xcov,print.table=TRUE) # 2 levels, Post-SB6 by Group, with Pre-SB6 as Covariates

There is not a significant effect of group on post-SB6 response after controlling for pre-SB6 response. F(1,98) = 1.81, p = .18 (i.e. no interaction effect)

```
## WRS2 Yuen

library("WRS2")

yuen(PANASP_Change ~ SA_Ctrl, data = data)

# Two-tailed Yuen-Welch Test (timmed-mean difference) t(58.3) = 2.20, p = .606,

# TMD = -.5199 95%CI [-4.0417, 2.3819], d =  0.09

# No significant effect of group.


## KW Test

kruskal.test(PANASP_Change ~ SA_Ctrl, data = data)

# chi-squared = 0.433, p = .511 - No significant difference between the groups,


## Exact Wilcoxon-Mann-Whitney

library("exactRankTests")

wilcox.exact(PANASP_Change ~ SA_Ctrl, data = data, conf.int = TRUE, conf.level = 0.95)

## W=1084, p = .511. Estimated difference of Church v.s. Sunday Assembly = -1.000 95% CI [-4,000, 2.000]

# None of the tests suggest a significant effect of group.


## Feys (2016). Nonparametric Tests for the Interaction in Two-way Factorial Designs Using R,

## The R Journal Volume 8(1):367-378

## DOI: 10.32614/RJ-2016-027
```

```
# PANAS-

PANASN.f1f1np <- nparLD(PANASN ~ FactRT * FactPP, data = ANOVAPANASdata_long, subject =
"Participant_Code", description = FALSE)

plot(PANASN.f1f1np)


summary(PANASN.f1f1np)


PANASN_ANOVA <- f1.ld.f1(ANOVAPANASdata_long$PANASN, ANOVAPANASdata_long$FactPP,
ANOVAPANASdata_long$FactRT, ANOVAPANASdata_long$Participant_Code)


PANASN_ANOVA$RTE

# RTE < .5 means there is less than 50% chance of randomly choosing a participant from this sample with a
higher than average PANAS-.

# RTE > .5 means there is greater than 50% chance of randomly choosing a participant from this sample with
a higher than average PANAS-.


PANASN_ANOVA$case2x2

#            Statistic  p-value(N)      df   p-value(T)

# Group      -5.1280163 2.928111e-07 91.74162 1.621034e-06    Sig effect of group

# Time        5.5051584 3.688364e-08 75.77492 4.829054e-07    Sig effect of time

# Group:Time -0.7249341 4.684925e-01 75.77492 4.707252e-01    No sig interaction effect
```

```
PANASN_ANOVA$ANOVA.test

#            Statistic  df     p-value

#  Group      26.2965513  1 2.928111e-07

#  Time       30.3067695  1 3.688364e-08

#  Group:Time  0.5255294  1 4.684925e-01



# Significant Main Effect Measurement Occasion (p < .001) and Group (p < .001)

# No Significant interaction effect (p = .468)



PANASN_ANOVA$ANOVA.test.mod.Box  # Whole model.

#       Statistic     df1   df2      p-value

# Group  26.29655       1   91.74162  1.621034e-06




## Figure 3 - PANAS GRAPHS ####



# PANAS+ Interaction box plot (Figure 3a)




PANASPInt <- ddply(ANOVAPANASdata_long,.(FactPP,FactRT),summarise, val = mean(PANASP))

Fig3a<- ggplot(ANOVAPANASdata_long, aes(x = FactPP, y = PANASP, colour = FactRT)) +

  geom_boxplot(position=position_dodge(1), notch = "TRUE", outlier.shape = NA) +

  geom_point(data = PANASPInt, aes(y = val)) +
```

```
  geom_line(data = PANASPInt, aes(y = val, group = FactRT)) +
  theme_bw()  +
  scale_x_discrete(limits=c("Pre-Ritual", "Post-Ritual")) +
  xlab("Measurement Occasion") +
  ylab("PANAS+") +
  labs(colour = "Ritual Group") +
  theme(panel.border = element_blank(), panel.grid.major = element_blank(),panel.grid.minor =
element_blank(),
        axis.line = element_line(colour = "black"))+
  theme(axis.text=element_text(size=12),
        axis.title=element_text(size=12),
        legend.text = element_text(size=12),
        legend.title = element_text(size=12))



# PANAS- Interaction box plot (Figure 3b)
PANASNInt <- ddply(ANOVAPANASdata_long,.(FactPP,FactRT),summarise, val = mean(PANASN))
Fig3b <- ggplot(ANOVAPANASdata_long, aes(x = FactPP, y = PANASN, colour = FactRT)) +
  geom_boxplot(position=position_dodge(1), notch = "TRUE", outlier.shape = NA) +
  geom_point(data = PANASNInt, aes(y = val)) +
  geom_line(data = PANASNInt, aes(y = val, group = FactRT)) +
  theme_bw()  +
  scale_y_continuous(limits = c(0,13)) +
```

```
    scale_x_discrete(limits=c("Pre-Ritual", "Post-Ritual")) +
    xlab("Measurement Occasion") +
    ylab("PANAS-") +
    labs(colour = "Ritual Group") +
    theme(panel.border = element_blank(), panel.grid.major = element_blank(),panel.grid.minor =
element_blank(),
          axis.line = element_line(colour = "black"))+
    theme(axis.text=element_text(size=12),
          axis.title=element_text(size=12),
          legend.text = element_text(size=12),
          legend.title = element_text(size=12))


  require(patchwork)  # plot grouping tool (Figure 3)
  Fig3 <- Fig3a / Fig3b # put plot 3a above 3b
  Fig3 + plot_annotation(tag_levels = 'a') # label them a and b.


### Hypothesis 3  - Relationship between SB6 and Affect ----


  SA_only_data <- read.csv("SA data only - WIDE.csv", header = TRUE) #
```

SA_reg_data <- SA_only_data[complete.cases(SA_only_data),] # Exclude NAs so addition of extra variables leads to same number of participants

differing number of missing values across variables leads to issues with regression comparisons in the stepmodel.

length(SA_reg_data$PANASP_Pre) # N = 47

Standardising variables

SA_reg_data <-

SA_reg_data %>%

mutate(PANASPZ = (PANASP_Change - mean(PANASP_Change, na.rm=T))/sd(PANASP_Change, na.rm=T)) %>% #grand-mean centred and standardised

mutate(PANASNZ = (PANASN_Change - mean(PANASN_Change, na.rm=T))/sd(PANASN_Change, na.rm=T)) %>%

mutate(SB6Z = (SB6_Change - mean(SB6_Change, na.rm=T))/sd(SB6_Change, na.rm=T)) %>%

mutate(SB6PreZ = (SB6_Pre - mean(SB6_Pre, na.rm=T))/sd(SB6_Pre, na.rm=T)) %>%

mutate(SB6PostZ = (SB6_Post - mean(SB6_Post, na.rm=T))/sd(SB6_Post, na.rm=T)) %>%

mutate(AgeC = (Age - mean(Age, na.rm=T))) %>% # Just grand-mean centred

mutate(EducationZ = (Education - mean(Education, na.rm=T))/sd(Education, na.rm=T)) %>%

mutate(BiggerZ = (Connected_Bigger - mean(Connected_Bigger, na.rm=T))/sd(Connected_Bigger, na.rm=T)) %>%

mutate(MonthsC = (Months - mean(Months, na.rm=T))) %>%

mutate(RelZ = (Religiosity - mean(Religiosity, na.rm=T))/sd(Religiosity, na.rm=T)) %>%

mutate(SpiritZ = (Spirituality - mean(Spirituality, na.rm=T))/sd(Spirituality, na.rm=T))

```
# Key:

# ___Z = Standardised

# ___C = Mean-Centred


{# Figure 4 - SA Correlation Plot ####


BondingChangeZ <- as.numeric(SA_reg_data$SB6Z)

PosAffectChangeZ <- as.numeric(SA_reg_data$PANASPZ)

NegAffectChangeZ <- as.numeric(SA_reg_data$PANASNZ)

MonthAttend <- as.numeric(SA_reg_data$MonthsC)

ConnectSomethBiggerZ <- as.numeric(SA_reg_data$BiggerZ)

ReligiosityZ <- as.numeric(SA_reg_data$RelZ)

SpiritualityZ <- as.numeric(SA_reg_data$SpiritZ)


correlationplot <- data.frame(BondingChangeZ, PosAffectChangeZ, NegAffectChangeZ, MonthAttend,
ConnectSomethBiggerZ, ReligiosityZ, SpiritualityZ)

colnames(correlationplot) = c('BondingChange' ,'PosAffectChange' ,'NegAffectChange'
,'MonthAttend','ConnectSomethBigger' ,'Religiosity','Spirituality')

# Visualize List of factors to determine which columns to include in analysis
```

```
grouping = list(BondingChange =c(1), PosAffectChange = c(2), NegAffectChange = c(3), MonthAttend = c(4),
ConnectSomethBigger = c(5), Religiosity = c(6), Spirituality = c(7))

require(qgraph)

require(igraph)



SuppA_qgraph <- qgraph::qgraph(cor(correlationplot, use = 'na.or.complete')

    , minimum="sig"  # only show connections which are significant

    , groups = grouping # group nodes in an appropriate manner

    , legend = TRUE # provide a legend

    , legend.cex = 0.53

    , layoutOffset = c(-0.12,0) # move graph so legend is not covering it

    , layout="spring"  # colour scheme

    , graph = "cor"  # correlation plot

    , vTrans = 180 # give nodes some transparency, so labels are clearer (out of 255)

    , sampleSize = 49 #number of participants

    , edge.labels = T # Provide the r-value in the connection

    , edge.label.bg =T # Give a background to the r-value, so it is more easily read.

    , edge.label.margin = 0.02 # give the background some margin

    , edge.label.position = 0.5) # Give a background to the r-value, so it is more easily read.



SuppA <- as.igraph(SuppA_qgraph)

SuppA
```

```
}

# Basic moodel for PANAS predicting SB6

model = lm(SB6Z ~ PANASPZ + PANASNZ,

        data = SA_reg_data)

summary(model)

confint(model)

apa.reg.table(model) # basis for Table 1

# PANAS+ is the only significant predictor  R^2 = .432 [.19, .58]

lm.beta(model) # get the beta values to more than 2.d.p.

## Assumptions of Model ##

## A:Mean of residuals is close to 0

mean(model$residuals) # this assumption holds

## A: Homoscedacisity and Normality

autoplot(model)

# Resid v.s. Fitted shows assumption holds

# Q-Q Plot (top right) appears close to Normal.
```

A: The X variable and residuals are uncorrelated

cor.test (SA_reg_data$PANASPZ, model$residuals) # assumption holds

cor.test (SA_reg_data$PANASNZ, model$residuals) # assumption holds

A: Durbin Watson (Autocorrelation)

dwtest(model) # DW = 2.25, p = 0.798. Data not auto-correlated. Assumption holds

A: Positive variability

var(SA_reg_data$PANASPZ) #assumption holds

var(SA_reg_data$PANASNZ) #assumption holds

A: No multicolineatrity

require(car)

vif(model)

low VIF. Little multi-colinearity.

Exploratory Analysis - Stepwise Regression ----

#stepwise regression analysis for exploratory variables

There are 2 main ways to run a stepwise regression, using the MASS package or olsrr package.

```
library(MASS)

stepwisedata <- select(SA_reg_data, SB6Z, SB6PreZ, PANASPZ, PANASNZ, BiggerZ, MonthsC, AgeC,
EducationZ, RelZ, SpiritZ) #choose which variables to include

full.model <- lm(SB6Z ~., data = stepwisedata) #create the full model with all variables



#stepAIC function uses low AIC as criteron for best model.

step.model <- stepAIC(full.model,  # the model.

                direction = "both", #use both forward- and backward-selection for the stepwise regression

                trace = T) # put F to no longer show the steps.

step.model$anova # shows how the predictors were removed (right column shows how much lower AIC is
without predictor)

summary(step.model) # show the final step model

# SB6 baseline, Positive affect change, connection to something bigger and age should be included in the model

# While improving the model, Age is not significant predictor. Other 3 variables are significant

#F(4,42) = 23.67, p <.001

apa.reg.table(step.model)  # basis for Table 2

# R2 = .693 95% CI = [.48, .77]



## Assumptions of step.model

  require(olsrr)

  # Assumption: Heteroskedasticity (check of constant variance)

  ols_test_breusch_pagan(step.model) # test heteroskedasticity of dependent variable. Not significant
(assumption holds)
```

ols_test_breusch_pagan(step.model, # model

rhs= T, # use independent variables

multiple = T) # perform multiple tests (not corrected for multiple comparisons)

the variance is constant (assumption holds)

Assumption: Check for multivariate normality

ols_plot_resid_qq(step.model) # looks mostly normal, some skewness at the low end (assumption may hold)

ols_plot_resid_lev (step.model) # 2 possible outliers, and 1 value providing leverage

ols_plot_resid_fit_spread(step.model) # Spread of residuals is not wider than centred fit. Assumption not violated.

ols_correlations(step.model)

ols_plot_obs_fit(step.model) # black line shows R2 = 1. Red line shows actual R2.

ols_plot_diagnostics(step.model) # plots all diagnositc graphs.

A: Mean of residuals is close to 0

mean(step.model$residuals) # this assumption holds

A: The X variable and residuals are uncorrelated

cor.test (stepwisedata$PANASPZ, step.model$residuals) # assumption holds

cor.test (stepwisedata$BiggerZ, step.model$residuals) # assumption holds

cor.test (stepwisedata$AgeC, step.model$residuals) # assumption holds

```
cor.test (stepwisedata$SB6PreZ, step.model$residuals) # assumption holds

## A: Durbin Watson (Autocorrelation)

dwtest(step.model) # DW = 1.97, p = 0.471. Data not significantly auto-correlated. Assumption holds

## A: Positive variability

var(stepwisedata$SB6PreZ) #assumption holds

var(stepwisedata$PANASPZ) #assumption holds

var(stepwisedata$BiggerZ) #assumption holds

var(stepwisedata$AgeC) #assumption holds

## A: No multicolineatrity

vif(step.model) # low multicolinearity, assumption holds

### What about the 4 churches?  ####

Chr_only_data <- read.csv("Church data only - WIDE.csv", header = TRUE) #

Chr_reg_data <- Chr_only_data[complete.cases(Chr_only_data), ] # Exclude NAs so addition of extra variables leads to same number of participants

# differing number of missing values across variables leads to issues with regression comparisons in the stepmodel.

Chr_reg_data <- Chr_reg_data[Chr_reg_data$Participant_ID != "AG06", ] # upon inspection, AG06 has no SB6 pre score
```

```
length(Chr_reg_data$PANASP_Pre) # N = 47



Chr_reg_data <-

  Chr_reg_data %>%

  mutate(PANASPZ = (PANASP_Change - mean(PANASP_Change, na.rm=T))/sd(PANASP_Change,
na.rm=T)) %>% #grand-mean centred and standardised

  mutate(PANASNZ = (PANASN_Change - mean(PANASN_Change, na.rm=T))/sd(PANASN_Change,
na.rm=T)) %>%

  mutate(SB6Z = (SB6_Change - mean(SB6_Change, na.rm=T))/sd(SB6_Change, na.rm=T)) %>%

  mutate(SB6PreZ = (SB6_Pre - mean(SB6_Pre, na.rm=T))/sd(SB6_Pre, na.rm=T)) %>%

  mutate(AgeC = (Age - mean(Age, na.rm=T))) %>% # Just grand-mean centred

  mutate(EducationZ = (Education  - mean(Education, na.rm=T))/sd(Education, na.rm=T)) %>%

  mutate(BiggerZ = (Connected_Bigger  - mean(Connected_Bigger, na.rm=T))/sd(Connected_Bigger,
na.rm=T)) %>%

  mutate(MonthsC = (Months  - mean(Months, na.rm=T))) %>%

  mutate(DUREL_ORAZ = (DUREL_Church  - mean(DUREL_Church, na.rm=T))/sd(DUREL_Church,
na.rm=T)) %>%

  mutate(DUREL_IRZ = (DUREL_3  - mean(DUREL_3, na.rm=T))/sd(DUREL_3, na.rm=T)) %>%

  mutate(DUREL_NORAZ = (DUREL_Private  - mean(DUREL_Private, na.rm=T))/sd(DUREL_Private,
na.rm=T)) %>%

  mutate(RelZ = (Religiosity  - mean(Religiosity, na.rm=T))/sd(Religiosity, na.rm=T))



# Key:

# ___Z = Standardised
```

```
# ___C = Mean-Centred


{# Figure 5 - Chruch Correlation plot ####


Chr_BondingChangeZ <- as.numeric(Chr_reg_data$SB6Z)

Chr_PosAffectChangeZ <- as.numeric(Chr_reg_data$PANASPZ)

Chr_NegAffectChangeZ <- as.numeric(Chr_reg_data$PANASNZ)

Chr_MonthAttend <- as.numeric(Chr_reg_data$MonthsC)

Chr_ConnectSomethBiggerZ <- as.numeric(Chr_reg_data$BiggerZ)

Chr_ReligiosityZ <- as.numeric(Chr_reg_data$RelZ)


Chr_correlationplot <- data.frame(Chr_BondingChangeZ, Chr_PosAffectChangeZ, Chr_NegAffectChangeZ,
Chr_MonthAttend, Chr_ConnectSomethBiggerZ, Chr_ReligiosityZ)

colnames(Chr_correlationplot) = c('BondingChange' ,'PosAffectChange' ,'NegAffectChange'
,'MonthAttend','ConnectSomethBigger' ,'Religiosity')

# Visualize List of factors to determine which columns to include in analysis


grouping = list(BondingChange =c(1), PosAffectChange = c(2), NegAffectChange = c(3), MonthAttend = c(4),
ConnectSomethBigger = c(5), Religiosity = c(6))
```

```
Chr_CorBubblePlot <- qgraph(cor(Chr_correlationplot, use = 'na.or.complete')

                        , minimum="sig"  # only show connections which are significant

                        , groups = grouping # group nodes in an appropriate manner

                        , legend = TRUE # provide a legend

                        , legend.cex = 0.7

                        , layoutOffset = c(-0.1,-0.1) # move graph so legend is not covering it

                        , layout="spring"  # colour scheme

                        , graph = "cor"  # correlation plot

                        , vTrans = 180 # give nodes some transparency, so labels are clearer (out of 255)

                        , sampleSize = 49 #number of participants

                        , edge.labels = T # Provide the r-value in the connection

                        , edge.label.bg =T # Give a background to the r-value, so it is more easily read.

                        , edge.label.margin = 0.02 # give the background some margin

                        , edge.label.position = 0.5) # Give a background to the r-value, so it is more easily read.

}



library(MASS)

Chr_stepwisedata <- select(Chr_reg_data, SB6Z, SB6PreZ, PANASPZ, PANASNZ, BiggerZ, MonthsC, AgeC,
EducationZ, RelZ) #choose which variables to include

Chr_full.model <- lm(SB6Z ~., data = Chr_stepwisedata) #create the full model with all variables



#stepAIC function uses low AIC as criteron for best model.

Chr_step.model <- stepAIC(Chr_full.model,  # the model.
```

```
direction = "both", #use both forward- and backward-selection for the stepwise regression

trace = T) # put F to no longer show the steps.

Chr_step.model$anova # shows how the predictors were removed (right column shows how much lower AIC is without predictor)

summary(Chr_step.model) # show the final step model

# SB6 baseline, Positive affect change, connection to something bigger and age should be included in the model

# While improving the model, Age is not significant predictor. Other 3 variables are significant

#(F(5,41) = 6.90, p <.001, R2 = .457, R2Adj = .391)

apa.reg.table(Chr_step.model)

# R2 = .457**, 95% CI [.16,.57]



## Assumptions Church Stepwise Model ##



## A:Mean of residuals is close to 0

mean(Chr_step.model$residuals) # this assumption holds



# Assumption: Heteroskedasticity (check of constant variance)

ols_test_breusch_pagan(step.model) # test heteroskedasticity of dependent variable. Not significant (assumption holds)

ols_test_breusch_pagan(step.model,  # model

rhs= T, # use independent variables

multiple = T) # perform multiple tests (not corrected for multiple comparisons)
```

the variance is constant (assumption holds)

Assumption: Check for multivariate normality

ols_plot_resid_qq(Chr_step.model) # looks mostly normal, some deviation from diagonal at the top end (assumption may hold)

ols_plot_resid_lev (Chr_step.model) # 2 possible outliers, and 5 values providing some leverage

ols_plot_resid_fit_spread(Chr_step.model) # Spread of residuals is not wider than centred fit. Assumption not violated.

ols_correlations(Chr_step.model)

ols_plot_obs_fit(Chr_step.model) # black line shows R2 = 1. Red line shows actual R2.

ols_plot_diagnostics(Chr_step.model) # plots all diagnositc graphs.

A: The X variable and residuals are uncorrelated

cor.test (Chr_stepwisedata$PANASPZ, Chr_step.model$residuals) # assumption holds

cor.test (Chr_stepwisedata$PANASNZ, Chr_step.model$residuals) # assumption holds

cor.test (Chr_stepwisedata$BiggerZ, Chr_step.model$residuals) # assumption holds

cor.test (Chr_stepwisedata$MonthsC, Chr_step.model$residuals) # assumption holds

cor.test (Chr_stepwisedata$SB6PreZ, Chr_step.model$residuals) # assumption holds

A: Durbin Watson (Autocorrelation)

dwtest(Chr_step.model) # DW = 2.06, p = 0.561. Data not significantly auto-correlated. Assumption holds

A: Positive variability

var(Chr_stepwisedata$SB6PreZ) #assumption holds

var(Chr_stepwisedata$PANASPZ) #assumption holds

var(Chr_stepwisedata$PANASNZ) #assumption holds

var(Chr_stepwisedata$BiggerZ) #assumption holds

var(Chr_stepwisedata$MonthsC) #assumption holds

A: No multicolineatrity

vif(Chr_step.model) # low multicolinearity, assumption holds

Appendix 17 – Study 2 Correlation Plots

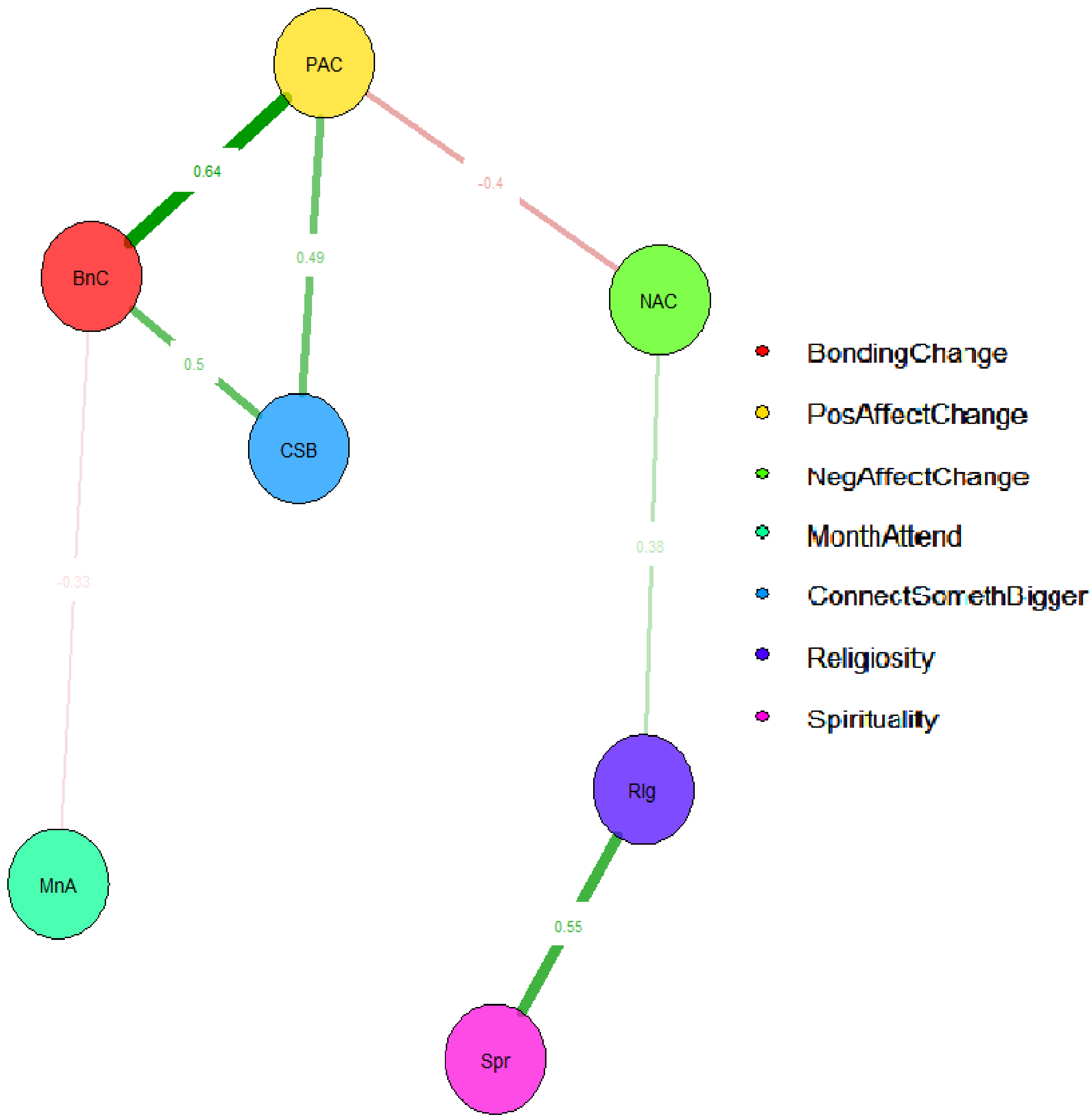


Figure A17.1. Correlation plot showing which items were correlated with which other items I the Sunday Assembly participants. Lines only show for significant correlations (p < .05). Line thickness and opacity relate to magnitude and color to direction of correlation (thicker, more opaque lines show a stronger correlation. Green shows a positive correlation, red a negative correlation).

Figure A17.1. shows significant correlations between each of social bonding change, positive affect change and the feeling of connection to something bigger, which is to be expected based on previous research. However, negative affect change was not directly correlated with social bonding change but was negatively correlated with positive affect change. Here, we also see that spirituality and religiosity are not directly correlated with bonding change or positive affect change nor, surprisingly, a connection to something bigger.

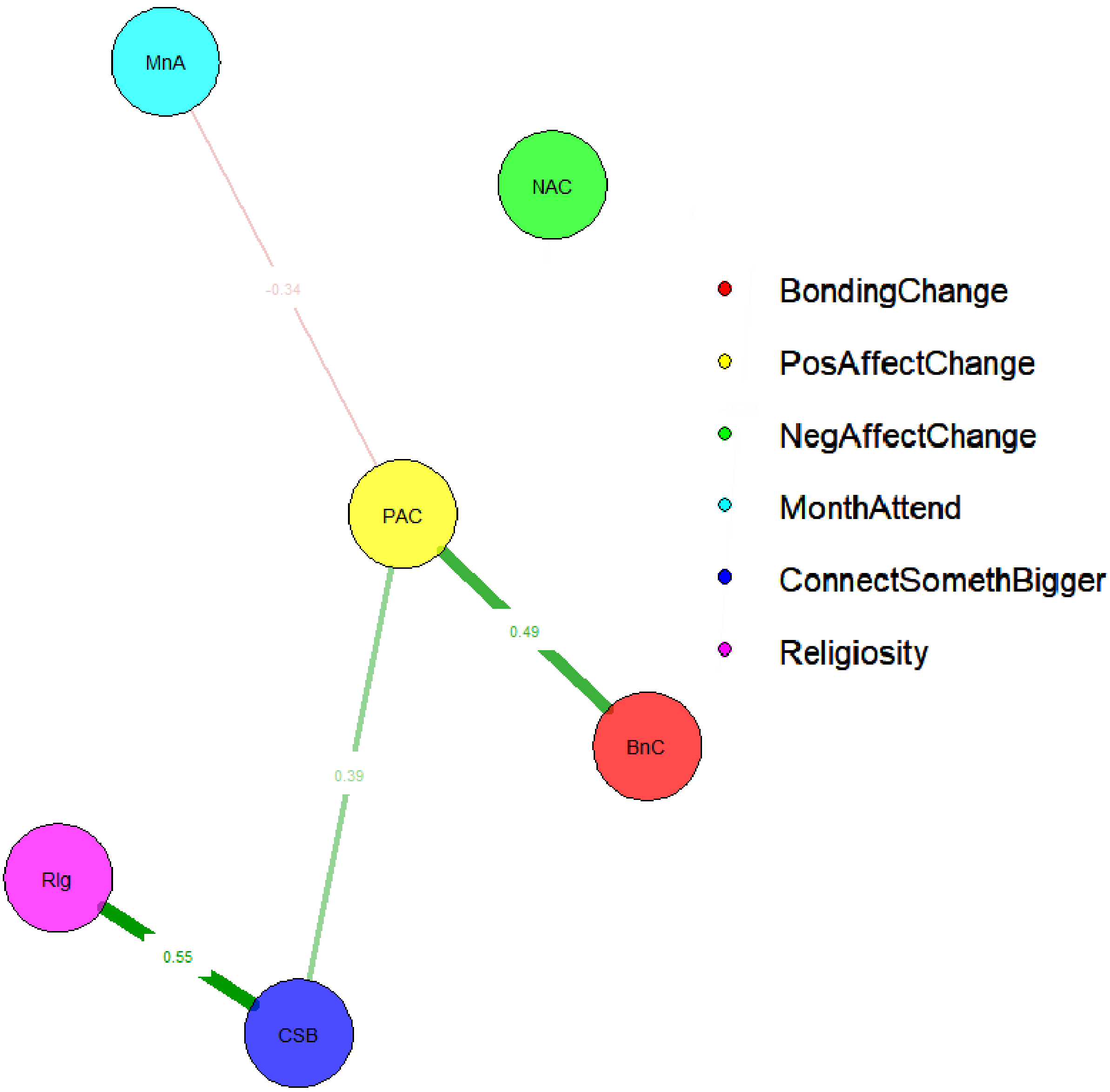


Figure A17.2. Correlation plot showing which items were correlated with which other items in the church participants. Lines only show for significant correlations (p < .05). Line thickness and opacity relate to magnitude and color to direction of correlation (thicker, more opaque lines show a stronger correlation. Green shows a positive correlation, red a negative correlation).

Figure A17.2. shows a somewhat different structure compared to the Sunday Assembly data (Figure A), as PANAS- was not correlated to any other variable in the church participants, compared to being correlated with PANAS+ change in Sunday Assembly participants. Moreover, connectedness to God was correlated to PANAS+ change and religiosity in the church participants, compared to connectedness to something bigger being correlated to PANAS+ change and social bonding change in Sunday Assembly participants.

Appendix 18 – ELISA Information

A18.1. QuickDetectTM beta-Endorphin (Human) ELISA Kit Information Sheet

(Catalog # E4458-100, 100 assays, Store at 4°C)

I. Introduction:

β-Endorphin (beta-EP) is an endogenous opioid neuropeptide and peptide hormone that is produced in certain neurons within the central nervous system and peripheral nervous system. It is one of five endorphins that are produced in human, the others of which include α-endorphin, γ-endorphin, α-neoendorphin, and β-neoendorphin. Function of β-endorphin has been known to be associated with hunger, thrill, pain, maternal care, sexual behavior, and reward cognition. In the broadest sense, β-endorphin is primarily utilized in the body to reduce stress and maintain homeostasis. In behavioral research, studies have shown that β-endorphin is released via volume transmission into the ventricular system in response to a variety of stimuli, and novel stimuli in particular. BioVision's beta-EP ELISA kit is a sandwich ELISA assay for the quantitative measurement of beta-EP in human serum, plasma and cell culture supernatants in 90 minutes. The density of color is proportional to the amount of beta-EP captured from the samples.

II. Application:

This ELISA kit is used for *in vitro* quantitative determination of beta-EP.

Detection Range: 3 - 200 pg/ml

Sensitivity: < 0.5 pg/ml

Assay Precision: Intra-Assay: CV < 10%; Inter-Assay: CV < 12% (CV (%) = SD/mean X 100)

Cross Reactivity: No significant cross-reactivity or interference between this analyte and its analogues was observed.

III. Specificity:

Human

IV. Sample Type:

Serum, plasma, urine, cell culture samples, biological fluid.

V. Kit Contents:	E4458-100	**Part No.**
Components		
Micro ELISA strip-plate	1	E4458-100-1
Standard (270 pg/ml)	0.5 ml	E4458-100-2

Standard diluent	6 ml	E4458-100-3
HRP- Conjugate reagent	10 ml	E4458-100-4
Sample diluent	6 ml	E4458-100-5
Chromogen Solution A	6 ml	E4458-100-6
Chromogen Solution B	6 ml	E4458-100-7
Stop Solution	6 ml	E4458-100-8
Wash buffer (20X)	25 ml	E4458-100-9
Plate sealers	2	E4458-100-10

A18.2. COSHH Safety Sheet

SECTION 1: PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: QuickDetect beta-Endorphin (Human) ELISA Kit

PRODUCT CODES: Cat# E4458-100

MANUFACTURER: BioVision, Inc.

DIVISION:

ADDRESS: 155 S. Milpitas Blvd. Milpitas, CA 95035

EMERGENCY PHONE: 858-373-8066

CHEMTREC PHONE:

OTHER CALLS: 408-493-1800

FAX PHONE: 408-493-1801

SECTION 2: HAZARDS IDENTIFICATION Component	**Description**	**Volume**	**Safety Information**
Micro ELISA strip-plate	--	1	No hazards
Standard (270 pg/ml)	Liquid	0.5 ml	No hazards
Standard diluent	Liquid	1.5 ml	No hazards
HRP- Conjugate reagent	Liquid	6 ml	No hazards
Sample diluent	Liquid	6 ml	No hazards
Chromogen Solution A	Liquid	6 ml	No hazards
Chromogen Solution B	Liquid	6 ml	No hazards
Stop Solution	Liquid (contains sulfuric acid >1%)	6 ml	See below
Wash buffer (30X)	Liquid	20 ml	No hazards
Plate sealers	--	2	No hazards

Appendix 19 – Study 3 Supplementary Information

This document contains a combination of tables, prose and in-line code. For ease of readability, and so that one can discern the prose from the code, all prose will be written in size-11 Times New Roman font, whereas all code will be written in `size-10 Lucida Console, with a grey highlight`. All code presented here is in the format to be used in the R programming language (All code was written and computed using R version 4.0.0, released 24th April 2020)

S1. Pre-planned blood analysis and technical difficulties

Blood from participants was collected by trained, qualified phlebotomists who were paid for their time. The needles used were Greiner Bio-One Safety Blood Collection Set + Holder 23G x 3/4" tubing length 7 1/2" (19 cm; item number 450086). The blood test tubes were the 5ml Vacutainers Tubes with serum separating tube gel - Gold (item number ML-K2170). The ELISA kit used to assess β-endorphin was the BioVision 'QuickDetectTM beta-Endorphin (Human) ELISA kit' (item code: E4458-100). The procedure for conducting the ELISA was provided by BioVision (2018). We took blood from participants on weeks 1, 3 and 5. Once the blood was taken, the blood was stored in a cool-box that was kept at approximately 0-5°C for the duration of the yoga sessions that day, and then transferred to a building 50 meters away with the facilities to spin the blood to separate the serum. Bloods were spun at 2,500 RPM for 20 minutes, as per the suggestions in the ELISA assay kit. Once separated, serum was aliquoted into separate tubes and frozen at -80°C, until all data collection was completed, so that all blood analysis could be done in the same lab conditions.

Sadly, due to COVID-19, we could no longer access the blood that was taken from participants, due to the country-wide lockdown leading to university building closures: Access to the frozen blood samples, and the related laboratories completely ceased for this time. During this time, one of the -80°C freezers in the lab broke down and some participants' blood samples were lost. We were left with only 16 participants' blood for all six time-points, all of which were in the secular yoga group. Consequently, hypothesis four from the pre-registration (a difference in blood-level beta-endorphin between the two yoga groups) could not be assessed. ELISA analyses were conducted on the remaining blood anyway to ensure I gained research experience in conducting ELISA analyses on human blood in laboratory settings.

S2. Reliability analysis rationale.

Scale reliability for longitudinal data is not calculated in the same way as for studies that measure a construct on a single occasion, or in a single day. This is because the usual coefficients used in psychology (such as Cronbach's alpha and McDonald's Omega) rely on Classical Test Theory models, which usually do not apply to longitudinal data. Cronbach and colleagues developed Generalisability Theory (G-Theory; Cronbach et al., 1972; Cronbach et al., 1963) to calculate reliability in longitudinal data. While this provided many developments to psychometrics and the ability to provide reliability for longitudinal data, G-Theory itself has assumptions that are routinely violated in real life longitudinal data, such as (1) the stability of the true scores over time, (2) an uncorrelated error structure, (3) uncorrelated random effects and (4) it requires a missingness completely at random mechanism when data are incomplete (Diggle et al., 1994; Laenen et al., 2009; Verbeke & Molenberghs, 2000). As these are often violated, the reliability estimates that are generated using G-Theory would be biased (Diggle et al., 1994). Consequently, Laenen and colleagues (Laenen et al., 2007; Laenen et al., 2009; Vangeneugden et al., 2004) have since developed a method of calculating scale reliability using longitudinal data via the use of linear mixed models (multilevel models) to provide a family of reliability measures depending on data structure: the Ω-family of reliability measures (Laenen et al., 2009).

In their article, using simulation studies Laenen and colleagues show that "both G-theory (reliability) coefficients…can be seen as special cases of the Ω-family" (Laenen et al., 2009, p. 248). The authors also demonstrate that the point estimates of Ω-family measures are accurate even with fairly low numbers of participants ($N = 50$), suggesting Ω-family reliability measures are appropriate for our data, with 52 participants. The three measures they focus on are R_T, θ_{max} and R_P. R_T is shown to be the average reliability across each timepoint (likened to Cronbach's alpha/McDonald's omega for conventional reliability). θ_{max} is shown to be the total reliability across the series of measurements, which always increases as more timepoints are added, and R_P is the cost of adding additional timepoints i.e. is a measure of efficiency. They note that, as reliability is contingent on the model being used, the Ω-family statistics can only be calculated once a model has been chosen (i.e. via the AIC/BIC selection process outlined in the 'Data analysis' section below). Consequently, reliability values reported are those that were calculated based on the final model used.

S3. Research Assistants in Study 3

In this section I am providing bullet-pointed lists of people who assisted with study 3 who were not named as co-authors due to only providing small amounts of help

S3.1. Academics who provided advise

- Dr Leon Turner
- Dr Joseph Watts
- Dr Michael J. Reiss
- Dr Alastair Lockhart

S3.2. Phlebotomists

- Dr Scott McGuire
- Deyaine Gummery
- Charles Steward
- Dr Hateem Kayani
- Sarah Elliott Louise

S3.3. Yoga session research assistants

- Fatmata Daramy
- Amna Abbasi
- Lauren Cummins
- Joshua Gerrard
- Alexia Ponce
- Brooke Murphy
- Krishma Jethwa
- Abberaame Srithar
- Erika Abric
- Hannah Martin
- Martina Marjanovic
- Gergana Prosenikova
- Erika Fiser Abric
- Hannah Todd

S4. Model Creation, presentation and description

When creating models to test our hypotheses, due to the vast number of possible models, we initially constrain the models to include only specific variables. These models start from a basic model and progress into more complex models, which can then be compared against each other. The most basic model one can make is measuring whether the dependent variable does change at all. In R script this can be done using the lm function with the following format:

```
require(stats) # the required package to run the lm function
basemodel <- lm(dependent.variable ~1 , data = mydata)
```

This code reads: "perform the linear model (lm) function, to test whether the dependent variable varies at all (against a constant of 1) where the dependent variable comes from the dataframe labelled mydata. This will produce a basic model, which will have its own AICc value if called for it:

```
require(MuMIn) # A package able to run the AICc function
AICc(basemodel)
```

As noted in the data analysis subsection in the main text of the thesis, a single AICc value is of no practical use by itself. However, we are then able to specify a more complex model, where we allow for the values of the dependent variable to vary within a participant across timepoints, and then call for an AICc value to compare it to the base model. To do this we need the lmer function from the lme4 package:

```
require(lme4) # A package able to run multilevel models
Model <- lme4::lmer(dependent.variable ~ 1+
                      (1|Participant), data=mydata, REML = F)
AICc(Model)
```

Here, you will notice that we have specified that we do not want the model to be fitted with the REML method (REML = F). This is because, in order to compare models with one another, the ML method is needed. The syntax we have used here is also somewhat different to how the lm function was called above. We have specified the package ahead of the function (lme4::lmer). This is because the Luke (2017) method of calculating p-values from the final model uses the lmer function from a different package, lmerTest (see below).

From this point, we can slowly add fixed or random effects, one by one, to create more and more complex models. These models can then be compared using the anova function from the lavaan package, to provide the $\chi 2$ test for the likelihood ratios. If a model significantly improves the fit of the data in a way that is more parsimonious, this will be represented in the output. Finally, once all of the specified models that relate to a single hypothesis have been created, all models can be compared with one another. The most parsimonious model is then re-run using the REML method, and then the Luke (2017) method for determining fixed-effects p-values can be determined:

```
TestModel <- lmerTest::lmer(final.model.structure, data=mydata, REML
= T)
summary(TestModel)
```

This Appendix provides a full outline of each of the models designed and compared against one another. We also provide AICc values for them, among other important information. The document will be split up into subsections, in such a way as to make the models easier to read and determine what they were created for. The tables showing the model comparisons will take the form shown in Table A19.1. Outputs of the results of individual models will take the form shown in Table A19.2.

Table A19.1.

Example table showing how model comparisons will be presented

Model	**LogLiklihood**	**AICc**	**Difference in AICc (cf. most parsimonious)**	df	Weight
Most parsimonious model	Value A	Value B	0	Value C	Value D
...	…	…	…	…	
Least parsimonious model	Value E	Value F	Value F – Value B	Value G	Value H

Note: Weight is calculated as $\frac{e^{(-\frac{AICc_i}{2})}}{\sum_i^N e^{(-\frac{AICc_i}{2})}}$, where i is the individual instance of AICc value, and N is the total number of AICc values.

Table A19.2.

Example table showing how individual model results will be shown.

Variable	**Estimate**	**S.E.**	**95% CI**	***t***	***Sig. (p)***

(Constant)	A (2.d.p)	B (2.d.p)	[C, D]	E (2.d.p)	F (3.d.p)
Variable 1	G (2.d.p)	H (2.d.p)	[I, J]	K (2.d.p)	L (3.d.p)
...	…	…	…	…	…
Variable N	M (2.d.p)	N (2.d.p)	[O, P]	Q (2.d.p)	R (3.d.p)

Note: All final output results were calculated using the Satterthwaite (1941) correction (see Luke, 2017). This is the case for all future tables. Noted here so that we do not have to repeat this statement in future tables.

S5. Hypothesis 1 and 2: Social bonding change over time

For this hypothesis, we first designed a base model, as no base model exploring whether social bonding changed at all has yet been determined. The base model is as follows:

```
basemodel <- lm(SB6Z ~ 1 , data = data)
```

We then created six possible models that might explain the social bonding score observed, using the time variables of measurement occasion (where 0 means pre-yoga and 1 means post-yoga) and Week, for which dummy codes are generated. The first of these models (`Model`) does not include any time variables, and simply allows for social bonding to vary within participant (adding the random effect of participant):

```
Model <- lme4::lmer(SB6Z ~ 1 + (1|Participant), data=data, REML = F)
```

The following five models each then add or remove a level of complexity. `Model1` added the fixed effect of measurement occasion, compared to `Model`. `Model2` added the fixed effect of Week compared to `Model1`. `Model3` added interaction effects between Measurement Occasion and Week. `Model4` proposed Week as a random effect instead of a fixed effect. `Model5` proposed measurement occasion as a random effect instead of a fixed effect.

```
Model1 <- lme4::lmer(SB6Z ~ Measurement.Occasion + (1|Participant),
data=data, REML = F)
```

```
    Model2 <- lme4::lmer(SB6Z ~ Measurement.Occasion + Week +
(1|Participant), data=data, REML = F)
    Model3 <- lme4::lmer(SB6Z ~ Measurement.Occasion * Week +
(1|Participant), data=data, REML = F)
    Model4 <- lme4::lmer(SB6Z ~ Measurement.Occasion + (1|Participant) +
(1|Week), data=data, REML = F)
# this model allows data to vary by week as well as by participant
# i.e. a 3-level model: Measurement Occasion within Week within
Participant
    Model5 <- lme4::lmer(SB6Z ~ Week + (1|Participant) +
(1|Measurement.Occasion), data=data, REML = F)
# this model allows data to vary by measurement occasion as well as by
participant
# i.e. a 3-level model Week within measurement occasion Participant
```

As shown in Table A19.3., the most parsimonious model was `Model3`. The full results of this model are already reported and presented in Table 5.3. (Model A) in chapter 5, and so are not presented here.

Table A19.3.

Hypothesis 1 model comparison table

Model	LogLiklihood	AICc	Difference in AICc	Df	Weight
Model3	-328.4	681.5	0	12	> .999
Model2	-342.8	702.0	20.5	8	< .001
Model5	-346.1	708.5	27.0	8	< .001
Model4	-353.4	717.0	35.5	5	< .001
Model1	-436.1	880.4	198.9	4	< .001
Model	-462.5	931.0	249.5	3	< .001
basemodel	-663.6	1331.2	649.7	2	< .001

S6. Hypothesis 3: Connection to Something Bigger

We measured the level of connection to something bigger than oneself after each session of yoga. Here we created a new base model, and four follow-up models. The follow-up models take the same format as those from section S5. Each of the models here had the prefix CB_ST_, for "**C**onnected **B**igger" and "**S**ession **T**ype" so it is clear what the model is designed to assess:

```
CB_ST_basemodel <- lm(BiggerZ ~1, data = data)
CB_ST_Model <- lme4::lmer(BiggerZ ~ 1 + (1|Participant), data= data, REML = F)
CB_ST_Model1 <- lme4::lmer(BiggerZ ~  Session_Type +(1|Participant), data= data, REML = F)
CB_ST_Model2 <- lme4::lmer(BiggerZ ~   Session_Type + Week +(1|Participant), data= data, REML = F)
CB_ST_Model3 <- lme4::lmer(BiggerZ ~   Session_Type * Week + (1|Participant), data= data, REML = F)
```

As shown in Table A19.4., the most parsimonious model was `CB_ST_Model3`.

Table A19.4.

Manipulation check model comparison table

Model	LogLiklihood	AICc	Difference in AICc	Df	Weight
CB_ST_Model3	-400.7	826.1	0	12	.994
CB_ST_Model1	-414.8	837.7	11.6	4	.003
CB_ST_Model2	-411.1	838.5	12.4	4	.002
CB_ST_Model	-417.1	840.3	14.2	3	< .001
CB_ST_basemodel	-663.6	1331.2	505.1	2	< .001

The full output for `CB_ST_Model3` is shown in Table 5.3. (Model B) in chapter 5. Here you can see that Session type did significantly predict the self-rated connection to something bigger than oneself, and that there was an interaction effect with week (see Figure 5.5 in the main manuscript, or Figure A23.2.).

S7. Hypothesis 4: Difference between session type – Manipulation Check

The fourth hypothesis we had was that the level of social bonding measured would be higher in those taking part in the spiritual sessions of yoga than those taking part in the secular sessions (results of which are presented in the main manuscript). Before this was conducted, manipulation checks were conducted

S7.1. Manipulation Check: Was there a difference in R/S measures between session types?

Religiosity and Spirituality are somewhat more concrete concepts, which tend to only change as an individual ages or becomes more educated (Ganzach & Gotlibovski, 2013). As such, self-rated spirituality and religiosity is unlikely to change over a 5-week period. Even so, it is worth checking to see whether yoga type did affect participants' self-rated spirituality or religiosity. To do so, participants were asked to rate, from zero to six, how spiritual and religious they considered themselves to be both before the first session and after the final session. Zero was given the prompt "Not at all" and six "Extremely so". To test whether yoga session type affected these variables, two within-between ANOVAs were conducted – one for each variable. First, assumptions for conducting a within-between ANOVA were tested. Pre- and post-experiment spirituality and religiosity were both tested for normality using the Shapiro-Wilk test for each session type. As shown in Table A19.5., Spirituality measures were normally distributed and so a parametric within-between ANOVA was conducted. For the Religiosity measure, only the secular pre-experiment religiosity was not significantly different from normally distributed, and so a non-parametric ANOVA was conducted for religiosity.

A within-between ANOVA was conducted to compare the effect of secular verses spiritual yoga over time. It was found that there was no main effect of session type ($F(1,39) = .87$, $p = .356$, $\eta^2_g = .020$) or time ($F(1,39) = 2.84$, $p = .100$, $\eta^2_g = .003$) on self-reported spirituality nor was there a significant interaction effect ($F(1,39) = 0.05$, $p = .831$, $\eta^2_g = <.001$). For religiosity, using the nparLD package of the R coding language, a non-parametric within-between ANOVA was run via the f1.ld.f1 function (Noguchi et al., 2012). The nparLD package's functions provide an ANOVA-like statistic with the denominator degrees of freedom listed as infinite. There are also no clear methods of calculating effect sizes using non-parametric methods for within-between ANOVAs (Though, see Feys, 2016 for how one might acomplish this in follow-up analyses). As such, no effect sizes are presented here. The f1.ld.f1 function found that there was no significant main effect of session type ($F(1,\infty) = 3.67$, $p = .055$) or time ($F(1,\infty) = 0.14$, $p = .707$), nor was there a significant interaction effect ($F(1,\infty) = 0.002$, $p = .961$). These results show that neither religiosity nor spirituality significantly changed over time, nor between session types. While this was expected, it would have been interesting were either were to have been changed over 5 weeks.

Table A.19.5.

Output of Shapiro-Wilk tests for the assessment of normality for pre- and post-experiment self-rated levels of spirituality and religiosity.

Variable	Session Type	Time	Mean (SD)	*W*	*Sig. (p)*
Spirituality	Secular	Pre-Experiment	3.47 (1.58)	.943	.304
		Post-Experiment	2.77 (1.60)	.948	.293
	Spiritual	Pre-Experiment	3.05 (1.53)	.950	.309
		Post-Experiment	2.77 (1.60)	.948	.293
Religiosity	Secular	Pre-Experiment	2.84 (2.09)	.912	.095
		Post-Experiment	1.64 (1.53)	.845	.003
	Spiritual	Pre-Experiment	1.68 (1.43)	.907	.042
		Post-Experiment	1.64 (1.53)	.845	.003

S7.2. Manipulation Check: Did participants guess the purpose of the experiment, and was there a difference in meaning from Yoga between session types?

After the 5th session of yoga, participants were asked to guess the purpose of the experiment. None guessed the purpose of the experiment was to compare between two types of yoga. We also asked whether or not the Yoga sessions that participants took part in provided meaning to them. A chi-squared test showed that there was no significant difference between session type on whether the set of yoga sessions were meaningful for the participants ($\chi 2 = .001$, $p = .971$).

S8. Hypothesis 5: Pain Tolerance

Table A19.6.

Hypothesis 4 model selection: Wall-Sit to predict social bonding

Model	LogLiklihood	AICc	Difference in AICc	Df	Weight
SB_WS_Model2	-323.8	678.7	0	15	.722
Model3	-328.4	681.5	2.8	12	.181
SB_WS_Model	-328.1	682.9	4.2	13	.088
SB_WS_Model3	-318.4	687.4	8.7	24	. 009
SB_WS_Model1	-324.3	694.9	16.2	22	< . 001

Table A19.7.

Model selection table for the wall-sit predicting social bonding, after outliers have been removed

Model	**LogLiklihood**	**AICc**	**Difference in AICc**	**Df**	**Weight**
SB_WS_Expl_Model	-304.5	635.8	0	13	.722
SB_WS_Expl_Model1	-296.4	639.3	4.2	22	.088
SB_WS_Expl_Model2	-304.4	639.9	8.7	15	. 009
SB_WS_Expl_Model3	-296.1	643.1	16.2	24	< . 001

S9. Hypothesis 6: Affect

Table A19.8.

Positive Affect follow-up analysis model comparison table

Model	LogLiklihood	AICc	Difference in AICc	Df	Weight
SB_PANAS_Model5	-292.8	625.4	0	19	.893
SB_PANAS_Model6	-285.3	630.4	5.0	28	.074
SB_PANAS_Model4b	-300.8	632.3	7.3	15	.023
SB_PANAS_Model4	-300.8	634.8	9.4	16	< . 001
SB_PANAS_Model7	-289.3	638.3	12.9	28	< . 001
SB_PANAS_Model3b	-313.8	654.3	29.0	13	< . 001
SB_PANAS_Model3	-313.7	656.3	31.0	14	< . 001
SB_PANAS_Model8	-311.8	663.3	37.9	19	< . 001
SB_PANAS_Model2b	-329.5	677.5	52.1	9	< . 001
SB_PANAS_Model2	-329.4	679.3	53.9	10	< . 001

Model3	-328.4	681.5	56.1	12	< . 001
SB_PANAS_Model1	-428.7	869.7	244.3	6	< . 001
SB_PANAS_Model1b	-434.2	878.4	253.1	5	< . 001
SB_PANAS_Model	-445.1	900.3	275.0	5	< . 001
SB_PANAS_Modelb	-4655.5	921.1	295.8	4	< . 001

S10. Follow-up: Exploratory Overall Model

Table A19.9.

Overall social bonding follow-up analysis model comparison table

Model	LogLiklihood	AICc	Difference in AICc	Df	Weight
Overall_Model5	-237.0	529.1	0	26	.685
Overall_Model6	-236.7	530.9	1.8	27	.283
Overall_Model7	-236.6	535.3	6.1	29	.032
Overall_Model3	-266.2	578.7	49.6	22	< .001
Overall_Model2	-270.2	580.2	51.0	19	< .001
Overall_Model1	-274.0	583.4	54.3	17	< .001
Overall_Model4	-264.7	584.5	55.4	26	< .001
Overall_Model	-291.8	610.4	81.2	13	< .001
SB_PANAS_Model	-292.8	625.4	96.2	19	< .001

Model3	-328.4	681.5	152.3	12	< .001

S11. Two-one-sided test (TOST)

First, a basic two-one-sided test (TOST) was conducted in R to assess whether a more complex model was necessary (if this was not significant, accounting for multi-level structure of data would not likely be significant). This was conducted in R using the TOSTER package:

```
TOSTER::dataTOSTtwo(data = data, deps = c("SB6Z"),group =
"Session_Type", plots = T)
```

This returned a significant effect for both upper and lower bounds (both p < .001). Consequently, another TOST was conducted with the multi-level structure of the data accounted for using MODEL C presented in Table 5.3. in the main body of the thesis (also known as Overall_Model5 presented in section S10, above). To do this, first lower and upper bounds are set manually:

```
bound_l <- -0.46 # Szucs & Ioannidis (2017; 2021) show this to be
the median moderate effect size across cognitive sciences
bound_u <- 0.46 # Szucs & Ioannidis (2017; 2021) show this to be the
median moderate effect size across cognitive sciences
```

Once the lower and upper bounds are manually set, the method suggested by Isager (2019) was conducted to provide p-values for tests of the estimate against the upper and lower bounds.

S12. Mediation of Positive affect via C2SB

Mediation analysis within multilevel models can be complicated if you are using unevenly balanced variables. This is because one method often used to do mediation analysis is via SEM. However, with unbalanced designs, the assumptions underlying SEM analysis are violated. The Causal Mediation Analysis package in R (named `mediation`) (Hicks & Tingley, 2011) allows one to use the `lme4` package (`lmer` models), used for the creation of mixed-effects models in this study, to conduct multi-level mediation analyses. To do so, one must create a mediator model, and a full model. In the mediator model, the mediator variable (in this case, C2SB) is predicted by all of the predictors of interest that are included in the full model, using the same multi-level structure model as the full model.

```
MedModel_base <- lm(BiggerZ ~ 1,
                            data=data, REML = F)

MedModel_model1 <- lme4::lmer(BiggerZ ~ 1+
                                     (1|Participant),
                                     data=data, REML = F)

MedModel_model2 <- lme4::lmer(BiggerZ ~ PANASPZ +
                              (1|Participant),
                            data=data, REML = F)

MedModel_model3 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ+
                                (1|Participant),
                              data=data, REML = F)

MedModel_model4 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ+ +
Measurement.Occasion +
                                (1|Participant),
                              data=data, REML = F)

MedModel_model5 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ +
Measurement.Occasion + Week +
                                (1|Participant),
                              data=data, REML = F)

MedModel_model6 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ+
Measurement.Occasion + Week + Session_Type+
                                (1|Participant),
                              data=data, REML = F)

MedModel_model7 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ+
Measurement.Occasion + Week + Session_Type+ WSZ +
                                (1|Participant),
                              data=data, REML = F)

MedModel_model8 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ+
Measurement.Occasion * Week+ Session_Type+ WSZ +
                                (1|Participant),
                              data=data, REML = F)
```

Table A19.10.

Comparison tables for mediation model to predict connection to something bigger than the self

Model	LogLiklihood	AICc	Difference in AICc	Df	Weight
MedModel_model2	-415.8	839.8	0	4	.272
MedModel_model1	-417.1	840.3	0.5	3	.208
MedModel_model6	-409.1	840.8	1.0	11	.165
MedModel_model7	-408.1	840.9	1.1	12	.154
MedModel_model3	-415.8	841.7	1.9	5	.104
MedModel_model5	-411.3	843.0	3.3	10	.053
MedModel_model4	-415.7	843.5	3.7	6	.042
MedModel_model8	-408.1	849.4	9.6	16	.002
MedModel_base	-663.6	1331.2	491.2	2	< .001

Slightly more complex models were then tested, where PANAS+ was allowed to vary within participants. Of these models, only 3 improved on the prior model. model2b improved over model2, model2c improved over model2b, and model2g improved over model2c (where d, e, and f did not). No further changes were significant (See Table A19.11.)

```
MedModel_model2b <- lme4::lmer(BiggerZ ~ PANASPZ +
                                (PANASPZ|Participant),
                              data=data, REML = F)

MedModel_model2c <- lme4::lmer(BiggerZ ~ PANASPZ + Session_Type +
                                 (PANASPZ|Participant),
                               data=data, REML = F)

MedModel_model2g <- lme4::lmer(BiggerZ ~ PANASPZ + Session_Type*Week
+
                                 (PANASPZ|Participant),
                               data=data, REML = F)
```

Table A19.11.

Further comparisons for mediation model to predict connection to something bigger than the self

Model	LogLiklihood	AICc	Difference in AICc	Df	Weight
MedModel_model2g	-372.1	775.3	0	15	> .999
MedModel_model2c	-388.7	791.7	16.4	7	< .001
MedModel_model2b	-392.1	796.4	21.1	6	< .001
MedModel_model2	-415.8	839.8	64.4	4	< .001

MedModel_model2g (renamed `MedModel_Mediator`) was used as the basis for the mediation analysis. The full model was created to be the same structure, but to predict SB6 with BiggerZ in the right hand side of the model:

```
MedModel_Full <- lme4::lmer(SB6Z ~ BiggerZ + PANASPZ + Session_Type*Week +
                  (PANASPZ|Participant), data=data, REML = F)
```

One can then use the `mediate` function to compare the direct effects with the indirect effects by specifying which variable is the 'treatment' variable (positive affect) and which variable is the mediating variable (C2SB):

```
med_results <- mediation::mediate(MedModel_Mediator, MedModel_Full,
treat = "PANASPZ", mediator = "BiggerZ")
```

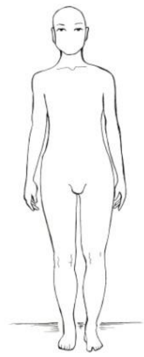
One can then summarise the results from this mediation analysis (`summary(med_results)`). The output of this tells one the Average Causal Mediation Effects (ACME), and the Average Direct Effects (ADE). In the case of positive affect via C2SB, see Figure A19.A.

```
> mediation_results

Causal Mediation Analysis

Quasi-Bayesian Confidence Intervals

Mediator Groups: Participant

Outcome Groups: Participant

Output Based on Overall Averages Across Groups

                         Estimate 95% CI Lower 95% CI Upper p-value
ACME (control)           0.048499     0.000239         0.11    0.05 *
ACME (treated)           0.048499     0.000239         0.11    0.05 *
ADE (control)            0.221333     0.124968         0.32  <2e-16 ***
ADE (treated)            0.221333     0.124968         0.32  <2e-16 ***
Total Effect             0.269832     0.164481         0.38  <2e-16 ***
Prop. Mediated (control) 0.180473     0.000760         0.36    0.05 *
Prop. Mediated (treated) 0.180473     0.000760         0.36    0.05 *
ACME (average)           0.048499     0.000239         0.11    0.05 *
ADE (average)            0.221333     0.124968         0.32  <2e-16 ***
Prop. Mediated (average) 0.180473     0.000760         0.36    0.05 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Sample Size Used: 468


Simulations: 1000
```

Figure A19.A. The output of summary(med_results) for the multi-level mediation analysis of the role of positive affect via connection to something bigger than the self. All *p*-values are based on 2-sided tests.

Appendix 20 – Secular Yoga Class Plan

Begin in simple Standing Posture (Tadāsana).



Standing Pose/ Tadāsana

Demonstration and Verbal Instruction by Tutor:

- Stand with feet hip distance apart, hands resting at your sides;
- Feel the contact you are making with the ground in this simple Standing Posture;
- Become aware of where the weight is falling through the feet, questioning whether it is falling in front (towards the toes), to the inside of the feet, to the outside;
- Gently begin to sway back and forward slightly to change that weight distribution;
- Using this motion become still again with the weight flowing through and just in front of the ankles, you should be able to raise your toes without disturbing the weight placement;
- Become aware of your breath, feeling the movement in your abdomen and ribs as you breath; feeling the flow of cool air in your nostrils as you inhale and the flow of warm air as you exhale. Throughout the class we will be breathing ~ exhaling and inhaling ~ through the nostrils.

Changing Postures

In all changing postures for the secular 'A' classes, attention will be drawn to muscles and the act of the stretching. This differs from the spiritual focus seen in the spiritual, 'B' classes

Into Warm-up movement from Standing Pose:

1.

- * Raise your arms overhead while breathing in, gently drawing up the pelvic floor muscles and tightening the buttocks muscles as you do so.
- Reach up, directing your gaze between your hands;

- As you exhale release your arms down through the side; releasing the muscles of the pelvis and buttocks, bend your knees and lightly touch the floor on either side of you. **
    - Repeat from * to ** five times.

2.

- * Place your left hand on your belly, just below the naval and the right hand on the base of skull;
- Inhaling, lengthening through the spine extend upward taking your right elbow back and slightly lifting the chin, again engaging the buttocks and pelvic floor muscles
- As you exhale release the head and pelvic floor and buttocks muscles, bend the knees let the head roll forward, the right elbow come forward and slightly flex at the waist. **
    - Repeat from * to ** three times.

3.

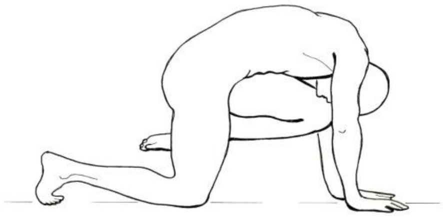
- * Step the feet approximately three feet apart;
- Stretch the right arm upward in a circular motion and then circle to touch the floor on the left side, bending the left knee and straightening to repeat the circle;
        - The Tutor informs the participants that they are warming the shoulder joint and by flexing the knee we engage the big muscles of thigh which call on more blood from the heart and gently speed up the heart rate.
- Repeat three times with the right arm;
- Stretch the right arm at shoulder height out to the right side and then make a sweeping ‘putting on a cloak movement’, again bending the left knee, taking the arm behind the head and then back to the stretch to the right. **
        - The tutor informs the Participants that this movement releases tension from the rotator cuff muscles of the shoulder that can become stiff and weakened. S/he might remind the Participants that a quarter of all people over 65 in this country are unable to wash their own hair because they cannot raise their arms over the heads. Movements like this help prevent that kind of weakening and stiffening of the shoulder joint muscles.

- Repeat from * to ** with the left arm.

4.

- *Participants are invited to sit, with their feet on the floor placed a bit more than hip distance apart and their hands wrapped around their shins.
- Their attention is directed towards their sitting bones and where the weight is being felt.
- They are instructed to slowly roll onto the front of the sitting bones, allowing the spine to lengthen as they draw their body towards their knees and inhale, feeling the lengthening in the front of the spine;
- As the exhale they allow the weight to roll onto the back of the sitting bones and the spine to bend as they lower the head and lengthen the back of the spine. **
- Repeat from * to ** twice.
  - During these movement the Tutor directs the Participants attention to the sensations of the weight shifting at the sitting bones, to the lengthening of the spine at the front and then the back, and to the inhalation and exhalation.

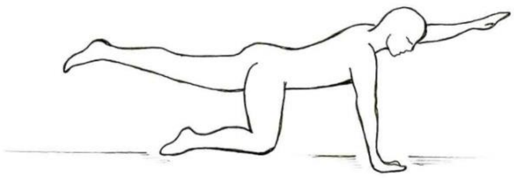
Tiger Posture to Goose to Salutations Postures.



Tiger Posture / Vyagrāsana

- From sitting Participants are invited to roll onto all fours ~ weight going through hands and knees;
- They are asked to extend the right leg behind them, parallel to the floor and to feel the muscles the in the back and buttocks that are holding the weight of the leg;
- They are then invited to bend the knee and bring it into flexion towards the head, which they gently drop, into Tiger Pose;

- They are invited to extend it back again and go for a diagonal stretch as the raise their left arm to shoulder height and to take a deep inhalation and exhalation in Goose Posture. **
    - **Tutor engages Participants attention and directs it to the muscles being engaged and being stretched.**

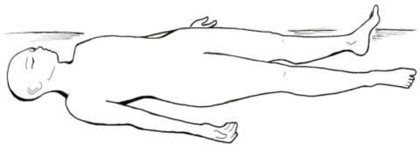


Goose Posture / Chakravākāsana

- Repeat * to ** three times **
- Once repeated three times with the right leg the weight is taken off then hands and the Participants rest in Prostration Posture, their attention on the movement of the breath in their backs;
    - As they rest in prostration Posture the Tutor takes the Participants attention to the movement of the muscles in the lower back, expanding outward as they inhale, contracting as they exhale; movement of the spine as they breath.
- Before repeating with the left leg the Participants are invited to roll their palms upward and then back three times.

Prostration Posture / Pranamāsana

Corpse Posture (Śavāsana) and Hip Joint Movement



- Participants are then invited to lie down on their back in Corpse Pose, with the feet slightly apart, the arms slightly away from the hips and the palms facing upward.

Corpse Pose / Śavāsana

  - For those Participants with lower back problems for whom this is uncomfortable, the 'Alexander Resting Position' will be offered as an alternative.

- Their attention will be directed to their breath and the contact they are making with the floor beneath them.

1.

- After one minute they will be instructed to bend their knees and, finding the outer edges of their mat, place their feet on the floor;
- Stretching their arms out on the floor at shoulder height they will be instructed to drop their knees over to the left and then, on the next inhalation, to drop them over to the right. They will be instructed to repeat this with the rhythm of the breath a few times.

2.

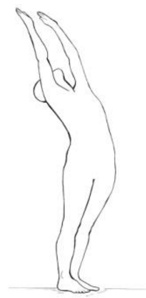
- *With the feet still on the ground and their hands placed on their hips the participants will be instructed to raise their right leg and, keeping the knee bent, and begin to make small circles from the hip while keeping the hips steady beneath their hands;
- After approximately six circles they will be instructed to stretch the leg up and make circles with the feet, feeling the movement in the ankle joint**.
- They will then lower the right leg and raising the left leg, repeat * to **.

3.

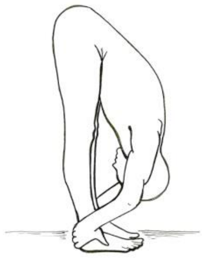
- Participants will then repeat 1 of this exercise, noticing any difference.

Back to Standing Pose (Tadāsana)

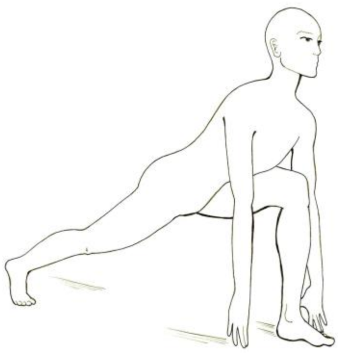
(Participants now begin to learn the first four movements of the Posture Flow (Vinyasa). Throughout the movements participants attention is directed towards the engagement of agonist muscle of groups and the stretch of the antagonist groups.



- *From Standing Pose (the first pose of the flow sequence) they are instructed to raise their arms overhead into an extension, simultaneously drawing up their pelvic floor muscles and tightening the buttocks (gluteus maximus) muscles, going into an Extended Stretch Pose (Hasta Uttanāsana). This is the second posture of the flow sequence.



- They bring their arms down and go into flexion, hands resting on their shins or fingertips to the floor. This is the second of the flow positions.
- Participants will be invited to bend their left knee and, placing the left fingertips on the floor, rotate their trunk to the right and rise their right arm, fingers pointing towards the ceiling.
- They will the lower the right arms and repeat this rotation and arm movement with the right knee and left arm.



- They will then be instructed to step their right leg back into Jumping Horse Posture, the fourth movement of the flow.
- Once in Jumping Hose Posture they will be instructed to place their right hand on the ground and, rotating their trunk, to raise the left fingertips towards the ceiling.
- They return to Jumping Horse Posture and step the right leg forward, back into Standing Pose.**
- Repeat from * to ** with the left leg.
- Repeat with each leg for another 2 flows (thus, six in all by the end).

Participants are invited to lie down in Corpse Posture again and observe the movement of the breath for approximately five breaths.

4.

Seated stretch postures will now follow:

- Bound Angle Pose (Baddha Konāsana)

Bound Angle Pose / Baddha Konāsana

- Head to Knee Pose (Jānuśirṣāsana) followed by
- Rotating Head to Knee Posture

  (Parivrtta Jānuśirṣāsana)

Head to Knee Pose / Jānuśirṣāsana

- Seated Angle Posture (Upaviṣtha Koṇāsana)

Seated Angle Pose / Upaviṣtha Koṇāsana

- Spinal rotation (Matsyendrāsana)

Spinal Rotation / Matsyendrāsana

This concludes the posture session of the class and we now move into the relaxation.

Progressive Relaxation (Yoga Nidra):

- Participants are asked to adopt either Corpse Pose or the Alexander Resting Pose.
- They are then talked through a ten-minute progressive relaxation beginning at the feet and finishing at the face and scalp.

Breathwork (Pranayama):

- The last five minutes of the class will be on conscious breathing.

- Participants will first be invited to focus on the sensations of the movement of breath and then sensations of warmth and coolness that go with the exhalation and inhalation;
- They will then be invited to focus on the space between the exhalation and the next inhalation.

Meditation (Dhyanam)

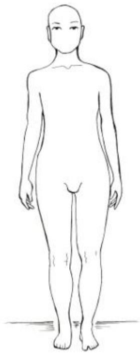
Participants will end with a short three minute 'mindfulness' meditation, focussing on the sensations arising from the body.

The class will end with a one-minute silence followed by the sound of a gong that will signal the end of the class.

Appendix 21 – Spiritual Yoga Class Plan

Yoga Class 1B (with 'spiritual' content)

Begin in Tadāsana (Simple Standing Posture).



Standing Pose/ Tadāsana

Demonstration and Verbal Instruction by Tutor:

- Stand with feet hip distance apart, hands resting at your sides;
- Feel the contact you are making with the ground in this simple Standing Posture;
- Become aware of where the weight is falling through the feet, questioning whether it is falling in front (towards the toes), to the inside of the feet, to the outside;
- Gently begin to sway back and forward slightly to change that weight distribution;
- Using this motion become still again with the weight flowing through and just in front of the ankles, you should be able to raise your toes without disturbing the weight placement;
- Become aware of your breath, feeling the movement in your abdomen and ribs as you breath; feeling the flow of cool air in your nostrils as you inhale and the flow of warm air as you exhale. Throughout the class we will be breathing ~ exhaling and inhaling ~ through the nostrils.

- *Instructor will chant the second verse of the Yoga Sutras and ask Participants to become as aware of the movement of thought flowing through consciousness, as they are of their physical posture and movement. Their teacher will inform them that awareness of the breath and its changes is how Yogins become aware of prāṇamaya kośa, the energy dimension of being.*

Posture-Changes Section

In all changing postures for the spiritual ‘B’ classes, attention will be drawn additional aspects highlighted in blue. This differs from the focus seen in the secular, ‘A’ classes

Into Warm-up movement from Standing Pose:

1.

- *Raise your arms overhead while breathing in, gently drawing up the pelvic floor muscles and tightening the buttocks muscles as you do so.
- Reach up, directing your gaze between your hands;
- As you exhale release your arms down through the side; releasing the muscles of the pelvis and buttocks, bend your knees and lightly touch the floor on either side of you.**
- Repeat from * to ** five times.

2.

- *Place your left hand on your belly, just below the naval and the right hand on the base of skull;
- Inhaling, lengthening through the spine extend upward taking your right elbow back and slightly lifting the chin, again engaging the buttocks and pelvic floor muscles
- As you exhale release the head and pelvic floor and buttocks muscles, bend the knees let the head roll forward, the right elbow come forward and slightly flex at the waist.**
- Repeat from * to ** three times.

3.

- *Step the feet approximately three feet apart;
- Stretch the right arm upward in a circular motion and then circle to touch the floor on the left side, bending the left knee and straightening to repeat the circle;

    - The Tutor informs the participants that they are warming the shoulder joint and by flexing the knee we engage the big muscles of thigh which call on more blood from the heart and gently speed up the heart rate.

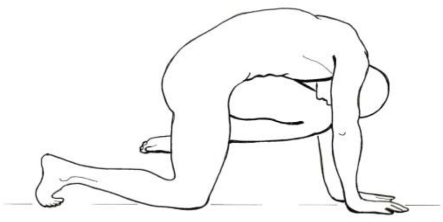
- Repeat three times with the right arm;
- Stretch the right arm at shoulder height out to the right side and then make a sweeping ‘putting on a cloak movement’, again bending the left knee, taking the arm behind the head and then back to the stretch to the right. **
    - The tutor informs the Participants that this movement releases tension from the rotator cuff muscles of the shoulder that can become stiff and weakened. S/he might remind the Participants that a quarter of all people over 65 in this country are unable to wash their own hair because they cannot raise their arms over the heads. Movements like this help prevent that kind of weakening and stiffening of the shoulder joint muscles.
- Repeat from * to ** with the left arm.

4.

- *Participants are invited to sit, with their feet on the floor placed a bit more than hip distance apart and their hands wrapped around their shins.
- Their attention is directed towards their sitting bones and where the weight is being felt.
- They are instructed to slowly roll onto the front of the sitting bones, allowing the spine to lengthen as they draw their body towards their knees and inhale, feeling the lengthening in the front of the spine;
- As the exhale they allow the weight to roll onto the back of the sitting bones and the spine to bend as they lower the head and lengthen the back of the spine. **
- *As they feel the extension and flexion of the spine, the flow of breath in and out of the nose, Participants will again be invited to observe the flow of thought, not rejecting nor following any one thought, simply aware that thought is moving through consciousness.*
- Repeat from * to ** twice.

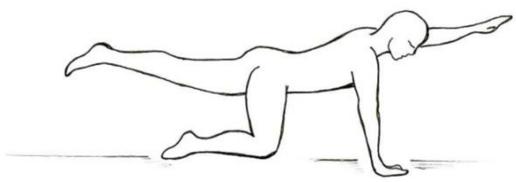
  - During these movement the Tutor directs the Participants attention to the sensations of the weight shifting at the sitting bones, to the lengthening of the spine at the front and then the back, and to the inhalation and exhalation.

Vyagrāsana (Tiger Posture) to Chakravākāsana (Goose Pose) to Pranamāsana (Salutations Posture).



Tiger Posture / Vyagrāsana

- From sitting Participants are invited to roll onto all fours ~ weight going through hands and knees;
- They are asked to extend the right leg behind them, parallel to the floor and to feel the muscles the in the back and buttocks that are holding the weight of the leg;
- They are then invited to bend the knee and bring it into flexion towards the head, which they gently drop, into Tiger Pose;



Goose Posture / Chakravākāsana

- They are invited to extend it back again and go for a diagonal stretch as the raise their left arm to shoulder height and to take a deep inhalation and exhalation in Goose Posture. **
  - Tutor engages Participants attention and directs it to the muscles being engaged and being stretched.
- Repeat * to ** three times **

- *Alongside the physical sensations of the movement, participants will be invited to be aware of the way in which the attention moves from thought to physical sensation. The tutor will explain that in this attention or awareness is known as the 'buddhi' in Yoga*.

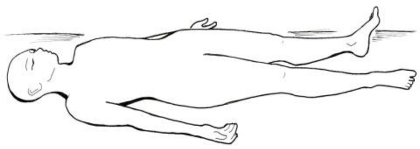
- Once repeated three times with the right leg the weight is taken off then hands and the Participants rest in Prostration Posture, their attention on the movement of the breath in their backs;
    - As they rest in prostration Posture the Tutor takes the Participants attention to the movement of the muscles in the lower back, expanding outward as they inhale, contracting as they exhale; movement of the spine as they breath.
    - *As the forehead touches the ground participants the awareness ~ buddhi ~ focuses of the movement of the breath in the back, feeling the muscles in the lower back expanding out to the side as they breathe in and exhale as they breathe out.*

- Before repeating with the left leg the Participants are invited to roll their palms upward and then back three times.

Prostration Posture / Pranamāsana

Śavāsana (Corpse Posture) and Hip Joint Movement

- Participants are then invited to lie down on their back in Corpse Pose, with the feet slightly apart, the arms slightly away from the hips and the palms facing upward.



Corpse Pose / Śavāsana

    - For those Participants with lower back problems for whom this is uncomfortable, the 'Alexander Resting
      Position' will be offered as an alternative.

- Their attention will be directed to their breath and the contact they are making with the floor beneath them.
- *Attention ~ buddhi ~ is taken back to the breath. As Participants rest the teacher will chant and explain verses 3 and 4 of the Sutras. H/she will explain that in Yoga we are seeking what is behind the physical and psychological: the subtle unknown from which both emerged. Yoga, the tutor will explain, does not articulate what that is, but invites us to allow thought to become thin and still in order to allow buddhi to look through its flow.*

1.

- After one minute they will be instructed to bend their knees and, finding the outer edges of their mat, place their feet on the floor;
- Stretching their arms out on the floor at shoulder height they will be instructed to drop their knees over to the left and then, on the next inhalation, to drop them over to the right. They will be instructed to repeat this with the rhythm of the breath a few times.

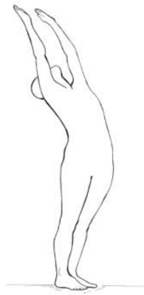
2.

- *With the feet still on the ground and their hands placed on their hips the participants will be instructed to raise their right leg and, keeping the knee bent, and begin to make small circles from the hip while keeping the hips steady beneath their hands;
- After approximately six circles they will be instructed to stretch the leg up and make circles with the feet, feeling the movement in the ankle joint**.
- They will then lower the right leg and raising the left leg, repeat * to **.

3.

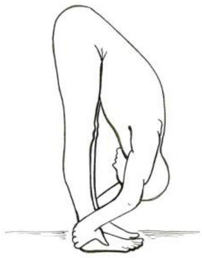
- Participants will then repeat 1 of this exercise, noticing any difference.

Back to Tadāsana (Standing Pose)

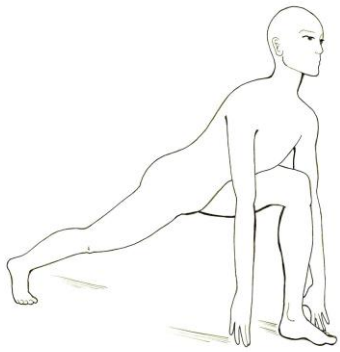


(Participants now begin to learn the first four movements of the Posture Flow (Vinyasa). Throughout the movements participants attention is directed towards the engagement of agonist muscle of groups and the stretch of the antagonist groups.

- *From Standing Pose (the first pose of the flow sequence) they are instructed to raise their arms overhead into an extension, simultaneously drawing up their pelvic floor muscles and tightening the buttocks (gluteus maximus) muscles, going into an Extended Stretch Pose (Hasta Uttanāsana). This is the second posture of the flow sequence.



- They bring their arms down and go into flexion, hands resting on their shins or fingertips to the floor. This is the second of the flow positions.
- Participants will be invited to bend their left knee and, placing the left fingertips on the floor, rotate their trunk to the right and rise their right arm, fingers pointing towards the ceiling.
- They will the lower the right arms and repeat this rotation and arm movement with the right knee and left arm.



- They will then be instructed to step their right leg back into Jumping Horse Posture, the fourth movement of the flow.
- Once in Jumping Hose Posture they will be instructed to place their right hand on the ground and, rotating their trunk, to raise the left fingertips towards the ceiling.
- They return to Jumping Horse Posture and step the right leg forward, back into Standing Pose.**
- Repeat from * to ** with the left leg.
- Repeat with each leg for another 2 flows (thus, six in all by the end).

- *Throughout this flow participants attention will be directed to the flow of breath and to be aware of keeping the awareness ~ buddhi ~ focussed on the sensations of the physical movement.*

Participants are invited to lie down in Corpse Posture again and observe the movement of the breath for approximately five breaths.

4.

Seated stretch postures will now follow:

Bound Angle Pose / Baddha Konāsana

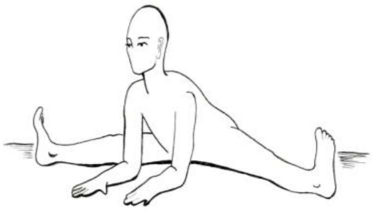
- Bound Angle Pose (Baddha Konāsana)
- In this first lesson participants awareness will be directed to the sensations of the stretch in the inner thigh. They will be asked to hold it there.
- Then they will be asked to direct the awareness to the breath and switch between the sensations of the stretch and the sensation of the breath.
- They will then be asked to expand their awareness to encompass both the sensations of breath and the stretch simultaneously.
- *The tutor will ask them to be aware of how difficult it is to keep the awareness ~ buddhi ~ stable.*

- Head to Knee Pose (Jānuśirṣāsana) followed by
- Rotating Head to Knee Posture

  (Parivrtta Jānuśirṣāsana)

  - *Attention is moved to the movement of the breath on the side being stretched and again try and hold it on stretch and breath and be aware of it becoming stable and then moving and falling into the stream of thought.*

Head to Knee Pose / Jānuśirṣāsana



- Seated Angle Posture (Upaviṣtha Koṇāsana)
- *As this posture is held and as Participants turn their attention to the sensation of the movement of breath in the back, expanding the awareness to encompass both.*

Seated Angle Pose / Upaviṣtha Koṇāsana

- Spinal rotation (Matsyendrāsana)
- *In this rotation Participants are invited to become aware of where breath feels as if it is inhibited and where the body moves to invite breath.*

Spinal Rotation / Matsyendrāsana

This concludes the posture session of the class and we now move into the relaxation.

Yoga Nidra (Progressive Relaxation):

- Participants are asked to adopt either Corpse Pose or the Alexander Resting Pose.

- They are then talked through a six-minute progressive relaxation beginning at the feet and finishing at the face and scalp.

Pranayama (Breathwork):

- The last five minutes of the class will be on conscious breathing.
- Participants will first be invited to focus on the sensations of the movement of breath and then sensations of warmth and coolness that go with the exhalation and inhalation;
- They will then be invited to focus on the space between the exhalation and the next inhalation.

Dhyanam (Meditation)

- Participants will end with a short three minute 'mindfulness' meditation, focussing on the sensations arising from the body, thoughts drifting through the consciousness and the sensations of breathing.
- *The tutor will explain that while consciousness is viewed by some as an epiphenomenon of the brain, in Yoga consciousness is primary and body and mind emerge from it.*
- The end of the meditation the Participants are invited to focus their attention primarily on the sensations of cool and warm air with the inhalation and exhalation.

The class will end with a one-minute silence followed by ‘compassion mantra’ being chanted by the teacher the sound of a gong that will signal the end of the class.

Appendix 22 Study 3 R Script

```
# Bending and Bonding - A 5 week Yoga study ####

#load packages
rm(list=ls())

library("MASS",character.only=TRUE)
library(lme4) # allows to build models
library(plyr) # Data manipulation
library(MBESS) # General methods package
library(dplyr) # Data manipulation
library(MASS) # Support functions
library(apaTables) # makes APA tables (used for sjPlot)
library(lavaan) # SEM/model building package
library(psychometric) # psychometrics
require(magrittr) # Pipe operators
require(lmerTest) # Allows for p-values from MLM
require(ggplot2) # Figure creation
require(ggpubr) # Makes ggplot2 create publication-ready figures
require(lattice) # More graphics for R
require(reshape2) # Reshape data
require(nlme) # linear and non-linear mixed-effects models
require(MuMIn) # Multimodel inference (model comparison)
require(PairedData) # Paired Data Analysis
require(gridExtra) #Misc. grid graphics
require(ggfortify) # Data visualisation tools
require(multilevel) # Multilevel functions
require(robumeta) # robust variance meta-regression
require(psych) # umbrella package for reliability
require(GPArotation) # allows for certain rotations when calculating
reliability
require(lmtest) # Testing linear regression models
require(car) # More regression functions
require(nparLD) # Non-parametric analyses
require(WRS2) # Robust statistical methods
require(npsm) # Non-parametric statistics
require(CorrMixed) #Reliability for longitudinal MLM
require(bbmle) # Maximum Likelihood Estimation
require(colorspace) # More colours
require(DescTools) # Descriptive statistics tools
require(patchwork) # Present figures adjacent/above one another
library(sjPlot) # APA-ready Tables for MLM
library(gmodels) # Model Fitting tools
library(extrafont) # Font package

# Import Data ####

data <- read.csv("Bending and Bonding Data LONG.csv", header = TRUE) #
includes participants otherwise excluded by cuff.
length(data$SB6) # 468 total instances of assessments

plyr::count(data$Participant) ## 52 participants attended at least 1 week


data <-
data %>%
  mutate(PANASPZ = (PANASP - mean(PANASP, na.rm=T))/sd(PANASP, na.rm=T))
%>% #grand-mean centred and standardised
  mutate(PANASNZ = (PANASN - mean(PANASN, na.rm=T))/sd(PANASN, na.rm=T))
%>%
  mutate(SB6Z = (SB6 - mean(SB6, na.rm=T))/sd(SB6, na.rm=T)) %>%
  mutate(BiggerZ = (Connected_Bigger  - mean(Connected_Bigger,
na.rm=T))/sd(Connected_Bigger, na.rm=T)) %>%
  mutate(WSZ = (Wall_Sit_s  - mean(Wall_Sit_s, na.rm=T))/sd(Wall_Sit_s,
na.rm=T))   %>%
```

```
  mutate(RelChangeZ = (Rel_Change  - mean(Rel_Change,
na.rm=T))/sd(Rel_Change, na.rm=T))   %>%
  mutate(SpiritChangeZ = (Spirit_Change  - mean(Spirit_Change,
na.rm=T))/sd(Spirit_Change, na.rm=T))   %>%
  mutate(AgeC = (Age - mean(Age, na.rm = T)))

# ____Z = grand-mean centred and standardised
# ____C = grand-mean centred, but not standardised

####
# Multilevel Models ####
####
summary(data)
data$Participant <- as.factor(data$Participant)
data$Season <- as.factor(data$Season)
data$Measurement.Occasion <- as.factor(data$Measurement.Occasion)
data$Week <- as.factor(data$Week)
data$Time <- as.factor(data$Time)
data$Session_Type <- as.factor(data$Session_Type)
data$RA <- as.factor(data$RA)
data$PainMed <- as.factor(data$PainMed)
data$Yoga_Meaning <- as.factor(data$Yoga_Meaning)
data$Gender <- as.factor(data$Gender)
data$Female <- as.factor(data$Female)


## Participants ####
data_W1 <- data[data$Week == 1,]
data_W1_Pre <- data_W1[data_W1$Measurement.Occasion == 0,]


Gender_table <- CrossTable(data_W1_Pre$Female,data_W1_Pre$Session_Type,
chisq =  T)
# No sig difference of Gender between yoga groups

lev1<-leveneTest(Age~Session_Type, data = data_W1_Pre, center="mean")
lev2<-leveneTest(Age~Session_Type, data = data_W1_Pre, center="median")
# not sig diff from equal variance
stats::t.test(Age~Session_Type, data = data_W1_Pre, var.equal=TRUE,
na.rm=TRUE)
# No significant difference in age between the 2 groups

Splev1<-leveneTest(Spirit_Pre~Session_Type, data = data_W1_Pre,
center="mean")
Splev2<-leveneTest(Spirit_Pre~Session_Type, data = data_W1_Pre,
center="median")
# not sig diff from equal variance
stats::t.test(Spirit_Pre~Session_Type, data = data_W1_Pre, var.equal=TRUE,
na.rm=TRUE)
# no sig difference in level of spirituality between 2 groups

Rellev1<-leveneTest(Rel_Pre~Session_Type, data = data_W1_Pre,
center="mean")
Rellev2<-leveneTest(Rel_Pre~Session_Type, data = data_W1_Pre,
center="median")
# Sig diff from equal variance
stats::t.test(Rel_Pre~Session_Type, data = data_W1_Pre, var.equal=FALSE,
na.rm=TRUE)
# no sig difference in level of religiosity between the 2 groups


## H1: Social Bonding v.s. Measurement Occasion ####

basemodel <- lm(SB6Z~1 , data = data)

Model <- lme4::lmer(SB6Z ~ 1+
                      (1|Participant), data=data, REML = F)
```

```
Model1 <- lme4::lmer(SB6Z ~ Measurement.Occasion + #fixed effect of pre
v.s. post
                       (1|Participant), data=data, REML = F)

Model2 <- lme4::lmer(SB6Z ~ Measurement.Occasion + Week + # add fixed
effect of Week of yoga
                       (1|Participant), data=data, REML = F)

Model3 <- lme4::lmer(SB6Z ~ Measurement.Occasion * Week + # check for
interaction between pre/post and Week
                       (1|Participant), data=data, REML = F)

Model4 <- lme4::lmer(SB6Z ~ Measurement.Occasion + #use Week as a level MO
within Week within ptp
                       (1|Participant) + (1|Week), data=data, REML = F)

Model5 <- lme4::lmer(SB6Z ~ Week + #nonsense model
                       (1|Participant) + (1|Measurement.Occasion),
data=data, REML = F)


require(bbmle)
AICctab(basemodel, Model, Model1, Model2, Model3, Model4, Model5,
       logLik=T, weights = T, base = T) #basemodel appears to be far worse
than other models.

anova(Model, Model1, Model4, Model5, Model2, Model3)
# best model here is Model3

SB_MO_Test <- lmerTest::lmer(SB6Z ~ Measurement.Occasion * Week + # check
for interaction between pre/post and Week
                               (1|Participant), data=data, REML = T)
summary(SB_MO_Test)


### Plotting H1 ####
h1colours <- c("red",
"red","red","red","red","blue","blue","blue","blue","blue")
H1plot <- ggplot(data, aes(x=Week, y=SB6Z, group=Measurement.Occasion))+
  stat_smooth(method="lm", se=F, size=1, show.legend = TRUE, colour
=h1colours )+ # slopes for different Session Type
  stat_smooth(aes (group=1), method="lm", size=1.5, colour = "black" #
average slope with SE
  )
H1plot <- (H1plot +
             theme_bw() +
             ylab("Standardised Social Bonding Score"))

H1plotb <- ggplot(data, aes(x=Measurement.Occasion, y=SB6Z, group=Week))+
  stat_smooth(method="lm", se=F, size=1, show.legend = TRUE, colour =
rainbow(10))+ # slopes for different Session Type
  stat_smooth(aes (group=1), method="lm", size=1.5, colour = "black" #
average slope with SE
  )
H1plotb <- (H1plotb +
              theme_bw() +
              ylab("Standardised Social Bonding Score"))
# Red = W1, Yellow = W2, Green = W3, Blue = W4 and Purple = W5
# Blue line is pre-yoga, red line is post-yoga

require(patchwork)
(H1plot/H1plotb) + plot_annotation(tag_levels = "a")

## H2 Connected Bigger v.s. Session Type ####
CB_ST_basemodel <- lm(BiggerZ ~1, data = data)

CB_ST_Model <- lme4::lmer(BiggerZ ~ 1 + (1|Participant), data= data, REML
= F)
```

```
CB_ST_Model1 <- lme4::lmer(BiggerZ ~  Session_Type +
                              (1|Participant), data= data, REML = F)

CB_ST_Model2 <- lme4::lmer(BiggerZ ~   Session_Type + Week +
                              (1|Participant), data= data, REML = F)
CB_ST_Model3 <- lme4::lmer(BiggerZ ~   Session_Type * Week +
                              (1|Participant), data= data, REML = F)


AICctab(CB_ST_basemodel, CB_ST_Model, CB_ST_Model1, CB_ST_Model2,
CB_ST_Model3,
        logLik=T, weights = T, base = T)

anova(CB_ST_Model, CB_ST_Model1, CB_ST_Model2, CB_ST_Model3)
# Best model is to include session type, within particopants, without week

CB_ST_testmodel <- lmerTest::lmer(BiggerZ ~  Session_Type * Week +
                                     (1|Participant), data= data, REML = T)
summary(CB_ST_testmodel)
# Spiritual Yoga significantly increased connectedness to something bigger

### Plotting C2SB ####
require(colorspace)
C2SBcolours <- c("red","red","red","red","red",
                 "blue","blue","blue","blue","blue")
C2SBplot <- ggplot(data, aes(x=Week, y=BiggerZ, group=Session_Type))+
  stat_smooth(method="lm", se=F, size=1, show.legend = TRUE, colour =
C2SBcolours)+ # slopes for different Session Type
  stat_smooth(aes (group=1), method="lm", size=1.5, colour = "black" #
average slope with SE
  )
C2SBplot <- (C2SBplot +
   theme_bw() +
ylab("Standardised Connection to Something Bigger Score"))


bitmap("ConnectionToSomethingBigger.tiff", height = 12, width = 17,
       units = 'cm', type="tifflzw", res=300)
postscript("ConnectionToSomethingBigger.eps", width = 8, height = 8,
           horizontal = FALSE, onefile = FALSE, paper = "special",
           colormodel = "cmyk", family = "Arial")
C2SBplot


tiff("C2SB.tiff", width = 5, height = 5, units = 'in', res = 300)
C2SBplot
dev.off()

# Manipulation Check: Change in R/S measures ####

# Religiosity and spirituality measured before first session and then
after final session.
#  Within-Between ANOVA appropriate


ANOVAdata <- read.csv("B and B Data Manip Check ANOVA - LONG.csv", header
= TRUE) # includes participants otherwise excluded by cuff.
ANOVAdata_Pre <- ANOVAdata[ANOVAdata$Time == 0,]

length(ANOVAdata_Pre$Participant) # 41 total participants

ANOVAdata_Pre_Sec <- ANOVAdata_Pre[ANOVAdata_Pre$Session_Type == 0,] #
Secular
ANOVAdata_Pre_Spirit <- ANOVAdata_Pre[ANOVAdata_Pre$Session_Type == 1,] #
Spirit
length(ANOVAdata_Pre_Sec$Participant) # 19 Participants in secular yoga
gave both pre-experiment levels of R/S measure
length(ANOVAdata_Pre_Spirit$Participant) # 22 Participants in spiritual
yoga gave both pre-experiment levels of R/S measure
```

```
ANOVAdata_Post <- ANOVAdata[ANOVAdata$Time == 1,] # Post-Experiment data
ANOVAdata_Post_Sec <- ANOVAdata_Post[ANOVAdata_Post$Session_Type == 0,] #
Secular
ANOVAdata_Post_Spirit <- ANOVAdata_Post[ANOVAdata_Post$Session_Type == 1,]
# Spiritual


# Secular Yoga Spirituality
mean(ANOVAdata_Pre_Sec$Spirituality)
sd(ANOVAdata_Pre_Sec$Spirituality)
shapiro.test(ANOVAdata_Pre_Sec$Spirituality) # W = .943, p = .304 - Not
stat. sig. dif. from normal
mean(ANOVAdata_Post_Sec$Spirituality)
sd(ANOVAdata_Post_Sec$Spirituality)
shapiro.test(ANOVAdata_Post_Sec$Spirituality) # W = .948, p = .293 - Not
stat. sig. dif. from normal


# Spiritual Yoga Spirituality
mean(ANOVAdata_Pre_Spirit$Spirituality)
sd(ANOVAdata_Pre_Spirit$Spirituality)
shapiro.test(ANOVAdata_Pre_Spirit$Spirituality) # W = .950, p = .309 - Not
stat. sig. dif. from normal
mean(ANOVAdata_Post_Spirit$Spirituality)
sd(ANOVAdata_Post_Spirit$Spirituality)
shapiro.test(ANOVAdata_Post_Spirit$Spirituality) # W = .948, p = .293 -
Not stat. sig. dif. from normal

# Parametric Within-Between ANOVA possible for spirituality comparison.

ANOVAdata$FactST <- as.factor(ANOVAdata$Session_Type)
ANOVAdata$FactTime <- as.factor(ANOVAdata$Time)

aov_Spirit_Type <- aov(Spirituality ~ FactST*FactTime +
Error(Participant/FactTime), data=ANOVAdata)
summary(aov_Spirit_Type)
require(DescTools)

EtaSq(aov_Spirit_Type, type = 1)
# No significant effects
# Session Type  F = 0.872, p =  0.356, eta^2(gen) = .020
# Time          F = 2.838, p =  0.100, eta^2(gen) = .005
# Time*ST       F = 0.046, p =  0.831, eta^2(gen) < .001



bxp <- ggboxplot(
  ANOVAdata, x = "FactTime", y = "Spirituality",
  color = "FactST", palette = "jco"
)
bxp
# Religiosity #

# Secular Yoga Religiosity
mean(ANOVAdata_Pre_Sec$Religiosity) # 2.84
sd(ANOVAdata_Pre_Sec$Religiosity) # 2.09
shapiro.test(ANOVAdata_Pre_Sec$Religiosity) # W = .912, p = .095 - Not
stat. sig. dif. from normal
mean(ANOVAdata_Post_Sec$Religiosity) # 1.64
sd(ANOVAdata_Post_Sec$Religiosity) # 1.53
shapiro.test(ANOVAdata_Post_Sec$Religiosity) # W = .845, p = .003 - Stat.
sig. dif. from normal


# Spiritual Yoga Religiosity
mean(ANOVAdata_Pre_Spirit$Religiosity) # 1.68
sd(ANOVAdata_Pre_Spirit$Religiosity) # 1.43
```

```
shapiro.test(ANOVAdata_Pre_Spirit$Religiosity) # W = .907, p = .042 -
Stat. sig. dif. from normal
mean(ANOVAdata_Post_Spirit$Religiosity) # 1.64
sd(ANOVAdata_Post_Spirit$Religiosity) # 1.53
shapiro.test(ANOVAdata_Post_Spirit$Religiosity) # W = .845, p = .003 -
Stat. sig. dif. from normal


# non-parametric Within-Between anova needed:

require(nparLD) # non-parametric ANOVA package

ex.f1f1np <- nparLD(Religiosity ~ FactST * FactTime, data = ANOVAdata,
subject = "Participant", description = FALSE)
plot(ex.f1f1np)

summary(ex.f1f1np)

nonpar_ANOVA <- f1.ld.f1(ANOVAdata$Religiosity, ANOVAdata$FactTime,
ANOVAdata$FactST, ANOVAdata$Participant)

nonpar_ANOVA$RTE
# RTE < .5 means there is less than 50% chance of randomly choosing a
participant from this sample with a higher than average SB6.
# RTE > .5 means there is greater than 50% chance of randomly choosing a
participant from this sample with a higher than average SB6.

nonpar_ANOVA$case2x2
#              Statistic  p-value(N)       df  p-value(T)
# Group       1.91641540 0.05531224 34.07447  0.06373115
# Time        0.37644508 0.70658604 36.88537  0.70874286
# Group:Time -0.04845333 0.96135496 36.88537  0.96161638

nonpar_ANOVA$ANOVA.test
#              Statistic  df     p-value
#  Group      3.672648000  1  0.05531224
#  Time       0.141710896  1  0.70658604
#  Group:Time 0.002347725  1  0.96135496

# No significant effects


Yoga_Meaningdata <- select(data, Participant, Week, Session_Type,
Yoga_Meaning)

Yoga_Meaningdata <- Yoga_Meaningdata[Yoga_Meaningdata$Week == 5,]
Yoga_Meaningdata <- Yoga_Meaningdata[complete.cases(Yoga_Meaningdata),]

table(Yoga_Meaningdata$Session_Type, Yoga_Meaningdata$Yoga_Meaning)
prop.table(table(Yoga_Meaningdata$Session_Type,
Yoga_Meaningdata$Yoga_Meaning))*100

xtabs(~Yoga_Meaning + Session_Type, data = Yoga_Meaningdata)

chisq.test(Yoga_Meaningdata$Session_Type, Yoga_Meaningdata$Yoga_Meaning)
fisher.test(Yoga_Meaningdata$Session_Type, Yoga_Meaningdata$Yoga_Meaning)


# H3: Social Bonding and Session Type ####


# Model3 from H1 brought forward
SB_ST_Model <- lme4::lmer(SB6Z ~ Session_Type + Week *
Measurement.Occasion +
                       (1|Participant), data=data, REML = F)
SB_ST_Model1 <- lme4::lmer(SB6Z ~ Session_Type * Week *
Measurement.Occasion +
                            (1|Participant), data=data, REML = F)
AICctab(Model3, SB_ST_Model, SB_ST_Model1,
```

```
       logLik=T, weights = T, base = T)

anova(Model3, SB_ST_Model, SB_ST_Model1)

# Provide fixed effects p-values using Luke (2017) suggestions of REML and
SB_STtest <- lmerTest::lmer(SB6Z ~ Session_Type + Week *
Measurement.Occasion +
                              (1|Participant), data=data , REML = T)

summary(SB_STtest)
# Session Type not significant predictor of change in social bonding,
However week and measurement occasion were.
# Fixed Effect of Session_Type,   p = 0.792910

# H4: Social bonding and Pain Tolerance/Wall-Sit ####
SB_WS_Model <- lme4::lmer(SB6Z ~ WSZ + Week * Measurement.Occasion +
                            (1|Participant), data=data, REML = F)
SB_WS_Model1 <- lme4::lmer(SB6Z ~ WSZ * Week * Measurement.Occasion +
                             (1|Participant), data=data, REML = F)
SB_WS_Model2 <- lme4::lmer(SB6Z ~ WSZ + Week * Measurement.Occasion +
                            (WSZ|Participant), data=data, REML = F)
SB_WS_Model3 <- lme4::lmer(SB6Z ~ WSZ * Week * Measurement.Occasion +
                             (WSZ|Participant), data=data, REML = F)

AICctab(Model3,SB_WS_Model,SB_WS_Model1,SB_WS_Model2,SB_WS_Model3,
        logLik = T, weights = T, base = T)
anova(SB_WS_Model1,SB_WS_Model3,SB_WS_Model, Model3,SB_WS_Model2)
anova(SB_WS_Model2,SB_WS_Model3, Model3)
# SB_WS_Model2 is best fit.

SB_WS_Test <- lmerTest::lmer(SB6Z ~ WSZ + Week * Measurement.Occasion +
                           (WSZ|Participant), data=data, REML = T)


summary(SB_WS_Test)
# Session Type not significant predictor of change in social bodning.
# However, including it  in the model improves model fit.
# WSZ estimate = 0.06166 t(20.39398)= 1.260, p =  0.222

#The only way I can get the colours to go well
h4colours <-
c("red","red","red","red","red","red","red","red","red","red",

"red","red","red","red","red","red","red","red","red","red",

"red","red","red","red","red","red","red","red","red","red",

"red","red","red","red","red","red","red","red","red","red",

"red","red","red","red","red","red","red","red","red","red",

"red","red","red","red","red","red","red","red","red","red",

"red","red","red","red","red","red","red","red","red","red",

"red","red","red","red","red","red","red","red","red","red",

"blue","blue","blue","blue","blue","blue","blue","blue","blue","blue",

"blue","blue","blue","blue","blue","blue","blue","blue","blue","blue",

"blue","blue","blue","blue","blue","blue","blue","blue","blue","blue",

"blue","blue","blue","blue","blue","blue","blue","blue","blue","blue",

"blue","blue","blue","blue","blue","blue","blue","blue","blue","blue",

"blue","blue","blue","blue","blue","blue","blue","blue","blue","blue",
```

```
"blue","blue","blue","blue","blue","blue","blue","blue","blue","blue",

"blue","blue","blue","blue","blue","blue","blue","blue","blue","blue")

  ## Plotting H4 ####

H4plot <- ggplot(data, aes(x=WSZ, y=SB6Z, group=Measurement.Occasion))+
  stat_smooth(method="lm", se=F, size=1, show.legend = TRUE, colour =
h4colours)+ # slopes for different Session Type
  stat_smooth(aes (group=1), method="lm", size=1.5, colour = "black" #
average slope with SE
  )
H4plot <- (H4plot +
              theme_bw() +
              ylab("Standardised Social Bonding Score") +
              xlab("Standardised Wall-Sit Measure")  )

# There may be outliers affecting results:
# WSZ range is from -1.5 to +7.5, where all WSZ values above +4 come from
pre-yoga.
# Given these are standardised values, > +4 are extreme values.

# Exploratory H4 - Outliers removed ####

Qs_WSZ <- quantile(data$WSZ)
Q1_WSZ <- -0.6538515
Q3_WSZ <- 0.3837056

WSZ_IQR <- IQR(data$WSZ)
Lower_Outlier_WSZ <-  -0.6538515 - WSZ_IQR
# -1.691
# Does not include any negative outliers
Upper_Outlier_WSZ <-  0.3837056 + WSZ_IQR
 # 1.421.

WSZoutlierremoved <- subset(data, WSZ < Upper_Outlier_WSZ)


SB_WS_Expl_Model <- lme4::lmer(SB6Z ~ WSZ + Week * Measurement.Occasion +
                             (1|Participant), data=WSZoutlierremoved, REML
= F)
SB_WS_Expl_Model1 <- lme4::lmer(SB6Z ~ WSZ * Week * Measurement.Occasion +
                              (1|Participant), data=WSZoutlierremoved, REML
= F)
SB_WS_Expl_Model2 <- lme4::lmer(SB6Z ~ WSZ + Week * Measurement.Occasion +
                              (WSZ|Participant), data=WSZoutlierremoved,
REML = F)
SB_WS_Expl_Model3 <- lme4::lmer(SB6Z ~ WSZ * Week * Measurement.Occasion +
                              (WSZ|Participant), data=WSZoutlierremoved,
REML = F)

AICctab(SB_WS_Expl_Model,SB_WS_Expl_Model1,SB_WS_Expl_Model2,SB_WS_Expl_Mo
del3,
        logLik = T, weights = T, base = T)
anova(SB_WS_Expl_Model, SB_WS_Expl_Model1,SB_WS_Expl_Model2,
SB_WS_Expl_Model3)
anova(SB_WS_Model,SB_WS_Model1)
# SB_WS_Expl_Model is best fit.

SB_WS_Expl_Test <- lmerTest::lmer(SB6Z ~ WSZ + Week * Measurement.Occasion
+
                                    (1|Participant),
data=WSZoutlierremoved, REML = T)


summary(SB_WS_Expl_Test)
# Session Type not significant predictor of change in social bodning.
# However, including it  in the model improves model fit.
```

```
# WSZ estimate = 0.06166 t(20.39398)= 1.260, p =  0.222

H4plotb <- ggplot(WSZoutlierremoved, aes(x=WSZ, y=SB6Z,
group=Measurement.Occasion))+
  stat_smooth(method="lm", se=F, size=1, show.legend = TRUE, colour =
h4colours)+ # slopes for different Session Type
  stat_smooth(aes (group=1), method="lm", size=1.5, colour = "black" #
average slope with SE
  )
H4plotb <- (H4plotb +
              theme_bw() +
              ylab("Standardised Social Bonding Score") +
              xlab("Standardised Wall-Sit Measuere")  )

(H4plot/H4plotb) + plot_annotation(tag_levels = "a")



# H5: Social Bonding and Affect ####

SB_PANAS_Model <- lme4::lmer(SB6Z ~ PANASPZ + PANASNZ +
                            (1|Participant), data=data, REML = F)
SB_PANAS_Modelb <- lme4::lmer(SB6Z ~ PANASPZ +
                               (1|Participant), data=data, REML = F)

SB_PANAS_Model1 <- lme4::lmer(SB6Z ~ PANASPZ + PANASNZ +
Measurement.Occasion +
                               (1|Participant), data=data, REML = F)
SB_PANAS_Model1b <- lme4::lmer(SB6Z ~ PANASPZ + Measurement.Occasion +
                                (1|Participant), data=data, REML = F)

SB_PANAS_Model2 <- lme4::lmer(SB6Z ~ PANASPZ + PANASNZ +
Measurement.Occasion + Week +
                              (1|Participant), data=data, REML = F)

SB_PANAS_Model2b <- lme4::lmer(SB6Z ~ PANASPZ + Measurement.Occasion +
Week +
                                (1|Participant), data=data, REML = F)

SB_PANAS_Model3 <- lme4::lmer(SB6Z ~ PANASPZ + PANASNZ +
Measurement.Occasion * Week +
                                (1|Participant), data=data, REML = F)

SB_PANAS_Model3b <- lme4::lmer(SB6Z ~ PANASPZ + Measurement.Occasion *
Week +
                                (1|Participant), data=data, REML = F)

SB_PANAS_Model4 <- lme4::lmer(SB6Z ~ PANASPZ + PANASNZ +
Measurement.Occasion * Week +
                                (PANASPZ|Participant), data=data, REML =
F) # Allow PANAS+ to have a random slope for each participant

SB_PANAS_Model4b <- lme4::lmer(SB6Z ~ PANASPZ + Measurement.Occasion *
Week +
                                (PANASPZ|Participant), data=data, REML =
F) # Allow PANAS+ to have a random slope for each participant

SB_PANAS_Model5 <- lme4::lmer(SB6Z ~ PANASPZ + PANASNZ +
Measurement.Occasion * Week +
                                (PANASPZ+PANASNZ|Participant), data=data,
REML = F) # Allow both PANAS+ and PANAS- to have a random slope for each
participant

SB_PANAS_Model6 <- lme4::lmer(SB6Z ~ PANASPZ + PANASNZ *
Measurement.Occasion * Week +
                                (PANASPZ+PANASNZ|Participant), data=data,
REML = F) # Allow both PANAS+ and PANAS- to have a random slope for each
participant
```

```
SB_PANAS_Model7 <- lme4::lmer(SB6Z ~ PANASNZ + PANASPZ *
Measurement.Occasion * Week +
                                (PANASPZ+PANASNZ|Participant), data=data,
REML = F) # Allow both PANAS+ and PANAS- to have a random slope for each
participant


SB_PANAS_Model8 <- lme4::lmer(SB6Z ~ PANASNZ + PANASPZ * Week +
Measurement.Occasion  +
                                (PANASPZ+PANASNZ|Participant), data=data,
REML = F) # Allow both PANAS+ and PANAS- to have a random slope for each
participant

AICctab(basemodel, Model3, SB_PANAS_Model, SB_PANAS_Model1,
SB_PANAS_Model2, SB_PANAS_Model3,SB_PANAS_Model4, SB_PANAS_Model5,
        SB_PANAS_Modelb, SB_PANAS_Model1b, SB_PANAS_Model2b,
SB_PANAS_Model3b,SB_PANAS_Model4b, SB_PANAS_Model6, SB_PANAS_Model7,
SB_PANAS_Model8,
       logLik=T, weights = T, base = T)

anova(SB_PANAS_Model, SB_PANAS_Model1, Model3, SB_PANAS_Model2,
SB_PANAS_Model3,SB_PANAS_Model4, SB_PANAS_Model5,
      SB_PANAS_Modelb, SB_PANAS_Model1b, SB_PANAS_Model2b,
SB_PANAS_Model3b,SB_PANAS_Model4b, SB_PANAS_Model6, SB_PANAS_Model)
# SB_PANAS_Model5 is best fit.

SB_PANAS_testmodel <- lmerTest::lmer(SB6Z ~ PANASPZ + PANASNZ +
Measurement.Occasion * Week +
                                       (PANASPZ+PANASNZ|Participant),
data=data, REML = T)
summary(SB_PANAS_testmodel)


## H5 Plot ####

H5plot <- ggplot(data, aes(x=PANASPZ, y=SB6Z,
group=Measurement.Occasion))+
  stat_smooth(method="lm", se=F, size=1, show.legend = TRUE, colour =
h4colours)+ # slopes for different Session Type
  stat_smooth(aes (group=1), method="lm", size=1.5, colour = "black" #
average slope with SE
  )
H5plot <- (H5plot +
              theme_bw() +
              ylab("Standardised Social Bonding Score") +
              xlab("Standardised PANAS+")  )

H5plotb <- ggplot(data, aes(x=PANASPZ, y=SB6Z, group=Week))+
  stat_smooth(method="lm", se=F, size=1, show.legend = TRUE, colour =
rainbow(400))+ # slopes for different Session Type
  stat_smooth(aes (group=1), method="lm", size=1.5, colour = "black" #
average slope with SE
  )
H5plotb <- (H5plotb +
  theme_bw() +
  ylab("Standardised Social Bonding Score") +
    xlab("Standardised PANAS+")  )
(H5plot/H5plotb)+ plot_annotation(tag_levels = "a")

# Follow-up Analyses ####
## Overall social bonding model ####

Overall_Model <- lme4::lmer(SB6Z ~ WSZ + PANASPZ + PANASNZ + BiggerZ +
Session_Type + Week +  Measurement.Occasion+
                              (1|Participant),
                            data=data, REML = F)

Overall_Model1 <- lme4::lmer(SB6Z ~ WSZ + PANASPZ + PANASNZ + BiggerZ +
Session_Type +  Measurement.Occasion * Week+
```

```
                              (1|Participant),
                            data=data, REML = F)

Overall_Model2 <- lme4::lmer(SB6Z ~ WSZ + PANASPZ + PANASNZ + BiggerZ +
Session_Type +  Measurement.Occasion * Week+
                              (PANASPZ|Participant),
                            data=data, REML = F)

Overall_Model3 <- lme4::lmer(SB6Z ~ WSZ + PANASPZ + PANASNZ + BiggerZ +
Session_Type +  Measurement.Occasion * Week+
                              (PANASPZ+PANASNZ|Participant),
                            data=data, REML = F)

Overall_Model4 <- lme4::lmer(SB6Z ~ WSZ + PANASPZ + PANASNZ + BiggerZ +
Session_Type +  Measurement.Occasion * Week+
                              (PANASPZ+PANASNZ+WSZ|Participant),
                            data=data, REML = F)

Overall_Model5 <- lme4::lmer(SB6Z ~ WSZ + PANASPZ + PANASNZ + BiggerZ +
Session_Type +  Measurement.Occasion * Week+
                              (PANASPZ+PANASNZ+BiggerZ|Participant),
                            data=data, REML = F)

Overall_Model6 <- lme4::lmer(SB6Z ~ WSZ + PANASPZ + PANASNZ + BiggerZ +
Session_Type +  Measurement.Occasion * Week+
                              AgeC +
                              (PANASPZ+PANASNZ+BiggerZ|Participant),
                            data=data, REML = F)

Overall_Model7 <- lme4::lmer(SB6Z ~ WSZ + PANASPZ + PANASNZ + BiggerZ +
Session_Type +  Measurement.Occasion * Week +
                              AgeC + Gender +
                              (PANASPZ+PANASNZ+BiggerZ|Participant),
                            data=data, REML = F)


AICctab(basemodel, Model3, SB_PANAS_Model5,
Overall_Model,Overall_Model1,Overall_Model2,Overall_Model3,Overall_Model4,
        Overall_Model5, Overall_Model6, Overall_Model7,
        logLik=T, weights = T, base = T)

anova(Overall_Model, Overall_Model1, Overall_Model2, Overall_Model3,
Overall_Model4,Overall_Model5,Overall_Model6,Overall_Model7)
# Overall_Model5 is significantly better fit than OM2.

Overall_testmodel <- lmerTest::lmer(SB6Z ~ WSZ + PANASPZ + PANASNZ +
BiggerZ +Session_Type+  Measurement.Occasion * Week +

(PANASPZ+PANASNZ+BiggerZ|Participant),
                                    data=data, REML = T)
summary(Overall_testmodel)



library(sjPlot)
# Model A
tab_model(SB_MO_Test,
          show.stat = T, show.se = T, show.df = T,show.aicc = T,
show.loglik = T, show.std  =T,
          p.val = "satterthwaite", p.style = "numeric_stars", p.threshold
= c(0.05, 0.01, 0.001),
          string.pred = "Predictors",string.se = "SE", string.ci = "95%
CI",
          string.std = "Standardised Beta", string.std.p =  "Standardised
p",
          string.stat = "t",   string.std.stat = "Standardised t",
          string.std_se = "Standardised SE", string.std_ci = "Standardised
95% CI",
```

```
          col.order = c("est", "se", "ci", "stat", "df.error", "p",
"std.est", "std.se", "std.ci", "ci.inner",
                        "ci.outer",  "std.stat" , "std.p",
"response.level")
)

# Model B
tab_model(SB_PANAS_testmodel,
          show.stat = T, show.se = T, show.df = T,show.aicc = T,
show.loglik = T, show.std  =T,
          p.val = "satterthwaite", p.style = "numeric_stars", p.threshold
= c(0.05, 0.01, 0.001),
          string.pred = "Predictors",string.se = "SE", string.ci = "95%
CI",
          string.std = "Standardised Beta", string.std.p =  "Standardised
p",
          string.stat = "t",   string.std.stat = "Standardised t",
          string.std_se = "Standardised SE", string.std_ci = "Standardised
95% CI",
          col.order = c("est", "se", "ci", "stat", "df.error", "p",
"std.est", "std.se", "std.ci", "ci.inner",
                        "ci.outer",  "std.stat",  "std.df.error" ,
"std.p",  "response.level")
)
# Model C
tab_model(Overall_testmodel,
          show.stat = T, show.se = T, show.df = T,show.aicc = T,
show.loglik = T, show.std  =T,
          p.val = "satterthwaite", p.style = "numeric_stars", p.threshold
= c(0.05, 0.01, 0.001),
          string.pred = "Predictors",string.se = "SE", string.ci = "95%
CI",
          string.std = "Standardised Beta", string.std.p =  "Standardised
p",
          string.stat = "t",   string.std.stat = "Standardised t",
          string.std_se = "Standardised SE", string.std_ci = "Standardised
95% CI",
          col.order = c("est", "se", "ci", "stat", "df.error", "p",
"std.est", "std.se", "std.ci", "ci.inner",
                        "ci.outer",  "std.stat",  "std.df.error" ,
"std.p",  "response.level")
)

# Grouped Model Tabel
tab_model(SB_MO_Test, SB_PANAS_testmodel,Overall_testmodel,
          show.stat = T, show.se = T, show.df = T,show.aicc = T,
show.loglik = T, show.std  =T,
          p.val = "satterthwaite", p.style = "numeric_stars", p.threshold
= 0.05,
          string.pred = "Predictors",string.se = "SE", string.ci = "95%
CI",
          string.std = "Standardised Beta", string.std.p =  "Standardised
p",
          string.stat = "t",   string.std.stat = "Standardised t",
          string.std_se = "Standardised SE", string.std_ci = "Standardised
95% CI",
          col.order = c("est", "se", "ci", "stat", "df.error", "p",
"std.est", "std.se", "std.ci", "ci.inner",
                        "ci.outer",  "std.stat",  "std.df.error" ,
"std.p",  "response.level")
)

# Scale Reliability ####

## Social Bonding Reliability ####
# Using the method outlined in Laenen et al. (2007; 2009) and Van der Elst
et al. (2016)
data$Weeknum <- as.numeric(data$Week)
```

```
myvars <- c("Participant", "Measurement.Occasion", "Session_Type",
"Weeknum", "SB6Z")
#468 observations, 5 variabvles.
# Participant: The Subject Identifier
# Measurement.Occasion: Pre-yoga or Post-yoga
# Session Type: The condition of the experiment
# Week: The timepoint at which the outcomes were measured.
# SB6Z: a continuous outcome variable
newdata <- data[myvars]

newdata$Week2 <- newdata$Weeknum**2
newdata$Week3 <- newdata$Weeknum**3
newdata$Week3_log <- (newdata$Weeknum**3)* (log(newdata$Weeknum))

newdata$ParticipantID <- as.integer(newdata$Participant)
str(newdata$ParticipantID)

CorrMixedmodel <- WS.Corr.Mixed(
  Fixed.Part = SB6Z ~ Weeknum + as.factor(Measurement.Occasion)
  + as.factor(Session_Type), Random.Part = ~ 1|ParticipantID,
  Dataset = newdata, Model = 1, Id = "ParticipantID", Time = Weeknum,
  Number.Bootstrap = 50, Seed = 12345)

summary(CorrMixedmodel)

# R: 0.7954364
# 95% confidence interval (bootstrap): [0.729254; 0.8678341]

## PANAS+ Reliability ####

myvars2 <- c("Participant", "Measurement.Occasion", "Session_Type",
"Weeknum", "PANASPZ")
newdata2 <- data[myvars2]

newdata2$Week2 <- newdata2$Weeknum**2
newdata2$Week3 <- newdata2$Weeknum**3
newdata2$Week3_log <- (newdata2$Weeknum**3)* (log(newdata2$Weeknum))

newdata2$ParticipantID <- as.integer(newdata2$Participant)
str(newdata2$ParticipantID)

CorrMixedmodel2 <- WS.Corr.Mixed(
  Fixed.Part = PANASPZ ~ Weeknum + as.factor(Measurement.Occasion)
  + as.factor(Session_Type), Random.Part = ~ 1|ParticipantID,
  Dataset = newdata2, Model = 1, Id = "ParticipantID", Time = Weeknum,
  Number.Bootstrap = 50, Seed = 12345)

summary(CorrMixedmodel2)

# R: 0.7121903
# 95% confidence interval (bootstrap): [0.5756121; 0.7734199]

## PANAS- Reliability ####

myvars3 <- c("Participant", "Measurement.Occasion", "Session_Type",
"Weeknum", "PANASNZ")
newdata3 <- data[myvars3]

newdata3$Week2 <- newdata3$Weeknum**2
newdata3$Week3 <- newdata3$Weeknum**3
newdata3$Week3_log <- (newdata3$Weeknum**3)* (log(newdata3$Weeknum))

newdata3$ParticipantID <- as.integer(newdata3$Participant)
str(newdata3$ParticipantID)

CorrMixedmodel3 <- WS.Corr.Mixed(
  Fixed.Part = PANASNZ ~ Weeknum + as.factor(Measurement.Occasion)
  + as.factor(Session_Type), Random.Part = ~ 1|ParticipantID,
  Dataset = newdata3, Model = 1, Id = "ParticipantID", Time = Weeknum,
```

```
  Number.Bootstrap = 50, Seed = 12345)

summary(CorrMixedmodel3)

# R: 0.5106225
# 95% confidence interval (bootstrap): [0.3577241; 0.5839008]




# TOST ####

## Basic TOST ####

TOSTER::dataTOSTtwo(data = data, deps = c("SB6Z"),group = "Session_Type",
plots = T)

## Mixed-Effects TOST ####

TOST_model <- lmer(SB6Z ~ Session_Type +BiggerZ + WSZ + PANASPZ + PANASNZ
+   Measurement.Occasion * Week+
                     (PANASPZ+PANASNZ+BiggerZ|Participant),
                   data=data, REML = F)
summary(TOST_model)

bound_l <- -0.46 # Szucs & Ioannidis (2017; 2021) show this to be the
median moderate effect size across cognitive sciences
bound_u <- 0.46# Szucs & Ioannidis (2017; 2021) show this to be the median
moderate effect size across cognitive sciences

lower <- contest1D(TOST_model, c(0,1,0,0,0,
                                 0,0,0,0,0,
                                 0,0,0,0,0), confint=TRUE, rhs=bound_l) #
get t value for test against lower bound
upper <- contest1D(TOST_model, c(0,1,0,0,0,
                                 0,0,0,0,0,
                                 0,0,0,0,0), confint=TRUE, rhs=bound_u) #
get t value for test against upper bound
lower
upper

pt(lower$`t value`, lower$df, lower.tail = FALSE) # test against lower
bound
# p =.019 significantly higher than -0.46
pt(upper$`t value`, upper$df, lower.tail = TRUE)  # test against upper
bound
# p <.001 significantly lower than 0.46
# therefore significant evidence for no difference


# Mediation Analyses ####
library(mediation)
## PANAS+ mediated via C2SB ####

### Build the models ####

#### Basic models ####
MedModel_base <- lm(BiggerZ ~ 1,
                            data=data, REML = F)

MedModel_model1 <- lme4::lmer(BiggerZ ~ 1+
                                     (1|Participant),
                                     data=data, REML = F)

MedModel_model2 <- lme4::lmer(BiggerZ ~ PANASPZ +
                              (1|Participant),
                            data=data, REML = F)

MedModel_model3 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ+
```

```
                                (1|Participant),
                              data=data, REML = F)

MedModel_model4 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ+ +
Measurement.Occasion +
                                (1|Participant),
                              data=data, REML = F)

MedModel_model5 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ +
Measurement.Occasion + Week +
                                (1|Participant),
                              data=data, REML = F)

MedModel_model6 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ+
Measurement.Occasion + Week + Session_Type+
                                (1|Participant),
                              data=data, REML = F)



MedModel_model7 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ+
Measurement.Occasion + Week + Session_Type+ WSZ +
                                (1|Participant),
                              data=data, REML = F)



MedModel_model8 <- lme4::lmer(BiggerZ ~ PANASPZ + PANASNZ+
Measurement.Occasion * Week+ Session_Type+ WSZ +
                                (1|Participant),
                              data=data, REML = F)

AICctab(MedModel_base, MedModel_model1, MedModel_model2,MedModel_model3,
MedModel_model4, MedModel_model5,
        MedModel_model6, MedModel_model7, MedModel_model8,
        logLik=T, weights = T, base = T)

anova(MedModel_model1, MedModel_model2,MedModel_model3, MedModel_model4,
MedModel_model5,
      MedModel_model6, MedModel_model7, MedModel_model8)
# Model2 has lowest AICc

#### Model2 variants ####

MedModel_model2b <- lme4::lmer(BiggerZ ~ PANASPZ +
                                (PANASPZ|Participant),
                              data=data, REML = F)

anova(MedModel_model2,MedModel_model2b)

# MedModel_model2b is better



MedModel_model2c <- lme4::lmer(BiggerZ ~ PANASPZ + Session_Type +
                                 (PANASPZ|Participant),
                               data=data, REML = F)

anova(MedModel_model2b, MedModel_model2c)
# MedModel_model2c is better


MedModel_model2d <- lme4::lmer(BiggerZ ~ PANASPZ + Session_Type + Week +
                                 (PANASPZ|Participant),
                               data=data, REML = F)

anova(MedModel_model2d, MedModel_model2c)
# MedModel_model2c is still better
```

```
MedModel_model2e <- lme4::lmer(BiggerZ ~ PANASPZ + Session_Type + WSZ +
                                  (PANASPZ|Participant),
                                data=data, REML = F)

anova(MedModel_model2e, MedModel_model2c)
# MedModel_model2c is still better

MedModel_model2f <- lme4::lmer(BiggerZ ~ PANASPZ * Session_Type +
                                  (PANASPZ|Participant),
                                data=data, REML = F)

anova(MedModel_model2f, MedModel_model2c)
# MedModel_model2c is still better


MedModel_model2g <- lme4::lmer(BiggerZ ~ PANASPZ + Session_Type*Week +
                                  (PANASPZ|Participant),
                                data=data, REML = F)
AICctab(MedModel_model2,MedModel_model2b, MedModel_model2c,
MedModel_model2g, logLik=T, weights = T, base = T)

anova(MedModel_model2g, MedModel_model2c)
# MedModel_model2g is better

### Run the mediation based on best model ####

MedModel_Mediator <- lme4::lmer(BiggerZ ~ PANASPZ + Session_Type*Week +
                                   (PANASPZ|Participant),
                                 data=data, REML = F)

sum_med <- summary(MedModel_Mediator)


MedModel_Full <- lme4::lmer(SB6Z ~ BiggerZ + PANASPZ + Session_Type*Week +
                                   (PANASPZ|Participant),
                             data=data, REML = F)
sum_full <- summary(MedModel_Full)

Baseeffect_b <- sum_med$coefficients[2]



#### mediation output ####
med_results <- mediation::mediate(MedModel_Mediator, MedModel_Full, treat
= "PANASPZ", mediator = "BiggerZ")

# manually calculated from model
Baseeffect_a <- sum_med$coefficients[2]
Baseeffect_b <- sum_full$coefficients[2]
Baseeffect_c <- sum_full$coefficients[3]
Baseeffect_ab <- Baseeffect_a* Baseeffect_b
# mediate function output
mediation_results <- summary(med_results)
effect_ab <- mediation_results$d1
effect_c <- mediation_results$z1

Baseeffect_ab-effect_ab # -0.0009, close to being equal

Baseeffect_c-effect_c # 0.0056, close to being equal

med_results$d.avg.p/2 # for 1-tailed p-value
```

Appendix 23 – Study 3, Supplemental Figures

A23.1. Hypothesis 1 and 2: Social bonding change, measurement occasion and time

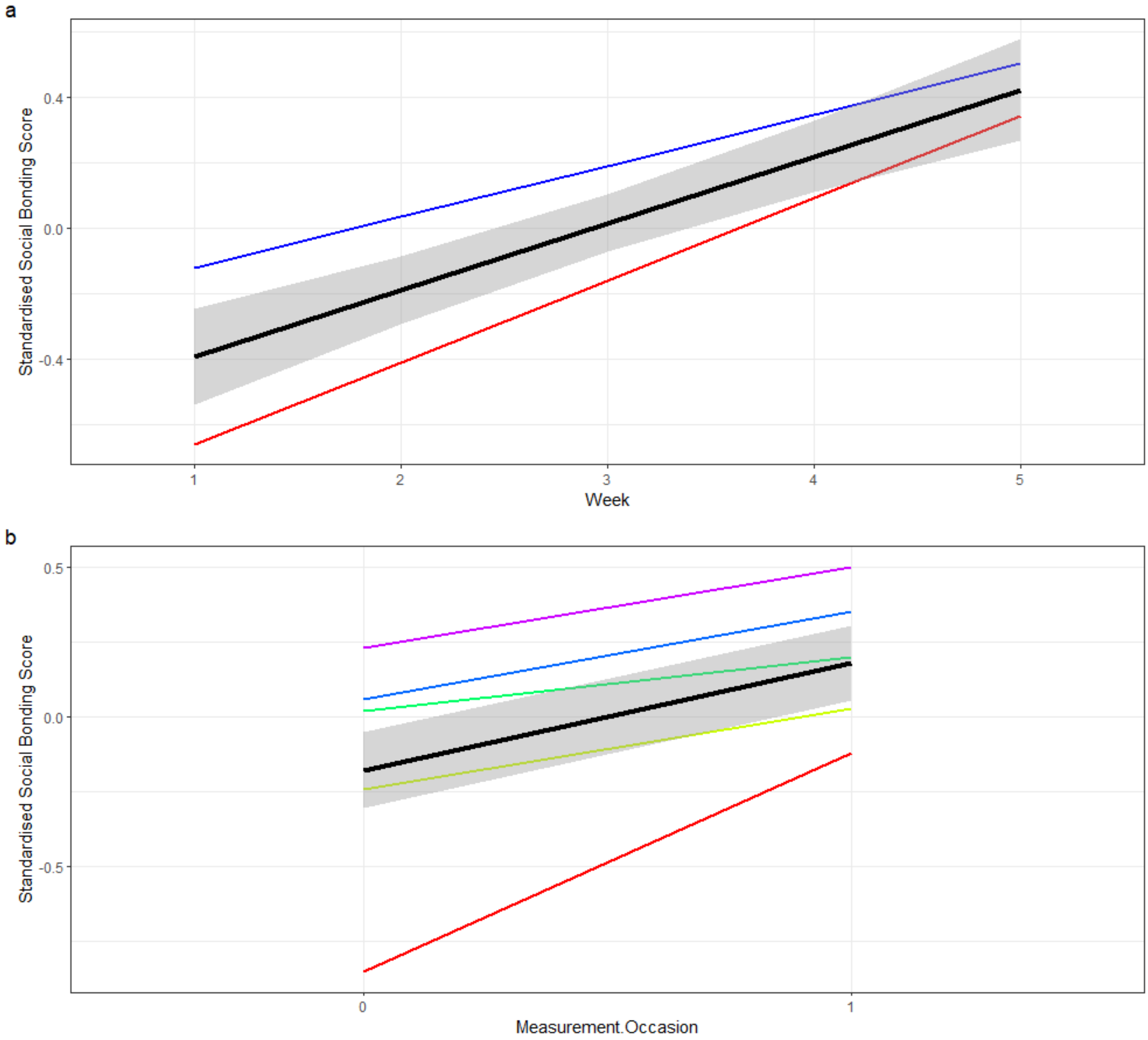


Figure A23.1. Graphs showing the relationship between social bonding, measurement occasion and week.
a) This shows how social bonding changed over each week, where the red line shows the pre-yoga values and the blue line post-yoga values for each week.
b) This graph shows the same information, in a different format, where pre-yoga (0) and post-yoga (1) are on the x-axis and each line shows each week (Red = W1, Yellow = W2, Green = W3, Blue = W4 and Purple = W5)

A23.2. Hypothesis 3: Session Type and connection to something bigger

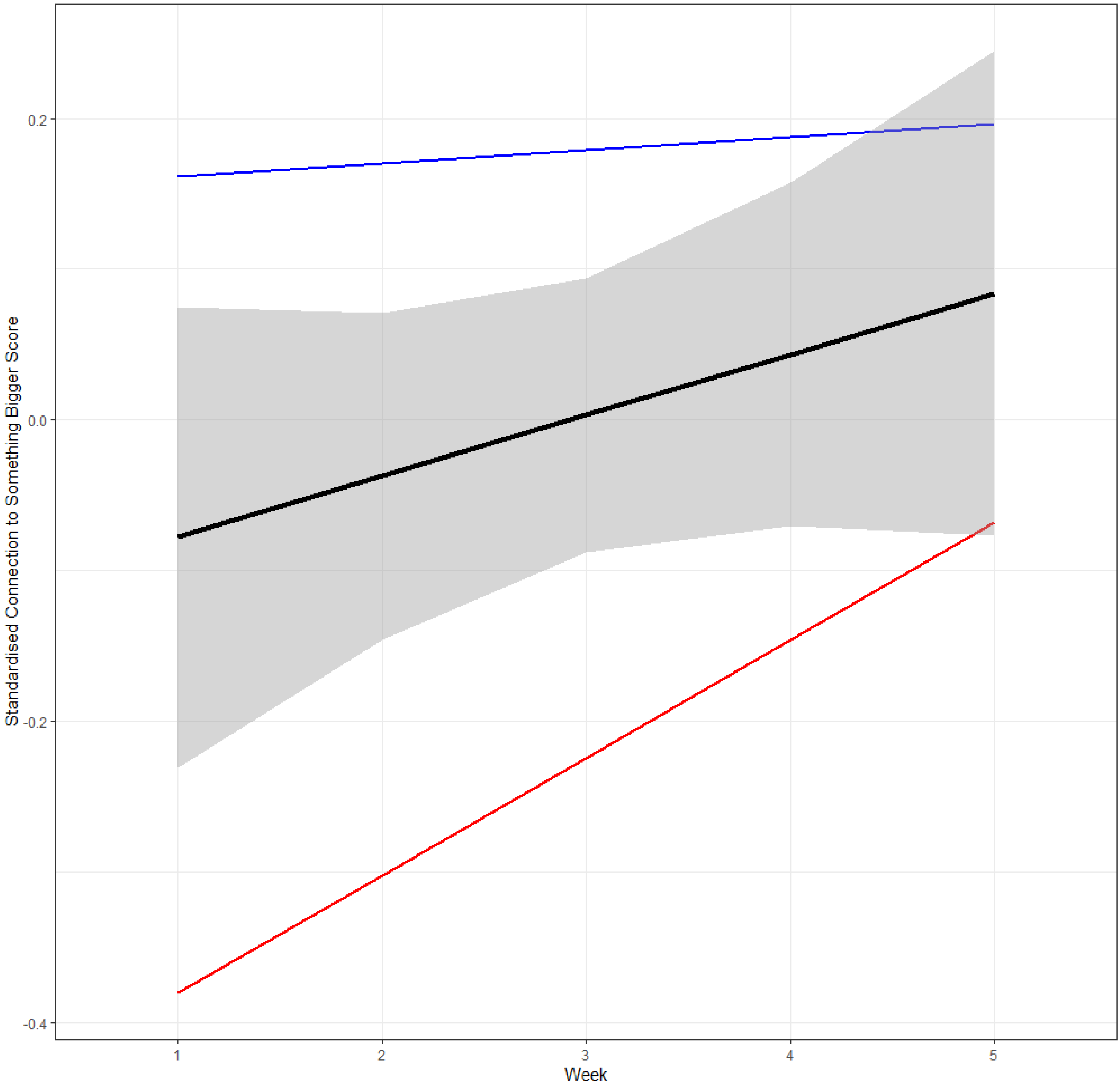


Figure A23.2. Graph showing the difference in self-rated connection to something bigger than oneself between secular yoga (red line) and spiritual yoga (blue line). The black line shows the average score with confidence intervals (grey)

A23.3. Hypothesis 5: Social bonding and pain tolerance

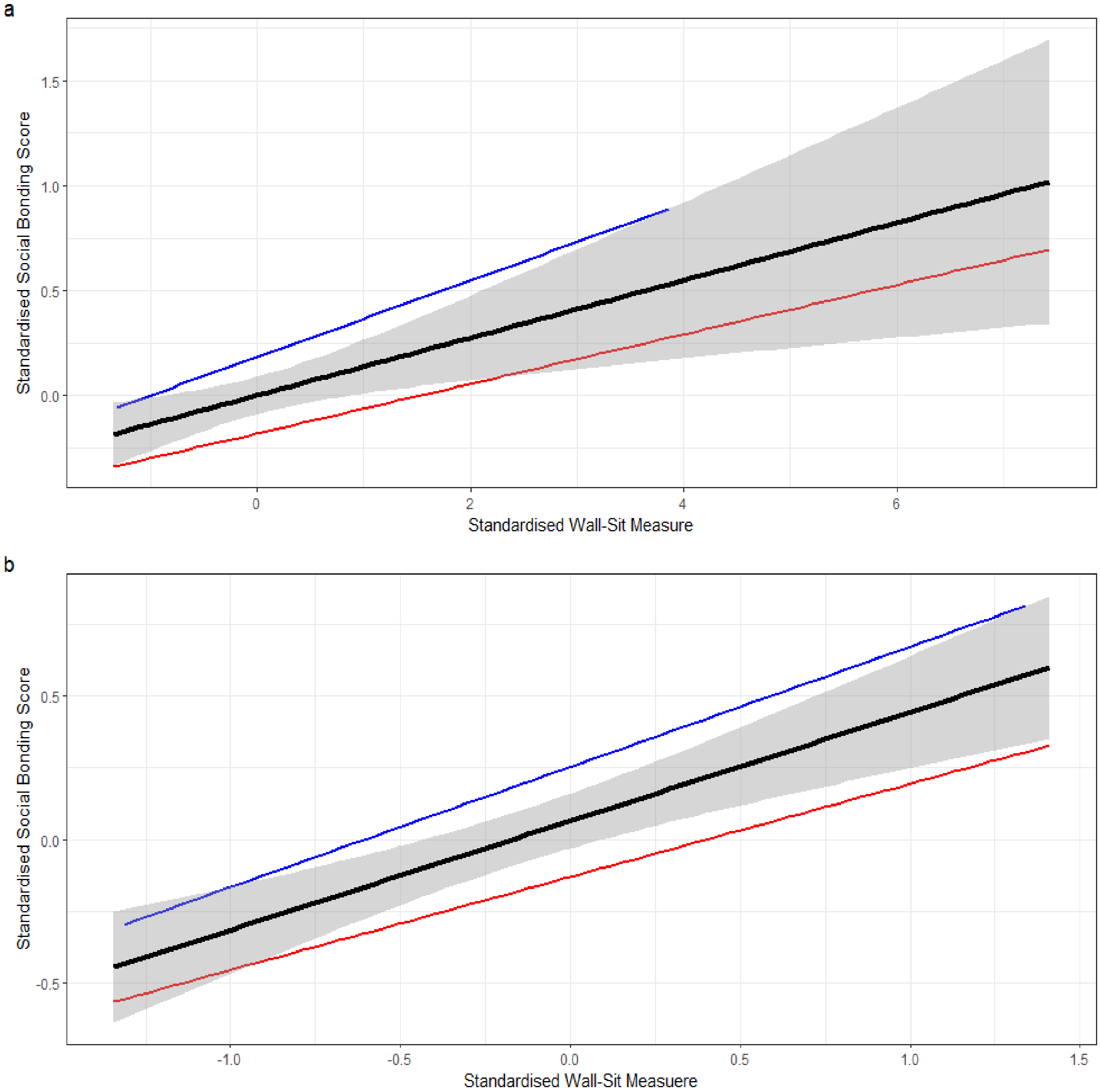
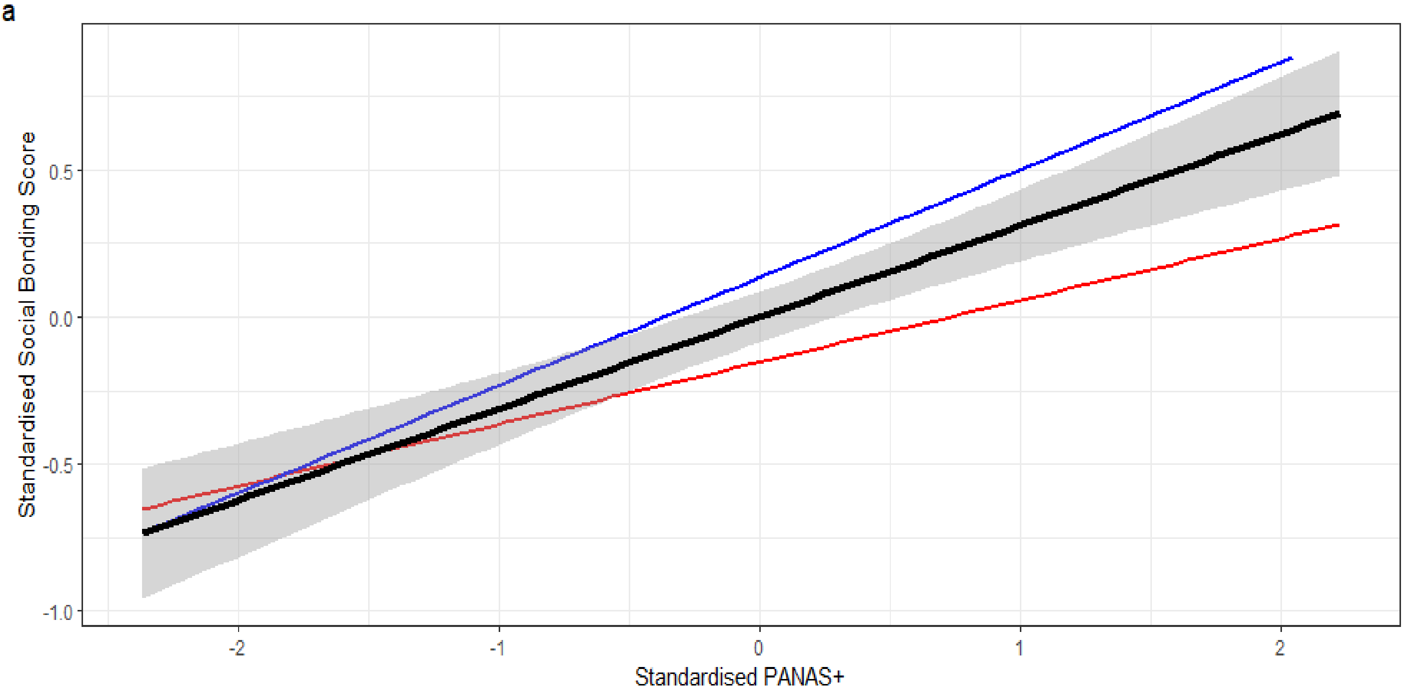


Figure A23.3. Graph showing the relationship between social bonding and the wall-sit pain tolerance test. Both shows how social bonding changed in relation to the wall-sit, where the red line shows the pre-yoga values and the blue line post-yoga values for each week.
a) No data is excluded
b) outliers (calculated via Tukey's fences criterion; ± 1.5 * IQR) are excluded.

A23.4. Hypothesis 6: Social bonding and Affect

a



b

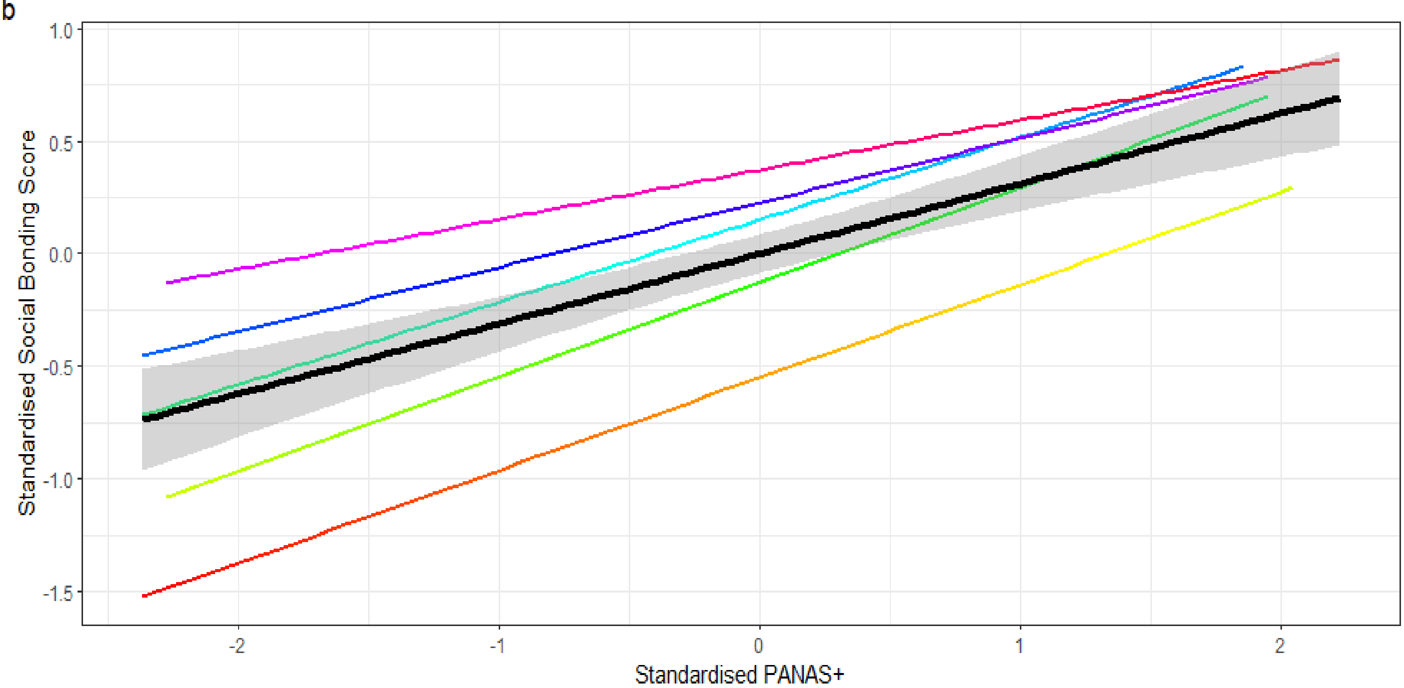


Figure A23.4. Graphs showing the relationship between social bonding and the positive affect (as measured by the PANAS+).
a) The red line shows the pre-session trend, and the blue line shows post-session trend. In both cases, PANAS+ seems to predict social bonding score.
b) The red-yellow line shows data for Week 1. The green line shows data from Week 2. The cyan-blue line shows data for Week 3. The dark blue-purple line shows data for Week 4. The purple-red line shows data for Week 5.

Appendix 24 – Study 3 Pre-Registration

Introduction

Background/Rationale

Rituals have played a central role in human activity throughout history. From spiritual activities to attending sports games, rituals pervade human behaviour to this day. Religious rituals make up a large subset of the rituals that humans take part in, and they are believed to be universal (Norenzayan, 2010). Evolutionary psychologists will often cite traits that appear universally across humanity and history as ones which confer an evolutionary advantage. Group living is an example of one such evolutionary adaptation that confers an advantage. In fact, "group living is thought to be one of the most significant evolutionary mechanisms by which human beings have survived and thrived" (Taylor, Dickerson & Klien, 2002, p. 556). However, group living requires those living together to develop some bond with one another to ensure it works in the longer term. Consequently, behaviours that foster the creation and/or maintenance of these bonds effectively would be evolutionarily beneficial.

Social bonding and ritual

Dunbar (2014) has proposed that the reason religious rituals are ubiquitous is that they help encourage the formation and maintenance of social bonds in an effective, efficient way. In his hypothesis, Dunbar suggests that religious rituals foster social bonding by containing a multitude of behaviours that each contribute to bonding independently (Machin & Dunbar 2011; Dunbar 2014; 2017a). By bringing these behaviours together into a single setting, religious rituals provide an efficient way to foster bonds, both in terms of time and energy. These behaviours include things such as shared attention (Reddish, Fischer & Bulbulia, 2013), shared goals (Wolf, Launay & Dunbar, 2016), synchronised movement (e.g. Pearce, Launay & Dunbar, 2015; Tarr Launay & Dunbar, 2014) and music making (Freeman III, 1998; Kirschner & Tomasello, 2010; Kreutz, 2014; Tarr et al., 2015). Though, other behaviours that are found in some, fewer rituals have also been highlighted, such as modest alcohol consumption (Dunbar et al., 2017) and communal eating (Dunbar, 2017b; Jaremka, Sunami & Nadzan, 2017).

In the brain opioid theory of social attachment (BOTSA), Machin & Dunbar develop work that implicated endogenous opioids as the neurochemical basis of bonding (Panksepp et al., 1978; 1980a; 1980b; 1986). They built on this work by proposing that mu-opioids, in particular, are likely the key neurochemical cause of social bonding (Machin & Dunbar, 2011). There is some evidence for mu-opioids playing a role in the social bonding, with research demonstrating that the behaviours that foster bonds release mu-opioids (Weinstein et al., 2016). Moreover, there is major support from neurochemical research in animal models (Burkett et al., 2011; Kobayashi et al., 2013; Kelm-Nelson et al., 2013; Parra-Gámez, Garcia-Hildalgo & Paredes, 2013; Resendez et al., 2013). The human body's main mu-opioid receptor agonist (activator) is β-endorphin (βe; see Benarroch, 2012 for a full overview of endogenous opioids compounds), best known for its role in the 'runner's high' (Boecker et al., 2008). This 'high' provided by βe may also explain why those in attendance at rituals often have some sense of communal euphoria (Durkheim, 1912/1964), if βe is being released during ritual to promote social bonding.

Studying ritual in a controlled setting

Although there is some evidence showing the role of βe in human social bonding (Cohen et al., 2010; Tarr et al., 2015; Tarr, Launay & Dunbar, 2016; Pearce et al., 2017), there are currently no studies in controlled conditions testing Dunbar's (2014) hypothesis of why it is specifically religious rituals, as opposed to other rituals, that are ubiquitous (see Dunbar, 2017a). One reason research looking into understanding the prevalence of religious rituals is limited is that finding sets of behaviours that conform to some definition of ritual, and also can contain both religious and non-religious forms is difficult. Another major reason that rituals have yet to be studied in this way in a lab setting is that the definition of 'ritual' in the literature has not always been clear (Hobson et al., 2018). There are various definitions (Bell, 1997; Bell, 2007; Boyer & Liénard, 2006; Humphrey & Laidlow, 1994) many of which are incompatible with one another (Beattie, 1966; Hobson et al., 2018). To attempt to resolve this issue, Hobson and colleagues (Hobson et al., 2018) put together a comprehensive framework that collates much of the recent research on ritual. In doing so, Hobson et al. (2018) provide a unifying definition of 'ritual'. They define ritual as "(a) predefined sequences characterized by rigidity, formality, and repetition that are (b) embedded in a larger system of symbolism and meaning, but (c) contain elements that lack direct instrumental purpose." (p. 261). Consequently, any research that attempts to study ritual in a controlled setting should consider these three factors.

Furthermore, Hobson et al. (2018) note that the mental processes that allow people to perceive something as a ritual "will vary as a person becomes more familiar with the actions through repeated exposure/practice" (p. 275). Thus, creating a novel ritual paradigm in a lab setting is likely not possible if participants only have a single exposure i.e. only take part once. This means that any design would need to be longitudinal in nature, to allow for repeated exposure/practice such that what is being measured is a valid analogue to what would happen during other well-practiced rituals.

Hatha Yoga is one school within the ideology of religious Yoga. It is a Hindu physical practice which has participants take up multiple postures (known as asanas). This practice has been imported into the West and simply dubbed 'Yoga'. Yoga, in this sense, conforms to Hobson et al's (2018) definition of a ritual, as it has (a) repeated, predefined posture sequences that (b) are embedded in a larger system of symbolism and (c) these postures lack a clear, direct, instrumental purpose. Yoga, as currently practiced in the Western world, sometimes maintains these Hindu roots, while others try to remove the spiritual aspect altogether to encourage a more physiotherapeutic or exercise focus (Yadav et al., 2012). As yoga can have both a religious and non-religious focus while having exactly the same physical behaviours, it serves as a suitable ritual basis for research seeking to understand the role of spiritual aspects of rituals that make religious rituals ubiquitous. There is also some research that links yoga practice with the release of βe (Yadav et al., 2012; Suri, Sharma & Saini, 2017). This means that using yoga as the ritual in a controlled condition should be a reliable way to encourage the release of βe to better its role on feelings of social bonding.

Measuring Beta-Endorphin

Whilst experimental evidence for the role of βe in social bonding is mounting (Machin & Dunbar, 2011; Loseth, Ellingsen and Lekens, 2014; Pellissier et al., 2018), and the links between music, singing, and synchronous movement – all behaviours that occur in religious rituals - and βe release are also established (Tarr et al., 2015; Tarr, Launay, & Dunbar, 2016; Weinstein et al., 2016), no research has been conducted to directly test the role religious aspects of ritual have on social bonding. This research project seeks to explore the role of religious aspects of ritual and to see if there is a link to βe release and social bonding that these aspects have.

As βe acts as a natural analgesic (Zubieta et al., 2001; Zubieta, Ketter et al., 2003; Zubieta, Heitzeg et al., 2003) pain threshold or pain tolerance have been used as proxy measures for βe release in experimental research (Cohen et al., 2010; Tarr et al., 2015; Tarr, Launay & Dunbar, 2016). In the current research, we seek to better understand the role of religious aspects of rituals and provide a test for the hypothesis that religious rituals are ubiquitous due to their evolutionary benefit of fostering social bonding proposed by Dunbar (2014; 2017a). We will do so by creating two sets of yoga paradigms; one spiritual in nature, and another secular in nature, and measure levels of social bonding and pain tolerance as a proxy for central βe levels before and after the sessions. We will also be measuring peripheral levels of βe as Veening, Gerrits & Barendregt (2012) suggest that although they are not strongly correlated, previous research "does not necessarily indicate that CSF (central) and peripheral plasma levels of βe are totally unrelated" (p. 2). They later clarify that peripheral levels likely serve no short-term effect, but that they likely serve a "long-term modulatory effect." (p.4). Consequently, peripheral levels of βe may have a long-term effect on social bonding, which can be measured in a longitudinal study.

Aims and Hypotheses

There are three main aims of the current research. (1) To provide an environment where ritual-like behaviours can be induced in a controlled way to mimic the effects found to occur during naturalistic rituals. (2) To understand if spiritual aspects of rituals play a role in levels of social bonding. (3) To better understand the role of β-endorphin in the social bonding that is found to occur during group behaviour. As such our hypotheses are as follows:

5. Taking part in a ritual-like group yoga session will lead to an increase in levels of social bonding with other attendees.
6. The level of social bonding measured will be different in those taking part in the spiritual sessions of Yoga than those taking part in the secular sessions.
7. Changes in self-reported measures of social bonding will be related to changes in the wall-sit endurance test.
8. Changes in beta-endorphin levels in the blood will be related to long-term social bonding as measured by self-report.

Method

Participants

Participants will be recruited from across the West-Midlands region of the UK.

Those that have diagnoses of arthritis (Wessel, 1995; Koesk & Ordeberg, 2000; Lee, Nassikas & Clauw, 2011), diabetes (Lee & McCarthy, 1992; Themistocleous et al., 2016), ADD/ADHD (Treister et al., 2015; Stickley et al., 2016) will be excluded from the study due to a change in pain perception that is reported in those with those diagnoses which could affect the results. Similarly, those with musculoskeletal, blood clotting or circulatory issues will be excluded because yoga/blood collection may be dangerous for those with these problems. Moreover, questions asking about recent alcohol intake (Horn-Hofmann et al., 2015; Thompson et al., 2017) and pain medication will be used as exclusion criteria after data collection given to the effects alcohol and pain medications have on pain perception.

The only effect size specifically linking pain threshold and a measure of social bonding comes from Dunbar et al. (2016). In this they provide an effect size of $r^2 = 0.08$. (p. 6). Based on the data analysis method we plan to use in this study, we are required to convert this into an *f* value to calculate effect size for our *a priori* power analysis. To do this we used the following equation from Cohen (1992, p 157):

$$f^2 = \frac{R^2}{1 - R^2}$$

In this instance:

$$f = \sqrt{\frac{0.08}{1 - 0.08}}$$

$$f = 0.295\ (3. s. f)$$

Using an online effect-size conversion calculator to check this calculation (Lenhard & Lenhard, 2016), the same result is reached.

Using this effect size, we calculated the required sample size needed to have a properly-powered study using G*Power (Faul et al., 2007; version 3.1.9.2). A between-participants ANOVA with an effect size of $f = 0.295$ $\alpha = 0.05$, Power ($1-\beta$) = 0.8 (this is the most commonly used power in biological sciences; McDonald, 2009, p34), two groups (spiritual, and secular yoga), the calculated total sample size that is required is 93. This means we will seek to have 47 participants in each group.

Materials

Social Bonding questions

Social bonding will be measured using the Inclusions of Others in Self scale (IOS; Aron, Aron & Smollan, 1992), a 7-point scale that uses Venn-diagrams to illustrate how connected one feels with others. The following questions, each measured on a 7-point Likert scale, will also be used:

- At this moment, how connected do you feel to the people in your congregation? (Please tick one).
- At this moment, how emotionally close do you feel to the other members of your congregation as a whole
- Thinking about everyone in your congregation now, how much do you trust the others in this group?
- How much do you like the people in your congregation overall?

- Thinking about everyone in your congregation now, do you feel you have a lot in common with others in this congregation?

A full example of the questionnaire can be found in the supplementary material on the OSF (LINK TO OSF).

Pain-tolerance measure

Pain tolerance will be measured by using a wall-sit test. This is a test where a participant sits with a straight back against a wall with their legs bent at the knee at a 90° angle. This is usually a test of lower-body endurance. However, it also causes pain due to lactic acid build-up in the muscles in the legs. The amount of time one can hold this is related to how much pain they are feeling. The difference in time (measured in seconds) able to hold this position before and after each session is the change in threshold (*ΔPT*):

$$\Delta PT = \mathit{Wall\ Sit\ Time\ After\ Service}\ (s) - \mathit{Wall\ Sit\ Time\ Before\ Service}\ (s)$$

This method of testing will be used over other pain measurement methods for multiple reasons:

1. The wall-sit test is easy to implement, can be used to measure multiple people at once and does not require expensive or hard-to-use equipment
2. Other methods have significant issues
    a. The cold pressor method (having participants put hands in freezing water for as long as they can maintain) requires the ability to keep the ice at the exact same temperature during measurement, which cannot be guaranteed. Moreover, it discounts the possibility of changes in temperature of the participants or sweat playing a role in the perception of temperature/pain.
    b. The pressure cuff method (measured by slowly inflating a sphygmomanometer cuff on the participant's upper, non-dominant arm until the participant signifies that they are 'very uncomfortable') has an upper-limit of 300mmHg.This limit is reached fairly easily by those who have high pain resistance, meaning their data would be unusable.
    c. Dolorimeters are not appropriate as they are not readily portable, and the venue for yoga being used needs to be cleared between data collection and yoga sessions.

Phlebotomy

To draw blood, phlebotomists are using 22g Vacutainer needles with EDRA (K2E) Vacutainer tubes. After collection, the wound will be covered using cotton wool balls stuck on with micropore surgical tape (in case of plaster allergies). Sharps will be disposed of using Cyto Sharps Disposal bins.

Yoga Equipment

Participants will all be using YogaMatters sticky yoga mats (MASTIC) and be given the same grey workout tops bought from Primark.

Blood Analysis

Blood analysis will be performed using an ELISA. The ELISA kit we are using is the BioVision QuickDetect™ beta-Endorphin (Human) ELISA Kit (E4458-100).

To use this ELISA kit, we will follow the manufacturer's guide on protocol. The full document is on the OSF (https://osf.io/bafud/).

Procedure

Upon recruitment for the study, participants were told they would be excluded based on our exclusion criteria. Following this, they were provided with the information sheet (https://osf.io/3cn5u/) and consent form (https://osf.io/7mvn5/) to sign in advance of attendance. Once these had been signed, participants were sent a survey to be completed via Qualtrics (Provo, UT; https://osf.io/sf7g8/). This is to ensure that they were naïve to yoga, as well as getting background data.

At each session, participants will arrive and take part in the wall-sit test, a questionnaire (sessions 1-4: https://osf.io/pcs9d/; session 5: https://osf.io/ydbrj/), a health screen (https://osf.io/q7zwa/) and in sessions 1,3 and 5 have their blood taken by a trained phlebotomist into a serum-based vacutainer.

Each week, participants will sign a continued consent form (https://osf.io/bvd42/), to ensure they still understand what is being asked of them.

Blood, is to be stored in a cool-box that is kept as cold as possible – likely to be at approximately -10°C. This will be transported to Coventry University's Health and Life Science's department (approximately 0.2miles /

320m from the yoga venue) and then spun for 10mins at 3000rpm to separate the serum from the other parts of the blood. These will then be aliquotted and frozen at -80°C until analysis.

Conflicts of interest statement

The funding for this project comes from the Templeton Religion Trust, a charitable foundation that looks to explore the role of religion on human behaviour. Grant number 0153.

Ethics Statement

This research was designed in accordance with the regulations of Coventry University, and has been reviewed and approved by the Coventry University Ethics Committee.

Appendix 25 Study 4 Pre-Registration

Pre-registration abstract

Ritual has long been shown to increase feelings of social bonding (Durkheim; 1912). One type of ritual, yoga, has been repeatedly shown to release beta-endorphin (Yadav et al., 2012; Suri, Sharma & Saini, 2017), and endorphins in turn might help foster social bonding (Curley & Keverne, 2005; Dunbar & Shultz, 2010; Dunbar, Baron, et al., 2012; Machin & Dunbar, 2011). The present study investigates the causal role of endorphins in social bonding that takes place during yoga sessions by blocking endorphin release (with the mu-opioid antagonist Naltrexone). This is a follow-up study to one that seeks to demonstrate the relationship between endorphin release and social bonding (https://osf.io/xat6m/). We will recruit healthy participants that took part in the previous study who are willing and able to give informed consent (male/female, age: 18-70). These participants for the previous study were recruited through both online (social media websites, forums) and offline (advertising posters at Coventry University/Warwick University/Birmingham University/Birmingham City University and Warwickshire libraries) pathways. Participants will be randomly allocated into groups. Half of the participants will receive placebo, and the other half Naltrexone (in a double-blind setting) and take part in a yoga session. Before and after the session, social bonding will be assessed, as well as endorphin release via a proxy measure. Endorphin release will be measured via changes in pain threshold (as endorphins elevate pain threshold). We predict that changes in social bonding that are usually seen after yoga will not be found in those who have endorphin receptors blocked by Naltrexone but will remain in those given the placebo. We also predict that the Naltrexone group should have a lower measured pain threshold after yoga compared to the placebo group.

Introduction

Background/Rationale

The universal presence of rituals in human societies is something that has sparked interest in social scientists for the last century (Durkheim, 1912/1964; Freud, 1961; Weber, 1920/2002; Cnaan and Heist, 2018). One possible reason for ritual to be so prevalent was proposed by Dunbar (2014; 2017). Dunbar (2014; 2017) has suggested that the release of mu-opioids, such as beta-endorphin, during rituals leads to increased levels of social bonding, where this social bonding leads to evolutionary advantages (Taylor, Dickerson & Klien, 2002). This proposition follows research that suggests that mu-opioids play a key role in social bonding (Curley & Keverne, 2005; Dunbar & Shultz, 2010; Dunbar, Baron, et al., 2012; Machin & Dunbar, 2011).

One ritual that is found in both secular and religious contexts and now occurs around the globe is yoga. Yoga also contains many of the behaviours that have been implicated in the cause of social bonding. These behaviours include joint attention (Wolf, Launay and Dunbar, 2016), shared goals (Reddish, Fischer & Bulbulia, 2013), co-ordinated, synchronised action (Freeman III, 1998; Kreutz, 2014; Tarr et al., 2015), and in some cases music-making (Kirschner & Tomasello, 2010; Weinstein et al., 2016), such as when chanting 'Om'. Similarly, yoga has been repeatedly shown to release beta-endorphins (Yadav et al., 2012; Suri, Sharma & Saini, 2017). This study seeks to investigate the causal role of beta-endorphin in social bonding observed in yoga by comparing 2 groups. One group will take a placebo, the other will take the opioid antagonist (blocker) Naltrexone, which has high specificity for mu-opioid receptors, i.e. an antagonist specifically targeted at beta-endorphins. Selectively blocking beta-endorphin from binding to receptors should allow us to understand if beta-endorphin is necessary for social bonding that takes place during yoga.

Studying ritual in a controlled setting

This study is a follow-up to a study which developed a novel paradigm in order to study ritual in a controlled setting (https://osf.io/xat6m/). This had to be developed as no such paradigm had been created before. The basis of this paradigm is to ensure that the activity (1) meets the definition of ritual and (2) makes the participants feel as though it is developed into a ritual. To meet criterion (1) first the definition of ritual had to be determined. There are various definitions in the literature (Bell, 1997; Bell, 2007; Boyer & Liénard, 2006; Liénard & Boyer, 2006; Humphrey & Laidlaw, 1994) many of which are incompatible with one another (Beattie, 1966; Hobson et al., 2018). To attempt to resolve this issue, Hobson and colleagues (Hobson et al., 2018) put together a comprehensive framework that collates much of the recent research on ritual. In doing so, Hobson et al. (2018) provide a unifying definition of 'ritual'. They define ritual as "(a) predefined sequences characterized by rigidity, formality, and repetition that are (b) embedded in a larger system of symbolism and meaning, but (c) contain elements that lack direct instrumental purpose." (p. 261). To meet criterion (2), it was important that participants also felt that they were in a ritual. Hobson et al. (2018) also note that the mental processes that allow people to perceive something as a ritual "will vary as a person becomes more familiar with the actions through repeated exposure/practice" (p. 275). Consequently, repeated exposure to the ritual is important for it to be perceived as a ritual to those taking part.

To meet both of these criteria, the previous study had participants take part in the novel ritual for 5 consecutive weeks (criterion (2)), and had participants take part in yoga that confirmed to the three sub-sections of criterion (1), including a) predefined sequences via the movement that takes place in yoga, b) embedded symbolism or meaning that was given by the swami leading the yoga and c) elements that lacked instrumental purpose, such as all participants being given identical tops to wear during the yoga. Given that these were required to create the sense of ritual, all participants in the current study were recruited from the previous study to take part in a follow-up 6th week.

Measuring Beta-Endorphin

Measuring central levels of beta-endorphin (βe) is not easy, as it does not pass readily through the blood brain barrier (Witt & Davis, 2006). As a result, βe's action as an analgesic (Zubieta et al., 2001; Zubieta, Ketter et al., 2003; Zubieta, Heitzeg et al., 2003) is utilised in research that uses change in pain threshold or tolerance as a proxy for βe release (Cohen et al., 2010; Tarr et al., 2015; Tarr, Launay & Dunbar, 2016; Charles et al., in prep). Some studies have also used βe antagonists, such as Naltrexone, in order to examine the role of mu-opioids on social bonding (Inagaki, Irwin & Eisenberger, 2015; Inagaki et al., 2016; Inagaki, Hazlett & Andreescu, 2019; Tarr et al., 2017). For example, Tarr et al. (2017) conducted a double-blind placebo-controlled study to administer Naltrexone to participants who took part in synchronised dance. After the activity, they measured social closeness using an average of four questions each measured on a 7-point Likert scale: The Inclusion of Others in Self scale (IOS; Aron, Aron & Smollan, 1992), connectedness (Wiltermuth & Heath, 2009), likability (Hove & Risen, 2009), and similarity to personality (Valdesolo & Desteno, 2011). However, they did not measure the change in these measures of social bonding from before to after the sessions.

Aims and Hypotheses

The main aim of this study is to better understand the role of βe in the social bonding that is found to occur during group behaviour. More specifically, to see if central beta-endorphin release is necessary for social bonding increase. As such our hypotheses are as follows:

9. Taking part in a ritual-like group yoga session will lead to an increase in levels of social bonding with other attendees.
10. The level of self-reported social bonding measured will be lower in those who are given Naltrexone than those who are given placebo.

11. Changes in self-reported measures of social bonding will be related to changes in the wall-sit endurance test, a proxy measure for βe activity in the central nervous system.

Method

Participants

Participants will be recruited from those who take part in a previous experiment that requires them to take part in 5 weeks of yoga, so that the ritual is established for these participants (see registration of the previous experiment here: https://osf.io/xat6m/). Participants from this study were recruited from across the West-Midlands region of the UK via both online and offline advertisements. The inclusion and exclusion criteria for participants are listed below. Participants will also be paid for their time for taking part in this study.

The only effect size specifically linking pain threshold (a proxy for endorphin release) and a measure of social bonding published so far comes from Dunbar et al. (2016). In this, they provide an effect size of $r^2 = 0.08$ (p. 6). A separate study by Inagaki et al. (2016) found that those who took naltrexone ($M = 5.92$, $SD = .924$) had a lower feeling of social connection than when they took placebo ($M = 6.47$, $SD = .487$). However, in their study they do not provide the correlation between the two measurements, which is needed to calculate an effect size for within-participant data.

Using the Dunbar et al. (2016) study, we calculated an effect size of Cohen's $d = .59$ using formula below.

$$d = \frac{2r}{\sqrt{1 - r^2}}$$

$$d = \frac{2\sqrt{0.08}}{\sqrt{1 - 0.08}}$$

$$d = 0.59\ (2\ d.p.)$$

Using the Inagaki et al. (2016) study, we calculated 3 possible effect sizes from their within-participants design: with low (0.3), medium (0.5) and high (0.8) within participant correlation. These gave a Cohen's d of .60, .68 and .90 respectively.

Taking the lowest of these possible values for Cohen's d, we used G*Power to calculate the number of participants we would need to find an effect, a one-tailed between-participants t-test with an effect size of .59, alpha value of 0.05 power of 0.8 and allocation value of 1, the most participants we would need is 37 participants per group (total 74). The fewest participants we can use (assuming the highest Cohen's *d* from the Inagaki et al. (2016) study of .90) is 17 in each group (34 participants total).

For this reason, we will aim for 74 participants.

Inclusion Criteria

- Participant is willing and able to give informed consent for participation in the study.
- Healthy adults, Male or Female, aged 18 - 65 years.
- Exclusion criteria do not apply

Exclusion Criteria

The participant may not enter the study if ANY of the following apply:

- Medical problems such as diabetes; hypertension; musculoskeletal, liver, brain, kidney, or other chronic disease;

- Individuals with rare hereditary problems (including galactose intolerance, the Lapp lactase deficiency or glucose-galactose malabsorption);

- Pregnant or lactating individuals;

- Individuals who have drunk alcohol on the day of the experiment;

- Individuals with a history of clinical depression, psychosis, or mania;

- Current use of anti-depressant medication or any other medication, with the exception of contraceptives and asthma inhalers;

- Use of cannabis or another illicit drug within the previous three months, or use of cannabis or illicit drugs more than four times in the past year, or having ever met criteria for cannabis dependence or harmful use;

- Any long-term recreational use of opiate drugs;

- Suffer from any physical disability that will prevent them from performing the physical activities required in the experiment.

Materials

Social Bonding questions

Assessment of social bonding:

- *Self-other distinction/overlap as proxy for social bonding*: as social cohesion increases self-other distinction decreases. We will administer the Inclusion-of-Other-in-Self (IOS) (Aron et al., 1992) rating scale and set of 5 other social bonding questions used in currently ongoing studies, including those used in Tarr et al. (2017), connectedness (Wiltermuth & Heath, 2009), likability (Hove & Risen, 2009), and similarity (Valdesolo & Desteno, 2011).

The following questions, each measured on a 7-point Likert scale, will also be used:

- At this moment, how connected do you feel to the people in this yoga session? (Please tick one). (Wiltermuth & Heath, 2009)
- At this moment, how emotionally close do you feel to the other members this yoga session as a whole
- Thinking about everyone in your congregation now, how much do you trust the others in this group?
- How much do you like the people in this yoga session overall? (Hove & Risen, 2009)
- Thinking about everyone at this yoga session now, do you feel you have a lot in common with others in this group? (Valdesolo & Desteno, 2011).

A full example of the questionnaire can be found in the supplementary material on the OSF (https://osf.io/p3aq5/).

Pain-tolerance measure

Pain tolerance will be measured by using a wall-sit test. This is a test where a participant sits with a straight back against a wall with their legs bent at the knee at a 90° angle. This is usually a test of lower-body endurance. However, it also causes pain due to lactic acid build-up in the muscles in the legs. The amount of time one can hold this posture is related to how much pain they are feeling. The difference in time (measured in seconds) able to hold this position before and after each session is the change in threshold (*ΔPT*):

$$\Delta PT = Wall\ Sit\ Time\ After\ Service\ (s) - Wall\ Sit\ Time\ Before\ Service\ (s)$$

This method of testing will be used over other pain measurement methods for multiple reasons:

3. The wall-sit test is easy to implement, can be used to measure multiple people at once and does not require expensive or hard-to-use equipment.
4. Other methods have significant issues:
    a. The cold pressor method (having participants put hands in freezing water for as long as they can maintain) requires the ability to keep the ice at the exact same temperature for both the

pre- and post- sessions for each participant, which cannot be guaranteed. Moreover, it is possible that the participant themselves changes temperature or may sweat due to the yoga. This could alter the perception of temperature-based pain and, thus, make the measure less valid.

b. The pressure cuff method (measured by slowly inflating a sphygmomanometer cuff on the participant's upper, non-dominant arm until the participant signifies that they are 'very uncomfortable') has an upper limit (300mmHg for many sphygmomanometers). If this limit is reached in the pre-session measurement, no upward change could be detected, meaning their data would be unusable.

Yoga Equipment

Participants will all be using YogaMatters sticky yoga mats (MASTIC) and be given the same grey workout tops bought from Primark.

Participants will also be given the same yoga top to wear for the experiment, which is a dark grey, short sleeve training top, sold by Komprexx Direct. The purpose of this was twofold. One, it introduced an element that lacked instrumental purpose to adhere to the Hobson et al. (2018) definition of ritual. Two, it would allow this paradigm to mimic other rituals (e.g. religious services, sporting events or music concerts), which often have specific clothing that attendees wear to signify they are part of the group.

Procedure

Recruitment

Advertisements for participants for the previous study included an online notice on the Coventry University website (to recruit students), and via various other email/online forums and offline posters around local universities including Coventry University, Warwick University, Birmingham City University, and University of Birmingham as well as at Warwickshire libraries and other public places. Participants who took part in the previous study that express an interest in taking part in this study and fulfil the eligibility criteria will be e-mailed a participant information sheet. They will be informed of the right to refuse to participate in the study or to withdraw consent to participate at any time without reprisal and will be given at least 24 hours to read over this information.

Screening and Eligibility Assessment

An email including all participant information and a copy of the consent form is sent out to all those interested. This email will also determine if the individual satisfies the relevant inclusion/exclusion criteria, as determined by a survey detailing the history and current health status of each potential participant (https://osf.io/gj7hx/). Once a participant has passed this screening, they will be scheduled to attend the experiment. Participants will be asked not to drink alcohol on the day of the study, not to take codeine for 24 hours prior to the experiment, and not to eat one hour prior to the experiment. Participants will receive this information once they have been screened, when they are scheduling their attendance (over email).

Randomisation

Once a group of participants has been confirmed for a testing session, the group will be randomly assigned to either the control condition (placebo) or the experimental condition (Naltrexone). Prof Dunbar (who will not be directly involved in the running the experiments) will be responsible for allocating reference numbers to the pills that will be given to each group. The researchers running the experiment will give out the pills and will not have access to the codes which enable distinguishing between placebo and naltrexone. The participants and the RA will not be aware of this allocation. A digitalised random number generator will allocate a three-digit number to each pack of pills (to be given to one group of people). A reference spread sheet will record these reference numbers and whether the pills are placebo or naltrexone and will be stored in an encrypted data file only accessibly (at the end of the experiments or when necessary in the case of reported adverse side effects) by Miguel Farias or Robin Dunbar, neither of whom will be dealing with the participants or be part of data collection.

As this study is carried out as a double-blind study, if, for whatever reason, participants or experimenters become unblinded, data from that participant will be excluded from data analysis.

A step-by-step summary of the planned procedure is listed below.

a. Participant indicates interest.

b. Participant is sent the information sheet and a copy of the consent form. They are then screened via an online exclusion questionnaire in order to determine the suitability of the participant for the study. The questionnaire will be accessible by potential participants via a private link sent via email and will be referenced by asking the participant to enter their initials and email address. Their responses will be collected in a spreadsheet and reviewed by Sarah Charles (PR). If they meet the requirements for this study, they will be contacted by email and invited to indicate their availability to attend an experimental session during the following two weeks.

If their responses indicate they are not suitable for this study, they will be invited instead to consider taking part in an alternative experiment that does not involve Naltrexone and will be sent the new information sheet and consent form for the relevant study. All responses will be stored (encrypted) until after the participant has completed the study, after which their responses pertaining to the health screening and personal details will be deleted, to adhere to data protection regulations.

Once a group of participants has been confirmed for a yoga session, the group will be randomly assigned to either the Naltrexone or placebo treatment. Prof Dunbar (who will not be directly involved in the running of the experiments on the day) will be responsible for allocating reference numbers to the pills that will be given to each group. A digitalised random number generator will allocate a three-digit number to each pack of pills (to be given to a participant). A reference spread sheet will record these reference numbers and whether the pills are placebo or naltrexone and will be stored in an encrypted data file only accessible (at the end of the experiments or when necessary in the case of reported adverse side effects) by Miguel Farias and Robin Dunbar. The researchers - Sarah Charles and research assistants (RAs) - running the experiment will give out the pills and note the code on given on the box, but will not have access to the spreadsheet that enable the distinction between placebo and naltrexone, nor will the participants be aware of this allocation – making it a double-blind design.

c. Participant arrives and is given a yoga top by an RA and directed to the changing room, before they go to the testing room (performance studio).

d. When in the performance studio, the participant are seated at a table where the PR/RA will take them through the consent form. They will be informed that the study is about taking part in yoga and endorphins. They will have an opportunity to ask any questions at this time. The participants will then sign another consent form to confirm that they still want to take part.

e. Each participant is given 2 pills (either 2 x placebo or 2 x 50mg of Naltrexone).

f. The participants are each allocated a reference number (participant ID number).

h. The participant will be asked to give their reference number to a PR/RA who will note it on the questionnaire the participant will complete. The participant will keep their paper slip. They will then take a pain threshold test (administered by the PR/RA).

Note that the pain threshold test will NOT be referred as such. Instead, the PR/RA will refer to this as a wall-sit ski exercise. No mention of 'pain threshold' should be made at any time to avoid pre-biasing the participant to reporting a higher (or lower) pain threshold.

i. The participant will then perform a series of very basic filler tasks for 60 minutes (e.g. light reading) to wait for the Naltrexone to have an effect (which takes approximately 1 hour).

j. The participant will take part in the 1-hour yoga session with other participants.

k. The participants will then return to the PR/RA with whom they conducted the pre-session wall-sit with and begin the assessment of the dependent variables:

- Assessment of pain threshold

- Assessment of social bonding

l. The participants are told they have completed the study. They will be thanked for their time and instructed to leave.

m. After the study, each participant will be provided a form on which to provide bank details to be transferred their remuneration. They will also be provided with a sheet debriefing them as to the actual aims of the study.

n. End of session. All participants will be escorted out of the building by the PR/RA

Ethics Statement

This research was designed in accordance with the regulations of Coventry University, and has been reviewed and approved by the Coventry University Ethics Committee (Project P89708).

Conflicts of interest statement

The funding for this project comes from the Templeton Religion Trust, a charitable foundation that looks to explore the role of religion on human behaviour. Grant number 0153.

Appendix 26 – Study 4 and 5 Exclusion Criteria

Any participants which met any of the following nine exclusion criteria were not able to take part in the study and were directed to take part in the service as they normally would:

(1) Long-term physical medical problems, such as liver, brain, kidney, or other chronic diseases;

(2) Individuals with hereditary problems (including galactose intolerance, the Lapp lactase deficiency or glucose-galactose malabsorption);

(3) Pregnant or lactating individuals were excluded based on the possibility of the drug transmission into the child;

(4) Individuals who had drunk alcohol on the day of the experiment;

(5) Individuals with a history of clinical depression, psychosis, or mania;

(6) Current use of anti-depressant medication or any other medication, with the exception of contraceptives and asthma inhalers;

(7) Use of cannabis or another illicit drug within the previous two days (ayahuasca use is possible in Brazil), or having ever met criteria for cannabis dependence or harmful use;

(8) Any long-term recreational use of opiate drugs;

(9) Under the age of 18, or otherwise unable to give informed consent themselves.

Any exclusion criteria for medical reasons were based on advice from a medical consultant.

Appendix 27 – Study 4 R Script

```
### RSB Yoga Naltrexone Study Script ###

#Required Packages#

rm(list=ls())

library("MASS",character.only=TRUE)
library(lme4)
library(MBESS)
library(dplyr)
library(MASS)
library(apaTables)
library(lavaan)
library(psychometric)
require(foreign)
require(magrittr)
require(lmerTest)
require(ggplot2)
require(ggpubr)
require(lattice)
require(reshape2)
require(nlme)
require(MuMIn)
require(PairedData)
require(gridExtra)
require(ggfortify)
require(multilevel)
require(robumeta)
require(psych)
require(GPArotation)
require(lm.beta)
require(rcompanion)

# Load a multiple packages because because I cannot recall which functions
come from which packages

# Import data ####
data <- read.csv("NalYoga - WIDE.csv", header=TRUE)

##Variables:####
##SB6 = Average score created for Social Bonding including IoS (Aron, Aron
Smollan, 1992) ##

data_Nal <- data[data$Nal_Plac==1,] # Naltrexone

data_Plac <- data[data$Nal_Plac==0,] # Placebo


mean(data$Wall_Sit_Pre) # 47167.78ms (47.17 seconds)
mean(data$Wall_Sit_Post) # 43654.44ms (43.65 seconds)
mean(data$Wall_Sit_Change) # -3513.333ms (-3.51 seconds)

mean(data_Nal$Wall_Sit_Pre) # 64465ms (64.47 seconds)
mean(data_Nal$Wall_Sit_Post) # 54905ms (54.91 seconds)
mean(data_Nal$Wall_Sit_Change) # -9560ms (-9.56 seconds)

mean(data_Plac$Wall_Sit_Pre) # 33330ms (33.33 seconds)
mean(data_Plac$Wall_Sit_Post) # 34654ms (34.65 seconds)
mean(data_Plac$Wall_Sit_Change) # 1324ms (+1.32 seconds)

# Reliability ####
## Social Bonding Measure - Factor Analysis and Reliability ---------
{### Factor Analysis of SB6 ####
```

```
  SB_CV <- read.csv("NalYoga - Social Bonding Construct Validity.csv",
header=TRUE) # Social Bonding construct validity file.


  #Factor Analysis:
  library("dplyr")
  SB6_Cor_Prea <- select(SB_CV, SB_Connect_Pre, SB_EmoClose_Pre,
SB_Trust_Pre, SB_Like_Pre, SB_Common_Pre, SB_IOS_Pre)
  head(SB6_Cor_Prea)
  SB6_Cor_Pre <- round(cor(SB6_Cor_Prea),2)
  SB6_Cor_Pre

  SB6_Cor_Posta <- select(SB_CV, SB_Connect_Post, SB_EmoClose_Post,
SB_Trust_Post, SB_Like_Post, SB_Common_Post, SB_IOS_Post)
  SB6_Cor_Post <- round(cor(SB6_Cor_Posta),2)
  SB6_Cor_Post

  #Factor analysis of the pre-service SB6 data
  factors_SB6_Pre <- fa(r = SB6_Cor_Pre, fm = "ml") ## maximum-liklihood
method used, to avoid errors likely caused by low N
  #Getting the factor loadings and model analysis
  factors_SB6_Pre
  scree(SB6_Cor_Pre) # scree plot suggests 1 factor
  #Factor Analysis using method =  principal axis (pa)
  #Default is oblimin - an oblique rotation
  # factor analysis shows that 1 factor is sufficient.
  #Mean item complexity = 1
  # var explained = .55 - 55%
  # df adjusted RMSR = .18

  #Factor analysis of the post-service SB6 data
  factors_SB6_Post <- fa(r = SB6_Cor_Post, fm = "ml") ## maximum-liklihood
method used, to avoid errors likely caused by low N
  #Getting the factor loadings and model analysis
  factors_SB6_Post
  scree(SB6_Cor_Post) # scree plot suggests 1 factor
  #Factor Analysis using method =  principal axis (pa)
  #Default is oblimin - an oblique rotation
  # factor analysis shows that 1 factor is sufficient.
  #Mean item complexity = 1
  # var explained = .55 - 55%
  # df adjusted RMSR = .19

  # Factor Diagrams, showing loadings for the single factor.
  fa.diagram(factors_SB6_Pre, sort = TRUE, main = "Pre-Service SB6 factor
analysis diagram")
  fa.diagram(factors_SB6_Post, sort = TRUE, main = "Post-Service SB6
factor analysis diagram")
  # SB6 shows 1 factor.
}
{### McDonald's Omega values ####
  SB6_pre_omega <- ci.reliability(SB6_Cor_Prea, type = "omega", conf.level
= 0.95, B=1000)
  SB6_pre_omega # SB6_Pre  omega = .87[.76, .98]
  SB6_post_omega <- ci.reliability(SB6_Cor_Posta, type = "omega",
conf.level = 0.95, B=1000)
  SB6_post_omega# SB6_post omega = .86[.70, >.99]

}

# Data Assumptions - Normality  ----
### ----------------------------- ###

## ------------- ##
{## Histograms  ====
  ## ------------- ##

  # -------------- #
  {### Social Bonding ####
```

```
    # -------------- #

    plotNormalHistogram(data$SB6_Pre,
                        main = "Histogram of Pre-Service Social Bonding
Measure",
                        xlab = "Pre-Session Social Bonding")

    # Looks somewhat normal.

    plotNormalHistogram(data$SB6_Post,
                        main = "Histogram of Post-Service Social Bonding
Measure",
                        xlab = "Post-Session Social Bonding")
    # Looks slightly skewed from normal

    plotNormalHistogram(data$SB6_Change,
                        main = "Histogram of change in Social Bonding
Measure",
                        xlab = "Social Bonding Change")

    # Looks somehwat normal

    #Naltrexone Ptps

    plotNormalHistogram(data_Nal$SB6_Change,
                        main = "Histogram of change in Social Bonding
Measure",
                        xlab = "Social Bonding Change")

    # looks "normal" (only 4 participants, so not really applicable)

    #Placebo Ptps
    plotNormalHistogram(data_Plac$SB6_Change,
                        main = "Histogram of change in Social Bonding
Measure",
                        xlab = "Social Bonding Change")
    # looks skewed (only 5 participants, 4 of which are around 1, so not
really applicable)

    #Non-parametric test may need to be used #
  }

  ## ----------------- ##
  {## Shaprio-Wilk Test ====


    {### Social Bonding ####
      # -------------- #


      # H1
      shapiro.test(data$SB6_Pre) # W = .969 - Not stat. sig. dif. from
normal(p = .883)
      shapiro.test(data$SB6_Post) # W = .909 - Not stat. sig. dif. from
normal(p = .306)

      # H2 - pre-registered analysis plan
      shapiro.test(data_Nal$SB6_Change) # W = .945 - Not stat. sig. dif.
from normal(p = .683)
      shapiro.test(data_Plac$SB6_Change) # W = .552 - stat. sig. dif. from
normal(p < .001)

      # H2 - ANOVA (more appropraite)
      shapiro.test(data_Nal$SB6_Pre) # W = .849 - Not stat. sig. dif. from
normal(p = .224)
      shapiro.test(data_Nal$SB6_Post) # W = .950 - Not stat. sig. dif.
from normal (p = .714)
      shapiro.test(data_Plac$SB6_Pre) # W = .911 - Not stat. sig. dif.
from normal(p = .475)
```

```
      shapiro.test(data_Plac$SB6_Post) # W = .988 - Not stat. sig. dif.
from normal (p = .971)


    }

  }

}


# Pre-registered Hypothesis 2 - Testing significant change in bonding
between groups####

## Descriptives ####

  #Naltrexone
  length(data_Nal$SB6_Change) # N = 4
  mean(data_Nal$SB6_Change) # -1
  sd(data_Nal$SB6_Change) # 0.816
  median(data_Nal$SB6_Change) # -1

  #Placebo
  length(data_Plac$SB6_Change) # N = 5
  mean(data_Plac$SB6_Change) # 0.2
  sd(data_Plac$SB6_Change) # 0.447
  median(data_Plac$SB6_Change) # 0


## non-parametric test of change in bonding ####


  # directional test (pre-registered)
  MannWhitney_SB_Direct <- wilcox.test(data_Nal$SB6_Change,
data_Plac$SB6_Change, alternative ="less", paired = FALSE,conf.int = TRUE,
conf.level = 0.95 )
  MannWhitney_SB_Direct #output result


  # U = 2, p = .022 - significantly different from 0. Naltrexone
significantly reduced
  # difference of -1.00 [-inf,-0.00], note: a -0.00 indicates it was a
negative number rounded to 0.

  # non-directional test (to check)
  MannWhitney_SB <- wilcox.test(data_Nal$SB6_Change, data_Plac$SB6_Change,
paired = FALSE, conf.int = TRUE, conf.level = 0.95)
  MannWhitney_SB #output result

  # U = 2, p = .043 - significantly different from 0. Naltrexone
significantly reduced
  # Difference of -1.00 95% CI = [-2.00, 0.00]



### Effect Sizes ####
  require(rcompanion)
  vda(SB6_Change ~ Nal_Plac, data = data, ci=TRUE)
  # VD Alpha = 0.9 (large) CI[ .667, 1] - VDA ranges from 0 to 1,
  # where 0.5 suggests no difference, 1 suggests complete dominance of
group 1 over group 2 and 0 complete dominance of group 2 over group 1.
  # In this instance, group 1 (Placebo) has near-complete dominance over
group 2 (Naltrexone)

  cliffDelta (SB6_Change ~ Nal_Plac, data = data, ci=TRUE)
  # Cliff Delta = 0.8 (large) CI[ .333, 1] - Delta ranges from -1 to 1,
Linearly related to VD Alpha.
  # where 0 suggests no difference, 1 suggests complete dominance of group
1 over group 2 and -1 complete dominance of group 2 over group 1.
```

```
  # In this instance, group 1 (Placebo) has near-complete dominance over
group 2 (Naltrexone)

  wilcoxonR(x = data$SB6_Change,
            g = data$Nal_Plac,
            ci = "TRUE")
  # r = .72 [.427, .927] - r is likely best known for use in article.

  freemanTheta(x = data$SB6_Change,
               g = data$Nal_Plac,
               ci = "TRUE")
  # theta = .8 [.324, 1]


## Pre-Registered Hypothesis 2 - Graph ####

data$Naltrexone <- factor(data$Nal_Plac)
YSB6_Summary <- data %>%
  group_by(Naltrexone) %>% # grouping variable
  summarise(mean_SB6C = mean(SB6_Change),
            sd_SB6C = sd(SB6_Change),
            n_SB6C = n(),
            SE_SB6C = sd(SB6_Change)/sqrt(n()))
head(YSB6_Summary)

YSB6bg <- ggplot(YSB6_Summary, aes(x=Naltrexone, y = mean_SB6C))+
  geom_col(fill= c("dark grey","light grey"))+
  geom_errorbar(aes(ymin = mean_SB6C - SE_SB6C, ymax = mean_SB6C +
SE_SB6C), width = .2) +
  labs (title = "Bar Chart showing Mean Change in Social Bonding Measure,
with Standard Error Bars",
        y = "Mean Change in Social Bonding Measure +/- SE",
        x = "Pill Type")

YSB6bg +
  scale_x_discrete(labels=c("Placebo","Naltrexone"))+
  theme_bw()



# Power Analysis for ANOVA ####

# Effect size converstion.

# smallest effect size from a priori analysis: d = .59, R^2 = .08

# ANOVA test requires effect size in format 'f' to calculate pwoer
# f^2 = R^2/ (1-R^2)
# f = sqrt (R^2/(1-R^2))
f = sqrt(0.08/(1-0.08)) #.29488... ~ .295


## Correlation Among Repeated Measures

cor(data$SB6_Pre,data$SB6_Post) # 0.683

# 18 participants needed for fully powered study with lowest effect size.
# If highest possible effect size assumed (from pre-Registration; d =
0.90): f = 0.45
# G*Power suggests 10 total participants (5 in each group)


## H2 variant - ANOVA/ MIXED-EFFECTS MODEL ####
## More appropriate statistical test ##

### Parametric ANOVA ####

ldata <- read.csv("NalYoga - LONG.csv", header=TRUE)
```

```
ldata$factParticipant <- factor(ldata$Participant)

aov_Nal_time <- aov(SB6 ~ Nal_Plac*Measurement.Occasion + Error
(factParticipant/Measurement.Occasion), data = ldata)
summary(aov_Nal_time)

library(apaTables)
require(ez)

ldata$FactNP <-factor(ldata$Nal_Plac)
ldata$FactMO <- factor(ldata$Measurement.Occasion)



options(digits = 10)
aov_NP_MO <- ezANOVA(data = ldata,
                     dv = .(SB6), wid = .(Participant),
                     between = .(FactNP), within = .(FactMO),
                     type = 2, detailed = TRUE)
aov_NP_MO
aovNPMO_table <- apa.ezANOVA.table(aov_NP_MO,
                                   filename = "Table1_APA.doc",
                                   table.number = 1)
print(aovNPMO_table)

## significant interaction effect of Nal_Plac and Measurement.Occassion on
SB6 score.
##

model.tables(aov_Nal_time, "means")

#  Nal_Plac:Measurement.Occasion
# Measurement.Occasion
# Nal_Plac  0     1
# 0       3.167  3.367
# 1       3.583  2.667
# Naltrexone (1) caused a significant decrease in post-session SB6.



### Non-Parametric ANOVA (Reviewer Suggested) ####

library("nparLD")
ex.f1f1np <- nparLD(SB6 ~ FactNP * Measurement.Occasion, data = ldata,
subject = "Participant", description = FALSE)
plot(ex.f1f1np)

summary(ex.f1f1np)

nonpar_ANOVA <- f1.ld.f1(ldata$SB6, ldata$Measurement.Occasion,
ldata$FactNP, ldata$Participant)

nonpar_ANOVA$case2x2
#                Statistic      p-value(N)          df    p-value(T)
# Group       0.07472976619 9.404297239e-01 4.708224556 0.94349997676
# Time        2.34367398999 1.909485374e-02 4.571349360 0.07092586200
# Group:Time -4.04816416452 5.162093597e-05 4.571349360 0.01183099502

# No significant main effects, but there is a significant interaction
effect of time*group.


## Feys (2016) suggest that in a non-parametric, Mixed-ANOVA design with
only 2 time points (pre-post test),
## a non-parametric ANCOVA should be used instead (p. 373-374). reccomends
a few options:

####Feys (2016) Follow-Up ####
```

```
  # The onecovahomog function from npsm
  # 'yuen', 'Kruskal-Wallis' and ' Exact Wilcoxon-Mann-Whitney'from WRS2

  ## NPSM ANCOVA results:  ###
  library("npsm")
  ANCOVAdata=data[,c('SB6_Post','Nal_Plac')] ## Data for ANOVA - Post-SB6
column 1 and Group in column 2
  xcov<-cbind(data['SB6_Pre']) # Covariate - in this case pre-SB6
  onecovahomog(2,ANCOVAdata,xcov,print.table=TRUE) # 2 levels, Post-SB6 by
Group, with SB6 as Covariates
  # There is a significant effect of pill type on post-SB6 response after
controlling for pre-SB6 response. F(1,8) = 12.34, p = .013


  ## WRS2 Yuen
  library("WRS2")
  yuen(SB6_Change ~ Nal_Plac, data = data)
  # Two-tailed Yuen-Welch Test (timmed-mean difference) t(3) = 2.45, p =
.092,
  # TMD = 1 95%CI [-.292, 2.30], d =  0.77
  # significant effect of group, where Naltrexone reduced social bonding
score by .389 compared to Placebo.

  ## KW Test
  kruskal.test(SB6_Change ~ Nal_Plac, data = data)
  # chi-squared = 4.65, p = .031 - significant difference between the
groups.

  ## Exact Wilcoxon-Mann-Whitney
  library("exactRankTests")
  wilcox.exact(SB6_Change ~ Nal_Plac, data = data, conf.int = TRUE,
conf.level = 0.95)
  ## W = 18, p = .040. Estimated difference caused by Naltrexone = 1.5 95%
CI [.000, 3]

  ## Feys (2016). Nonparametric Tests for the Interaction in Two-way
Factorial Designs Using R,
  ## The R Journal Volume 8(1):367-378
  ## DOI: 10.32614/RJ-2016-027



### Graphs ####

interaction.plot(ldata$Nal_Plac, ldata$Measurement.Occasion, ldata$SB6)

library(FSA)
library(psych)
ldata$NP[ldata$Nal_Plac == 0] = "Placebo"
ldata$NP[ldata$Nal_Plac == 1] = "Naltrexone"

ldata$FactNP <- factor(ldata$NP)


ldata$MO[ldata$Measurement.Occasion == 0] = "Pre"
ldata$MO[ldata$Measurement.Occasion == 1] = "Post"
ldata$FactMO <- factor(ldata$MO)


Sum = Summarize(SB6 ~ FactNP + FactMO,
                data=ldata,
                digits=3)
Sum$se = Sum$sd / sqrt(Sum$n)

Sum$se = signif(Sum$se, digits=3)

Sum
```

```
levels(Sum$FactNP)[levels(Sum$FactNP)=="Placebo"] <- "Placebo"
levels(Sum$FactNP)[levels(Sum$FactNP)=="Naltrexone"] <- "Naltrexone"
Sum$FactNP = factor(Sum$FactNP,
                    levels=unique(Sum$FactNP))
levels(Sum$FactMO)[levels(Sum$FactMO)=="Pre"] <- "Pre-Yoga"
levels(Sum$FactMO)[levels(Sum$FactMO)=="Post"] <- "Post-Yoga"
Sum$factMO = factor(Sum$FactMO,
                    levels=unique(Sum$FactMO))

library(ggplot2)

pd = position_dodge(.4)

intplot <- ggplot(Sum, aes(x = factMO,
                           y = mean,
                           color = FactNP)) +
  geom_errorbar(aes(ymin = mean - se,
                    ymax = mean + se),
                width=.3, size=1.5, position=pd) +
  geom_point(shape=15, size=4, position=pd) +
  scale_x_discrete(limits=c("Pre-Yoga", "Post-Yoga"))

intplot +
  labs(y = "Mean Social Bonding Score (0-7)") +
  labs(x = "Measurement Occasion") +
  labs(title = "Effect of Naltrexone on Social Bonding Before and After
Group Yoga") +
  labs(color = "Pill Type")+
  theme(legend.justification=c(1,1),
        legend.position=c(1,1))


data$Naltrexone <- as.factor(data$Nal_Plac)


Naltrexone_Summary <- data %>%
  group_by(Naltrexone) %>% # grouping variable
  summarise(mean_SB6 = mean(SB6_Change),
            sd_SB6 = sd(SB6_Change),
            n_SB6 = n(),
            SE_SB6 = sd(SB6_Change)/sqrt(n()))
head(Naltrexone_Summary)

bg <- ggplot(Naltrexone_Summary, aes(x=Naltrexone, y = mean_SB6))+
  geom_col(fill= c("red","blue"))+
  geom_errorbar(aes(ymin = mean_SB6 - SE_SB6, ymax = mean_SB6 + SE_SB6),
width = .2)

bg + labs (title = "Bar Chart showing Mean Change in Social Bonding, with
Standard Error Bars",
           y = "Change in Social Bonding +/- SE",
           x = "Placebo (0) or Naltrexone (1)")


# Pre-registered Hypothesis 3 ####
## Not included in article, but here for completeness ##

data <-
  data %>%
  mutate(Wall_SitCh_Seconds = (Wall_Sit_Change/1000)) %>% # Convert Wall
Sit time from miliseconds to seconds
  mutate(Wall_SitPre_Seconds = (Wall_Sit_Pre/1000)) %>% # Convert Wall Sit
time from miliseconds to seconds
  mutate(Wall_SitPost_Seconds = (Wall_Sit_Post/1000)) %>% # Convert Wall
Sit time from miliseconds to seconds
  mutate(Wall_SitC = (Wall_Sit_Change - mean(Wall_Sit_Change, na.rm=T)))
%>%  #grand-mean centred
  mutate(Wall_SitC_Seconds = (Wall_SitC/1000)) %>% # Convert centred Wall
Sit time from miliseconds to seconds
```

```
  mutate(PANASPZ = (PANASP_Change - mean(PANASP_Change, 
na.rm=T))/sd(PANASP_Change, na.rm=T)) %>% #grand-mean centred and 
standardised
  mutate(PANASNZ = (PANASN_Change - mean(PANASN_Change, 
na.rm=T))/sd(PANASN_Change, na.rm=T)) %>% #grand-mean centred and 
standardised
  mutate(SB5Z = (SB5_Change - mean(SB5_Change, na.rm=T))/sd(SB5_Change, 
na.rm=T)) %>% #grand-mean centred and standardised   #grand-mean centred
  mutate(SB6Z = (SB6_Change - mean(SB6_Change, na.rm=T))/sd(SB6_Change, 
na.rm=T))

##Variables:##
##___C = Centred around the grand mean ##
##___Z = converted to z-score/standardised ##
##PANASP = PANAS Positive ##
##PANASN = PANAS Negative ##
##SB5 = Average score created for Social Bonding excluding IoS (Aron, Aron 
Smollan, 1992) ##
##SB6 = Average score created for Social Bonding including IoS (Aron, Aron 
Smollan, 1992) ##
##Wall_Sit = Wall Sit measure ##

data_Nal <- data[data$Nal_Plac==1,] # Naltrexone

data_Plac <- data[data$Nal_Plac==0,] # Placebo

## plot scatterplot to visualise data using standardised/centred values
plot(data$Wall_SitC_Seconds,data$SB6Z, main = "Relationship Between Pain 
Tolerance and Social Bonding",
     xlab = "Change in Wall-Sit Measure (Pain Tolerance)", ylab = "Change 
in Social Bonding Measure")
abline(lm(data$SB6Z~data$Wall_SitC_Seconds), col="red") # regression line 
(y~x)

#  Include confidence interval of regression line
ggplot(data = data, aes(x = Wall_SitC_Seconds, y = SB6Z)) +
geom_point(size = 1, shape = 1) +
  geom_smooth(data = data, method = lm, color = "black", 
              fill = "darkgrey", se= TRUE, level =0.95, formula = y ~ x)+
  labs(title="Relationship Between Pain Tolerance and Social Bonding",
       x = "Change in Wall-Sit (Pain Tolerance)",
       y = "Change in Social Bonding Measure")+
  theme(panel.grid.major=element_blank(),
        panel.grid.minor=element_blank(),
        panel.border=element_blank(),
        text=element_text(family='Times'))


model1 <- lm(SB6_Change ~ Wall_SitC_Seconds, data = data)
summary(model1) # F(1,7) = 4.659, p = .068
confint(model1)
apa.reg.table(model1) # R^2 = .400 - 40% of the variance accounted for.
# N likely too low to be reasonably powered.
# Note assumption of normality and homoscedacisity do not hold.

##Assumptions##
## A:Mean of residuals is close to 0
mean(model1$residuals) # this assumption holds

## A: Homoscedacisity and Normality
autoplot(model1)
# Resid v.s. Fitted shows assumption does **NOT** hold.
# Q-Q Plot (top right) appears somewhat non-Normal.
# 2, 5 and 7 appear as outliers in plots 1 and 2.
# 2 and 5 appear as outlier on plot 3
# 2, 5 and 8 appear as outliers on plot 4
# Assumption does **NOT** hold

## A: The X variable and residuals are uncorrelated
```

```
cor.test (data$Wall_SitC_Seconds, model1$residuals) # assumption holds

## A: Durbin Watson (Autocorrelation)
require(lmtest)
dwtest(model1) # DW = 1.83, p = .462. Data not significantly auto-
correlated. Assumption holds

## A: Positive variability
var(data$Wall_SitC_Seconds) #assumption holds

## A: No multicolineatrity
# Only 1 predictor - no multicolinearity possible.


## Speaman's Rank Correlation ##

SB6_WallSit_SR <- cor.test(data$Wall_Sit_Change,data$SB6_Change, method =
"spearman", conf.level = 0.95) # Pre-service construct validity
SB6_WallSit_SR
# Rho = .624, p = .073


## --------------- ##
## Testing Link ====
  ## ------------- ##

  # Mixed Within-Between ANOVA #
  WSaov_Nal_time <- aov(Wall_Sit_s ~ Nal_Plac*Measurement.Occasion + Error
(factParticipant/Measurement.Occasion), data = ldata)
  summary(WSaov_Nal_time)
  # Significant interaction between Naltrexone and Measurement occasion on
Wall-Sit.
  # Naltrexone caused a significant reduction in Wall-Sit

  library(apaTables)
  require(ez)
  options(digits = 10)
  WSaov_NP_MO <- ezANOVA(data = ldata,
                         dv = .(Wall_Sit_s), wid = .(Participant),
                         between = .(FactNP), within = .(FactMO),
                         type = 2, detailed = TRUE)
  WSaov_NP_MO
  WSaovNPMO_table <- apa.ezANOVA.table(WSaov_NP_MO,
                                        filename = "Table2_APA.doc",
                                        table.number = 2)
  print(WSaovNPMO_table)

  ## Interaction Graph ##

  WSSum = Summarize(Wall_Sit_s ~ FactNP + FactMO,
                    data=ldata,
                    digits=3)
  WSSum$se = WSSum$sd / sqrt(WSSum$n)

  WSSum$se = signif(WSSum$se, digits=3)

  WSSum

  levels(WSSum$FactNP)[levels(Sum$FactNP)=="Placebo"] <- "Placebo"
  levels(WSSum$FactNP)[levels(Sum$FactNP)=="Naltrexone"] <- "Naltrexone"
  WSSum$FactNP = factor(WSSum$FactNP,
                        levels=unique(WSSum$FactNP))
  levels(WSSum$FactMO)[levels(WSSum$FactMO)=="Pre"] <- "Pre-Yoga"
  levels(WSSum$FactMO)[levels(WSSum$FactMO)=="Post"] <- "Post-Yoga"
  WSSum$factMO = factor(WSSum$FactMO,
                        levels=unique(WSSum$FactMO))

  library(ggplot2)
```

```
  pd = position_dodge(.4)

  intplot <- ggplot(WSSum, aes(x = factMO,
                               y = mean,
                               color = FactNP)) +
    geom_errorbar(aes(ymin = mean - se,
                      ymax = mean + se),
                  width=.3, size=1.5, position=pd) +
    geom_point(shape=15, size=4, position=pd) +
    scale_x_discrete(limits=c("Pre-Yoga", "Post-Yoga"))

  intplot +
    labs(y = "Mean Wall-Sit Measure Time (seconds)") +
    labs(x = "Measurement Occasion") +
    labs(title = "Effect of Naltrexone on Wall-Sit Measure Before and
After Group Yoga") +
    labs(color = "Pill Type")+
    theme(legend.justification=c(1,1),
          legend.position=c(1,1))


  data$Naltrexone <- as.factor(data$Nal_Plac)

  ## Bar graph ##
  WSNaltrexone_Summary <- data %>%
    group_by(Naltrexone) %>% # grouping variable
    summarise(mean_WSC = mean(Wall_SitCh_Seconds), ## mean of Wall Sit
Change (s)
              sd_WSC = sd(Wall_SitCh_Seconds), ## sd of Wall Sit Change
(s)
              n_WSC = n(),
              SE_WSC = sd(Wall_SitCh_Seconds)/sqrt(n())) ## SE of Wall Sit
Change (s)
  head(WSNaltrexone_Summary)

  bg <- ggplot(WSNaltrexone_Summary, aes(x=Naltrexone, y = mean_WSC))+
    geom_col(fill= c("red","blue"))+
    geom_errorbar(aes(ymin = mean_WSC - SE_WSC, ymax = mean_WSC + SE_WSC),
width = .2)

  bg + labs (title = "Bar Chart showing Mean Change in Wall Sit, with
Standard Error Bars",
             y = "Change in Wall Sit (Error bars indicate +/- 1SE)",
             x = "Placebo (0) or Naltrexone (1)")


  ## Post-Hoc Analysis ##
  ## If Naltrexone affected Wall-Sit negatively, and placebo did not,
  ## this would provide some evidence that wall-sit was a reliable measure
of central opioid binding.

  ## Independent samples t-test (comparing means)

  Nal_mean <- mean(data_Nal$Wall_SitCh_Seconds)
  Nal_sd <- sd(data_Nal$Wall_SitCh_Seconds)
  Nal_n <- length(data_Nal$Wall_SitCh_Seconds)

  Plac_mean <- mean(data_Plac$Wall_SitCh_Seconds)
  Plac_sd <- sd(data_Plac$Wall_SitCh_Seconds)
  Plac_n <- length(data_Plac$Wall_SitCh_Seconds)

  #Which type of t-test to use (are there equal variances)
  var.test(data_Nal$Wall_SitCh_Seconds,data_Plac$Wall_SitCh_Seconds)
  # F(3,4) = 4.9017, p = .159 - Not significantly different variance.
  # Can use a Student's t-test instead of Welch t-test

  NalWS_Check <-
t.test(data_Nal$Wall_SitCh_Seconds,data_Plac$Wall_SitCh_Seconds, var.equal
= TRUE)
```

```
  NalWS_Check
  # t = -3.2456, df = 7, p-value = 0.01414
  # alternative hypothesis: true difference in means is not equal to 0
  # 95 percent confidence interval:
  #  -18.813639  -2.954361
  # sample estimates:
  #  mean of x mean of y
  # -6.046667  4.837333

  direc_NalWS_Check <-
t.test(data_Nal$Wall_SitCh_Seconds,data_Plac$Wall_SitCh_Seconds, var.equal
= TRUE, alternative = "less")
  direc_NalWS_Check

  ##Effect size (Cohen's D)
  ##Sum of squares
  Plac_SS <- (Plac_sd^2) * (Plac_n-1) #3.059^2 * (5-1)
  Nal_SS <- (Nal_sd^2) * (Nal_n-1) #6.771^2 * (4-1)

  cohensd <- (Nal_mean-Plac_mean )/sqrt((Nal_SS+Plac_SS)/((Nal_n + Plac_n)
- 2))
  cohensd # d = -2.18
  library("MBESS")
  ci.smd(ncp=-3.2456, n.1=5, n.2=4, conf.level=0.95)
  # 95% CI of d [-3.86, -.41]
```

Appendix 28 – Study 5 Pre-Registration

Pre-registration abstract

Religious ritual has long been noted to increase feelings of social bonding (Durkheim; 1912/1964; Freud, 1961; Weber, 1920/2002; Cnaan and Heist, 2018). In a previously pre-registered study (Charles et al., in prep, https://osf.io/85unz/) we sought to demonstrate not only that religious rituals increase feelings of social bonding, but that this increase is linked to increases in the mu-opioid β-endorphin, as measured by the proxy measure of pain threshold. This research built on previous work suggesting that β-endorphins might help foster social bonding (Curley & Keverne, 2005; Dunbar & Shultz, 2010; Dunbar, Baron, et al., 2012; Machin & Dunbar, 2011). The present study further investigates the role of endorphins in social bonding that takes place during religious rituals through an experimental design aimed to elucidate a causal link: during a religious ritual, we will block β-endorphin binding in the brain with the mu-opioid antagonist Naltrexone. To do this, we will recruit healthy participants from a church in Brazil who are willing and able to give informed consent (male/female, age: 18-70). These participants will be recruited through contacts made with the church during the previous research project (https://osf.io/85unz/). Participants will randomly receive either placebo or Naltrexone in a double-blind fashion and then take part in their religious ritual as per usual. Before and after the ritual, social bonding will be assessed, as well as β-endorphin release via a proxy measure of pain threshold. Pain threshold will be used because β-endorphins elevate pain threshold. We predict that changes in social bonding that are usually seen after religious ritual will not be found in those who have mu-opioid receptors blocked by Naltrexone but will remain in those given the placebo. We also predict that the Naltrexone group should have a lower measured pain threshold after the religious ritual compared to the placebo group.

Introduction

Background/Rationale

The universal presence of religious rituals in human societies is something that has sparked interest in social scientists for at least the last century (Durkheim, 1912/1964; Freud, 1961; Weber, 1920/2002; Cnaan and Heist, 2018). One possible reason for ritual to be so prevalent is that a release of mu-opioids (such as β-endorphin) during rituals leads to increased levels of social bonding (Dunbar, 2014; 2017), with the social bonding in turn leading to evolutionary advantages (Taylor, Dickerson & Klien, 2002). This theory is based on previous research demonstrating that mu-opioids play a crucial part in social bonding (Curley & Keverne, 2005; Dunbar & Shultz, 2010; Dunbar, Baron, et al., 2012; Machin & Dunbar, 2011). So far, tests of this hypothesis have only used proxy measures of mu-opioid release in the form of pain threshold or pain tolerance (Charles et al., in prep). As a result, previous findings were correlational in nature only. With the introduction of an experimental manipulation of mu-opioids, we will be able to show a direct causal link.

Measuring β-endorphin

Measuring central levels of β-endorphin is not easy, as it does not pass readily through the blood brain barrier (Witt & Davis, 2006). As a way around this issue, research utilises β-endorphin's action as an analgesic (Zubieta et al., 2001; Zubieta, Ketter et al., 2003; Zubieta, Heitzeg et al., 2003), by measuring a change in pain threshold or tolerance as a proxy for β-endorphin release (Cohen et al., 2010; Tarr et al., 2015; Tarr, Launay, Tarr & Dunbar, 2016; Charles et al., in prep). Moreover, some studies have used mu-opioid antagonists, such as Naltrexone, in order to examine the role of mu-opioids on social bonding (Inagaki, Irwin & Eisenberger, 2015; Inagaki et al., 2016; Inagaki, Hazlett & Andreescu, 2019; Tarr et al., 2017). For example, Tarr et al. (2017) conducted a double-blind, placebo-controlled study where they administered Naltrexone to participants who then took part in synchronised dance. After the activity, they measured social closeness using an average of four questions each measured on a 7-point Likert scale: The Inclusion of Others in Self scale (IOS; Aron, Aron & Smollan, 1992), connectedness (Wiltermuth & Heath, 2009), likability (Hove & Risen, 2009), and similarity to personality (Valdesolo & Desteno, 2011). Tarr et al. (2017) did not find a significant difference between the two groups. However, Tarr et al. (2017) did not measure the change in these measures of social bonding from before to after the sessions: they only assessed the levels of social closeness after the dance intervention, which means that base levels of feelings of social bonding for each group were not accounted for.

Seperately, in a series of experiments, Inagaki and colleagues have demonstrated that Naltrexone does seem to inhibit or attenuate feelings of social bonding, which they named as 'social warmth' (Inagaki, Irwin & Eisenberger, 2015; Inagaki et al., 2016; Inagaki, Hazlett & Andreescu, 2019). Gangestad & Grebe (2017) suggested that field research was needed to put lab findings of the role of β-endorphin on social bonding into context with ecologically valid studies. Consequently, we believe that conducting a placebo-controlled study in a field setting that has previously shown to increase feelings of social bonding and links this increase to β-endorphin (Charles et al., in prep, https://osf.io/85unz) is a necessary step in understanding the role of β-endorphin in social bonding and testing the hypothesis that religious rituals could have developed as a method to improve social bonding (Dunbar, 2014).

Why not Oxytocin?

Over the last decade, there has been a wealth of research on animal models that suggests that the nonapeptide oxytocin is the neurochemical which plays a key role in social bonding (Crockford et al., 2013; Romero et al., 2014; Ross & Young, 2009; Smith et al., 2010). The amassing of literature suggesting a key role of oxytocin in the social bonding process in animal models gave precedence to research on the role of oxytocin on human social bonding. This has taken the form of 3 main methodologies (Nave, Camerer & McCullough, 2015, p. 773):

4. Using placebo-controlled studies measuring behavioural outcomes of administered intranasal oxytocin (See reviews by Bakermans-Kranenburg & Van Ijzendoorn, 2013; Bartz et al., 2011; Bos et al., 2012);
5. Correlating plasma oxytocin levels with behaviours (Feldman, 2012)
6. Correlating OT-related gene polymorphisms with behaviours. (Donaldson & Young, 2008; Ebstein et al., 2012; Pearce et al., 2017).

A seminal paper by Kosfeld and colleagues (Kosfeld et al., 2005) using the intranasal oxytocin method showed that intranasal oxytocin increases interpersonal trust. This finding was corroborated by an article correlating plasma oxytocin levels with trust suggesting the same effect - oxytocin increases trust (Zak, Kurzban & Matzner, 2005). These initial studies linking oxytocin to trust provided psychobiologists a neurotransmitter to cite as playing a key role in human social bonding. Furthermore, research looking at the facilitation of approach behaviour in humans has been able to replicate the findings of those in animals for both men (Scheele et al., 2012; Striepens et al., 2014) and women (Preckel et al., 2014).

However, the literature on the role of oxytocin and bonding in humans is far from clear. For one, oxytocin may play a more complex role in human social bonding than in animal models. Goodson (2013) also noted that the suggestion that oxytocin selectively fosters positive social behaviour is contradicted by an increasingly large number of studies. Goodson's (2013) criticism has developed into what is now termed the 'Oxytocin Paradox' (Bethlehem et al., 2014), which describes the inconsistent findings of oxytocin research in humans such as context dependency (Bartz et al., 2011) and gender differences (Bos et al., 2012). Bethlehem et al. (2014) recommend a shift away from viewing oxytocin as playing a role in social bonding specifically, to having a more generalised effect on anxiety (Eckstein et al., 2015) and reward sensitivity (Feng et al., 2015).

Moreover, the *necessary* role of oxytocin in human bonding becomes questionable when these effects are scrutinised (i.e., it not clear that oxytocin release is needed/required for social bonding to occur). A recent meta-analysis of the oxytocin-trust effect (Nave, Camerer & McCullough, 2015) describes issues with many of these studies including the measures of trust and oxytocin that were used, among other issues. Moreover, they found that the overall effect size was so small that it was not significantly different from zero (Cohen's $d = 0.077$, 95% CI [−0.124, 0.278], $z = 0.75$, $p = .45$), indicating that there likely is no oxytocin-trust effect. Additionally, a meta-analysis reviewing research on oxytocin receptor genotypes and behavioural and health outcomes, including sociability (Bakermans-Kranenberg & van IJzendoom, 2014), found that the effect size, once again, did not significantly differ from zero. This supports previous allegations that the studies that have found a positive effect were likely to be false positives in underpowered studies (Benjamin et al., 2012; Hewitt, 2012; Walum, Waldman & Young, 2016) and that the skew for positive effects in the published literature is due to a "file drawer" problem (Lane et al., 2016). For this reason, we believe that studying the role of another other proposed neurotransmitter, mu-opioids, in social bonding is timely.

Why Naltrexone?

Naltrexone is an opioid antagonist with a high specificity to bind with mu-opioid receptors in the brain, with a much lower affinity for delta-opioid and kappa-opioid receptors. Other opioid antagonsits that are currently available for use in humans include Naloxone and Nalmefene. Naloxone is a non-selective and competitive opioid receptor antagonist (Malenka et al., 2009) and Nalmefene is a structurally and chemically similar drug to Naltrexone, with a similar affinity to mu-opioid receptors. However, Nalmefene also binds "somewhat more avidly" (Niciu & Arias, 2013, p. 780) to both the delta- and kappa-opioid receptors than Naltrexone (Bart et al., 2005; Niciu & Arias, 2013), meaning that it is less suitable to assess the role of specifically mu-opioids.. Thus, the only opioid antagonist with a high specificity for mu-opioid receptors that is available for use in humans is Naltrexone.

Affect and social bonding

There is some research that suggests that emotional state, or affect, is related to both pain perception (Edwards et al., 2016; Finan & Garland, 2015; Rhudy & Meagher, 2001) and changes in background opioid activity, aka opioid tone (Koepp et al. 2009; Nummenmaa & Tuominen, 2018). There is also some research that suggests positive affect plays a role in social bonding (Fredrickson, 2013, Kok et al., 2013). Religious rituals may lead to changes in affect (Charles et al., in prep). Therefore, it is important to consider the potential role of affect changes on the social bonding that takes place during rituals.

To date, no research has used mu-opioid antagonists as a direct way to test the hypothesis that religious rituals lead to social bonding via the release of mu-opioids. In this study, we seek to provide participants who regularly attend religious rituals at their church with the mu-opioid antagonist Naltrexone. We will measure the change of social bonding from before to after the religious service using measures of social bondedness utilized in previous research (Aron, Aron & Smollan, 1992; Hove & Risen, 2009; Valdesolo & Desteno, 2011; Wiltermuth & Heath, 2009; Charles et al., in prep). We will measure change in pain threshold from before to after the church service as a way of testing whether or not the proxy measure used in previous studies (Charles et al., in prep) was a valid measure of central β-endorphin release.

Aims and Hypotheses

The main aim of this study is to better understand the role of β-endorphin in the social bonding taking place during religious rituals. More specifically, the aim is to see if central β-endorphin release is *necessary* for social bonding increase as opposed to playing an additive role in a larger neurochemical process. As such our hypotheses are as follows:

12. Taking part in a religious ritual will lead to an increase in self-reported levels of social bonding with other attendees measured both before and after the service for those who take a placebo.
13. The change in level of self-reported social bonding measured from before to after the religious service will not be significantly different from zero in those who are given Naltrexone.
14. There may be a mediating or moderating role of affect in the change in social bonding from before to after the religious service.
15. Pain threshold will increase in the placebo group but not the Naltrexone group from before to after the religious service.

Method

Participants

Participants will be recruited from a church in Brazil that took part in a previous, related study (https://osf.io/85unz/). The inclusion and exclusion criteria for participants are listed below.

The only published effect size specifically linking pain threshold (a proxy for endorphin release) and a measure of social bonding comes from Dunbar et al. (2016). In this study, the authors provide an effect size of $r^2 = 0.08$

(p. 6). A separate study by Inagaki et al. (2016) found that those who took Naltrexone (*M* = 5.92, *SD* = .924) had a lower feeling of social connection than when they took placebo (*M* = 6.47, *SD* = .487). However, in their study the authors do not provide the correlation between the two measurements, which is needed to calculate an effect size for within-participant data.

Using the Dunbar et al. (2016) study, we calculated an effect size of Cohen's *d* = .59 using formula below.

$$d = \frac{2r}{\sqrt{1 - r^2}}$$

$$d = \frac{2\sqrt{0.08}}{\sqrt{1 - 0.08}}$$

$$d = 0.59\ (2\ d.p.)$$

Using the Inagaki et al. (2016) study, we calculated 3 possible effect sizes from their within-participants design: with low (0.3), medium (0.5) and high (0.8) within participant correlation. These gave a Cohen's *d* of .60, .68 and .90 respectively.

Taking the lowest of these possible values for Cohen's *d*, we used G*Power to calculate the number of participants we would need to find an effect, a one-tailed between-participants t-test with an effect size of .59, alpha value of 0.05 power of 0.8 and allocation value of 1, the most participants we would need is 37 participants per group (total 74). The fewest participants we can use (assuming the highest Cohen's *d* from the Inagaki et al. (2016) study of .90) is 17 in each group (34 participants total).

For this reason, we will aim for 74 participants, but will still conduct analyses if we fail to recruit enough participants, so long as there are at least 17 participants in each group.

Inclusion Criteria

- Participant is willing and able to give informed consent for participation in the study.
- Healthy adults, Male or Female, aged 18 - 70 years.
- None of exclusion criteria apply

Exclusion Criteria

The participant may not enter the study if ANY of the following apply:

- Medical problems such as diabetes; hypertension; musculoskeletal, liver, brain, kidney, or other chronic disease;

- Individuals with rare hereditary problems (including galactose intolerance, the Lapp lactase deficiency or glucose-galactose malabsorption);

- Pregnant or lactating individuals;

- Individuals who have drunk alcohol on the day of the experiment;

- Individuals with a history of clinical depression, psychosis, or mania;

- Current use of anti-depressant medication or any other medication, except for contraceptives and asthma inhalers;

- Use of cannabis or another illicit drug within the previous 48 hours;

- Any long-term recreational use of opiate drugs.

A questionnaire asking about these exclusion criteria will be given to participants before they can take part (https://osf.io/x2f9z/).

Materials

Social Bonding questions

Assessment of social bonding:

- *Self-other distinction/overlap as proxy for social bonding*: We will administer the IOS (Aron, Aron & Smollan, 1992) rating scale (since as social cohesion increases, self-other distinction decreases).
- *Trust, connectedness, liking, similarity and emotional closeness as aspects of social bonding*: There were five other questions, each measured on a 7-point Likert scale, with one being the lowest score of "not at all" and seven being the highest of "extremely" These five questions were: (1) "At this moment, how connected do you feel to the people in your congregation?" (Wiltermuth & Heath, 2009); (2) "At this moment, how emotionally close do you feel to the other members of your congregation as a whole"; (3) "Thinking about everyone in your congregation now, how much do you trust the others in this group?"; (4) "How much do you like the people in your congregation overall?" (Hove & Risen, 2009); and (5) "Thinking about everyone in your congregation now, do you feel you have a lot in common with others in this congregation?" (Valdesolo & Desteno, 2011) Answers to these questions were averaged into a single social bonding scale.

A full example of the questionnaire can be found in the supplementary material on the OSF (https://osf.io/j6wsq/ (English) https://osf.io/cj3e4/ (Portuguese)).

Pain-threshold measure

Pain threshold will be measured by the so-called 'pressure cuff measure', which involves slowly inflating a sphygmomanometer cuff on the participant's upper, non-dominant arm until the participant indicates that they are 'very uncomfortable'. The pressure (in mmHg) that is listed on the sphygmomanometer when a participant signals the experimenter to stop is noted. This measure of pain threshold has previously been used in studies similar in set-up (e.g. Cohen et al., 2010; Dunbar et al., 2012a; Dunbar et al., 2012b). The pressure is taken before and after the service, with the difference in pressure taken as the change in threshold (ΔPT):

$$\Delta PT = Pressure\ of\ Cuff\ after\ service\ (mmHg)\ - Pressure\ of\ Cuff\ before\ service\ (mmHg)$$

This method of testing will be used over other pain measurement methods for multiple reasons:

5. The pressure cuff method usually takes no longer than 30 seconds to explain and one minute to conduct. In a time-sensitive environment, such as before a church service begins, using a method that is easier and faster to conduct means that more participants can be measured before the start of the service. It also does not rely on environmental factors as others do, described below.
6. Other methods have significant issues:
    a. The cold pressor method (having participants put hands in freezing water for as long as they can maintain) requires the ability to keep the ice at the exact same temperature for both the pre- and post- sessions for each participant, which cannot be guaranteed. Moreover, it is possible that the participant themselves changes temperature during the service. This could alter the perception of temperature-based pain and, thus, make the measure less valid.
    b. The wall-sit method (having participants sit with a straight back against a wall with their legs bent at the knee at a 90° angle and hold for as long as they can maintain - it causes pain due to lactic acid build-up in the muscles in the legs) has no upper limit, and some people can hold the posture for 3-4 minutes, which would cause issues in a time-sensitive environment, such as in this field study. Moreover, it relies on access to flat wall surfaces where participants can stand/sit against that cannot be guaranteed in a church environment.
7. This method of testing will be used over other pain-threshold measurements methods as others tend to test pain tolerance rather than pain threshold, where tolerance is the most amount of pain one can endure before finding it too much and threshold is the point at which one starts to feel pain. This means we are subjecting people who are attending church to less pain, which allows their usual ritual to be as undisturbed as possible.

The pressure of the sphygmomanometer we will use in this study is measured in mmHg. For reference, if future studies seek to replicate this study but end up using a different measuring tool that uses the international standard (SI) units, 1mmHg = 133.32Pa, such that an equivalent upper bound of 300mmHg is 39,996.7Pa, or ~40kPa.

Procedure

Randomisation

Once a participant has volunteered to take part in the study during on the day of the service, participants they will be randomly assigned to either the control condition (placebo) or the experimental condition (Naltrexone). Sarah Charles will be responsible for allocating reference numbers to the pills that will be given to each group, but will have no direct role in the distribution of the pills to participants, nor see which pills the participants have been given. The research assistants running the experiment will give out the pills and will not have access to the codes which enable distinguishing between placebo and Naltrexone. A digitalised random number generator will allocate a three-digit alphanumeric code to each pack of pills (to be given to one person). A reference spread sheet will record these reference numbers and whether the pills are placebo or naltrexone and will be stored in an encrypted data file only accessible (at the end of the experiments or when necessary in the case of reported adverse side effects) by Sarah Charles or Dr. Miguel Farias. As this study is carried out as a double-blind study, if, for whatever reason, participants or experimenters become unblinded, data from that participant will be excluded from data analysis.

A step-by-step summary of the planned procedure is listed below.

a. Participant indicates interest at the service.

b. Participant is provided the information sheet and a consent form. They are then screened via a medical exclusion questionnaire (https://osf.io/x2f9z/) in order to determine the eligibility for the participant to possibly take Naltrexone.

If their responses indicate they are not suitable for this study, they will be informed that they are not eligible.

If a participant is eligible, they will be randomly assigned to either the Naltrexone or placebo treatment

c. Each participant is given 2 pills (either 2 x placebo or 2 x 50mg of Naltrexone).

d. The participants are each allocated a reference number (which is their participant ID number preceded by a "B". So, if their pill pack code was A1Z, the participant ID will be BA1Z. This is to differentiate the numbers from data collected during a similar study conducted in the UK using three-character codes (https://osf.io/z87p4/)).

e. The participant will be asked to give their reference number to a research assistant who will note it on the questionnaire the participant will complete. The participant will keep their pack with the ID code to match them back with their responses after the service. They will then take a pain threshold test (administered by the research assistant).

Note that the pain threshold test will NOT be referred as such. Instead, the research assistant will refer to this as a 'pressure cuff measure'. No mention of 'pain threshold' should be made at any time to avoid pre-biasing the participant to reporting a higher (or lower) pain threshold. (Please see the pressure cuff protocol on the OSF: https://osf.io/shvq6/)

f. The participants will take part in their religious rituals as normal

g. The participants will then return to the PR/RA with whom they conducted the pre-service pressure-cuff measure with and begin the assessment of the dependent variables:

- Assessment of pain threshold
- Assessment of social bonding
- Assessment of affect
- Control variables (age, gender, level of education, number of years attended service, sense of connection to higher power, religiosity measured by the Duke University Religion Index (Koenig & Büssing, 2010))

h. The participants are told they have completed the study. They will be thanked for their time and given a debriefing form (https://osf.io/hv2k3/).

Ethics Statement

This research was designed in accordance with the regulations of Coventry University, and has been reviewed and approved by the Coventry University Ethics Committee (Project P96831).

Conflicts of interest statement

The funding for this project comes from the Templeton Religion Trust, a charitable foundation that looks to explore the role of religion on human behaviour. Grant number 0153.

Appendix 29 – Study 5 R Script

```
 ### RSB Brazil Naltrexone Study Script ###

#Required Packages####

rm(list=ls())

library("MASS",character.only=TRUE)
library(lme4)
library(MBESS)
library(dplyr)
library(MASS)
library(apaTables)
library(lavaan)
library(psychometric)
require(foreign)
require(magrittr)
require(lmerTest)
require(ggplot2)
require(ggpubr)
require(lattice)
require(reshape2)
require(nlme)
require(MuMIn)
require(PairedData)
require(gridExtra)
require(ggfortify)
require(multilevel)
require(robumeta)
require(psych)
require(GPArotation)
require(lm.beta)
require(rcompanion)

# Load a multiple packages because because I cannot recall which functions
come from which packages
# Load Data ####
data <- read.csv("NalBrazil - LONG.csv", header=TRUE)
data$factParticipant_Code <- factor(data$Participant_Code)

data_pre <- data[data$Pre_Post=="Pre",]
mean(data_pre$Age) # 42.7
sd(data_pre$Age)# 15.26
##Variables:##

##SB5 = Average score created for Social Bonding excluding IoS (Aron, Aron
Smollan, 1992) ##
##SB6 = Average score created for Social Bonding including IoS (Aron, Aron
Smollan, 1992) ##

## Sub-datasets ####

data_Nal <- data[data$Nal_Plac==1,] # Naltrexone # 11 participants, pre
and post

data_Nal_Pre <- data_Nal[data_Nal$Pre_Post=="Pre",]  #Naltrexone - 11
participants pre ritual
mean(data_Nal_Pre$Age) #38.8
sd(data_Nal_Pre$Age) # 13.59
data_Nal_Post <- data_Nal[data_Nal$Pre_Post=="Post",] #Naltrexone - 11
participants post ritual

data_Plac <- data[data$Nal_Plac==0,] # Placebo only # 13 participants

data_Plac_Pre <- data_Plac[data_Plac$Pre_Post=="Pre",]  #Placebo - 13
participants pre ritual
```

```
mean(data_Plac_Pre$Age) #47.7
sd(data_Plac_Pre$Age) # 15.3
data_Plac_Post <- data_Plac[data_Plac$Pre_Post=="Post",] #Placebo - 13
participants post ritual


# Descriptives ####

## Social Bonding ####

### Naltrexone ####
meanSB6_NalPre <- mean(data_Nal_Pre$SB6) # 5.59
meanSB6_NalPost <- mean(data_Nal_Post$SB6) # 5.42
sdSB6_NalPre <- sd(data_Nal_Pre$SB6) # 0.68
sdSB6_NalPre <- sd(data_Nal_Post$SB6) # 0.61

### Placebo ####
meanSB6_PlacPre <- mean(data_Plac_Pre$SB6) # 5.55
meanSB6_PlacPost <- mean(data_Plac_Post$SB6) # 5.77
sdSB6_PlacPre <- sd(data_Plac_Pre$SB6) # 0.91
sdSB6_PlacPost <- sd(data_Plac_Post$SB6) # 0.80


# Social Bonding Measure - Factor Analysis and Reliability ####
## Factor Analysis of SB5 ####

  Brazil_SB_CV <- read.csv("Brazil Naltrexone Data - SB Construct
Validity.csv", header=TRUE) # Social Bonding construct validity file.

  IOS_Pre <- Brazil_SB_CV$SB_IOS_Pre
  SB5_Pre <- Brazil_SB_CV$SB5_Pre
  IOS_Post <- Brazil_SB_CV$SB_IOS_Post
  SB5_Post <- Brazil_SB_CV$SB5_Post


  #Factor Analysis:
  SB5_Cor_Prea <- Brazil_SB_CV[,2:6]
  SB5_Cor_Pre <- round(cor(SB5_Cor_Prea),2)
  SB5_Cor_Pre

  SB5_Cor_Posta <- Brazil_SB_CV[,9:13]
  SB5_Cor_Post <- round(cor(SB5_Cor_Posta),2)
  SB5_Cor_Post

  #Factor analysis of the pre-service SB5 data
  factors_SB5_Pre <- fa(r = SB5_Cor_Pre, fm = "pa")
  #Getting the factor loadings and model analysis
  factors_SB5_Pre
  scree(SB5_Cor_Pre) # scree plot suggests 1 factor
  #Factor Analysis using method =  principal axis (pa)
  #Default is oblimin - an oblique rotation
  # factor analysis shows that 1 factor is sufficient.
  #Mean item complexity = 1
  # var explained = .50 - 50%
  # df adjusted RMSR = .22

  #Factor analysis of the post-service SB5 data
  factors_SB5_Post <- fa(r = SB5_Cor_Post, fm = "pa")
  #Getting the factor loadings and model analysis
  factors_SB5_Post
  scree(SB5_Cor_Post) # scree plot suggests 1 factor
  #Factor Analysis using method =  principal axis (pa)
  #Default is oblimin - an oblique rotation
  # factor analysis shows that 1 factor is sufficient.
  #Mean item complexity = 1
  # var explained = .56 - 56%
  # df adjustecd RMSR = .05

## Validity check of SB5 and IOS (similar Constructs?) ####
```

```
  IOS_Post <- Brazil_SB_CV$SB_IOS_Post
  SB5_Post <- Brazil_SB_CV$SB5_Post

  Pre_CV <- cor.test(IOS_Pre,SB5_Pre, method = "pearson", conf.level =
0.95) # Pre-service construct validity
  Pre_CV
  # Significant correlation - r = .68 [.39, .85] , p < .001
  Post_CV <- cor.test(IOS_Post,SB5_Post, method = "pearson", conf.level =
0.95) # post-service construct validity
  Post_CV
  #significant - r = .79 [.58, .91] , p < .001

  ## suggests that these are measuring similar constructs of bonding.

  ## in case of non-parametric ##
  Pre_CVSR <- cor.test(IOS_Pre,SB5_Pre, method = "spearman", conf.level =
0.95) # Pre-service construct validity
  Pre_CVSR
  # significant - rho = .45,  p = .029
  Post_CVSR <- cor.test(IOS_Post,SB5_Post, method = "spearman", conf.level
= 0.95) # post-service construct validity
  Post_CVSR
  # significant - rho = .81,  p < .001


## Factor Analysis of SB6 ####
  #Factor Analysis:
  library("dplyr")
  SB6_Cor_Prea <- select(Brazil_SB_CV, SB_Connect_Pre, SB_EmoClose_Pre,
SB_Trust_Pre, SB_Like_Pre, SB_Common_Pre, SB_IOS_Pre)
  head(SB6_Cor_Prea)
  SB6_Cor_Pre <- round(cor(SB6_Cor_Prea),2)
  SB6_Cor_Pre

  SB6_Cor_Posta <- select(Brazil_SB_CV, SB_Connect_Post, SB_EmoClose_Post,
SB_Trust_Post, SB_Like_Post, SB_Common_Post, SB_IOS_Post)
  SB6_Cor_Post <- round(cor(SB6_Cor_Posta),2)
  SB6_Cor_Post

  #Factor analysis of the pre-service SB6 data
  factors_SB6_Pre <- fa(r = SB6_Cor_Pre, fm = "pa")
  #Getting the factor loadings and model analysis
  factors_SB6_Pre
  scree(SB6_Cor_Pre) # scree plot suggests 1 factor
  #Factor Analysis using method =  principal axis (pa)
  #Default is oblimin - an oblique rotation
  # factor analysis shows that 1 factor is sufficient.
  #Mean item complexity = 1
  # var explained = .50 - 50%
  # df adjusted RMSR = .17

  #Factor analysis of the post-service SB6 data
  factors_SB6_Post <- fa(r = SB6_Cor_Post, fm = "pa")
  #Getting the factor loadings and model analysis
  factors_SB6_Post
  scree(SB6_Cor_Post) # scree plot suggests 1 factor
  #Factor Analysis using method =  principal axis (pa)
  #Default is oblimin - an oblique rotation
  # factor analysis shows that 1 factor is sufficient.
  #Mean item complexity = 1
  # var explained = .58 - 58%
  # df adjusted RMSR = .08

  # Factor Diagrams, showing loadings for the single factor.
  fa.diagram(factors_SB5_Pre, sort = TRUE, main = "Pre-Service SB5 factor
analysis diagram")
```

```
  fa.diagram(factors_SB5_Post, sort = TRUE, main = "Post-Service SB5
factor analysis diagram")
  # SB5 is 1 factor
  fa.diagram(factors_SB6_Pre, sort = TRUE, main = "Pre-Service SB6 factor
analysis diagram")
  fa.diagram(factors_SB6_Post, sort = TRUE, main = "Post-Service SB6
factor analysis diagram")
  # SB6 shows 1 factor.

## McDonald's Omega values ####
  SB5_pre_omega <- ci.reliability(SB5_Cor_Prea, type = "omega", conf.level
= 0.95, B=1000)
  SB5_pre_omega # SB5_Pre  omega = .83[.69, .97]
  SB5_post_omega <- ci.reliability(SB5_Cor_Posta, type = "omega",
conf.level = 0.95, B=1000)
  SB5_post_omega# SB5_post omega = .86[.79, .93]
  SB6_pre_omega <- ci.reliability(SB6_Cor_Prea, type = "omega", conf.level
= 0.95, B=1000)
  SB6_pre_omega # SB6_Pre  omega = .86[.72, .99]
  SB6_post_omega <- ci.reliability(SB6_Cor_Posta, type = "omega",
conf.level = 0.95, B=1000)
  SB6_post_omega# SB6_post omega = .90[.84, .95]


# Data Assumptions - Normality  ####

## Histograms  ####

  ### Naltrexone ####
    plotNormalHistogram(data_Nal_Pre$SB6,
                        main = "Histogram of Naltrexone Pre-Service Social
Bonding Measure",
                        xlab = "Naltrexone Participants'Pre-Service Social
Bonding")

    # Looks non-normal, skewed.

    plotNormalHistogram(data_Nal_Post$SB6,
                        main = "Histogram of Naltrexone Post-Service
Social Bonding Measure",
                        xlab = "Naltrexone Participants' Post-Service
Social Bonding")
    # Looks non-normal, flat distribution.

  ### Placebo ####
    plotNormalHistogram(data_Plac_Pre$SB6,
                        main = "Histogram of Placebo Pre-Service Social
Bonding Measure",
                        xlab = "Placebo Participants' Pre-Service Social
Bonding")

    # Looks non-normal, skewed.

    plotNormalHistogram(data_Plac_Post$SB6,
                        main = "Histogram of Post-Service Social Bonding
Measure",
                        xlab = "Placebo Participants' Post-Service Social
Bonding")
    # Looks non-normal, skewed distribution.

  ## QQ Plots ####
    ggqqplot(data_Nal_Pre$SB6)+
      labs (title = "Naltrexone Pre-SB6 QQ-Plot") # Some deviation from
the line
    ggqqplot(data_Nal_Post$SB6)+
      labs (title = "Naltrexone Post-SB6 QQ-Plot") # Litte deviation from
the line
    ggqqplot(data_Plac_Pre$SB6)+
```

```
      labs (title = "Placebo Pre-SB6 QQ-Plot") # Fair amount of  deviation
from the line, likely to be not normal.
    ggqqplot(data_Plac_Post$SB6)+
      labs (title = "Placebo Post-SB6 QQ-Plot") # Litte deviation from the
line


## ----------------- ##
## Shaprio-Wilk Test ####
## ----------------- ##

  data_wide <- read.csv("NalBrazil - Wide.csv", header=TRUE)
  Nal_data_wide <- data_wide[data_wide$Nal_Plac=="1",]
  Plac_data_wide <- data_wide[data_wide$Nal_Plac=="0",]

  shapiro.test (Nal_data_wide$SB6_Change)  # Change in SB6. W= .914, p =
.274
  shapiro.test (Plac_data_wide$SB6_Change)   # Change in SB6. W= .980, p =
.979


# Pre-Registered Analysis Plan ####

## descriptives ####

SBNal_mean <- mean(Nal_data_wide$SB6_Change) # - 0.17
SBNal_sd <- sd(Nal_data_wide$SB6_Change) # 0.49
SBNal_n <- length(Nal_data_wide$SB6_Change) #11


SBPlac_mean <- mean(Plac_data_wide$SB6_Change) # 0.22
SBPlac_sd <- sd(Plac_data_wide$SB6_Change) # 0.45
SBPlac_n <- length(Plac_data_wide$SB6_Change) #13
SBPlac_median <-  median(Plac_data_wide$SB6_Change) # 0.17

## t-test ####

#Which type of t-test to use (are there equal variances?)
var.test(Nal_data_wide$SB6_Change,Plac_data_wide$SB6_Change)
# not significantly different, therefore equal variances can be assumed

t.test(Nal_data_wide$SB6_Change,Plac_data_wide$SB6_Change,var.equal =
TRUE, paired = FALSE, alternative = "less", conf.level = .95)
#t(22) = -2.00, p = .029

### Effect size (Cohen's D) ####
##Sum of squares
SBPlac_SS <- (SBPlac_sd^2) * (SBPlac_n-1)
SBNal_SS <- (SBNal_sd^2) * (SBNal_n-1)

SBcohensd <- (SBPlac_mean -
SBNal_mean)/sqrt((SBPlac_SS+SBNal_SS)/((SBNal_n + SBPlac_n) - 2))
SBcohensd # d = 0.82
library("MBESS")
ci.smd(ncp=-1.998569, n.1=13, n.2=11, conf.level=0.95)
# 95% CI of d [-.03, 1.65]


data_wide$Naltrexone <- factor(data_wide$Nal_Plac)
SB6_Summary <- data_wide %>%
  group_by(Naltrexone) %>% # grouping variable
  summarise(mean_SB6C = mean(SB6_Change),
            sd_SB6C = sd(SB6_Change),
            n_SB6C = n(),
            SE_SB6C = sd(SB6_Change)/sqrt(n()))
head(SB6_Summary)

SB6bg <- ggplot(SB6_Summary, aes(x=Naltrexone, y = mean_SB6C))+
  geom_col(fill= c("dark grey","light grey"))+
```

```
  geom_errorbar(aes(ymin = mean_SB6C - SE_SB6C, ymax = mean_SB6C +
SE_SB6C), width = .2) +
  labs (title = "Bar Chart showing Mean Change in Social Bonding Measure,
with Standard Error Bars",
        y = "Mean Change in Social Bonding Measure +/- SE",
        x = "Pill Type")

SB6bg +
  scale_x_discrete(labels=c("Placebo","Naltrexone"))+
  theme_bw()

# Hypothesis 1 ####

#Pre descriptives
mean(data_Plac_Pre$SB6) # 5.55
sd(data_Plac_Pre$SB6) #.906
median(data_Plac_Pre$SB6) # 5.83

#Post descriptives
mean(data_Plac_Post$SB6) # 5.77
sd(data_Plac_Post$SB6) #.803
median(data_Plac_Post$SB6) # 5.83

Hypothesis_1 <- wilcox.test(data_Plac_Pre$SB6, data_Plac_Post$SB6, paired
=  TRUE, exact = TRUE)

SB_diff <- c(data_Plac_Pre$SB6 - data_Plac_Post$SB6) #create the
differences
SB_diff <- SB_diff[ SB_diff!=0 ] #delete all differences equal to zero
SB_diff_rank <- rank(abs(SB_diff)) #check the ranks of the differences,
taken in absolute
SB_diff_rank_sign <- SB_diff_rank * sign(SB_diff) #check the sign to the
ranks, recalling the signs of the values of the differences
SB_ranks_P <- sum(SB_diff_rank_sign[SB_diff_rank_sign > 0]) #calculating
the sum of ranks assigned to the differences as a positive, ie greater
than zero
SB_ranks_N <- -sum(SB_diff_rank_sign[SB_diff_rank_sign < 0]) #calculating
the sum of ranks assigned to the differences as a negative, ie less than
zero

SB_ranks_P # used in effect size calculation (Kerby)
SB_ranks_N # used in effect size calculation (Kerby)

# effect size #
Zstat_SB<-qnorm(Hypothesis_1$p.value/2) #Z score
Zstat_SB #print the Z-score = -1.57
SB_Bf_pval <- Wilcox_Plac_SB$p.value * 2 # Bonferroni correction (should
it be needed)
SB_Bf_pval
SB_rR <- abs(Zstat_SB)/sqrt(13*2)
# Effect size (Rosenthal, 1994) - more conservative effect size.
SB_rR # rR = 0.31
SB_rK <- ((SB_ranks_P/(SB_ranks_P+SB_ranks_N))-
(SB_ranks_N/(SB_ranks_P+SB_ranks_N)))
# Effect size (Kerby, 2014) - Less conservative, skewed by sample size.
abs(SB_rK) # rK= 53


# Hypothesis 2 ####



library(TOSTER)
Hypothesis_2 <- TOSTER::dataTOSTone(data = Nal_data_wide, vars =
c("SB6_Change"), mu = 0, low_eqbound = -0.46,
                    high_eqbound = 0.46, eqbound_type = 'd')

cohen.d(SB6 ~ Pre_Post, data = data_Nal)
# d = 0.27
```

```
M2 <- mean(data_Nal_Pre$SB6)
SD2 <- sd(data_Nal_Pre$SB6)

M1 <- mean(data_Nal_Post$SB6)
SD1 <- sd(data_Nal_Post$SB6)

R12 <- cor(data_Nal_Pre$SB6, data_Nal_Post$SB6)

Hypothesis_2b <- TOSTER::TOSTpaired(n = 11, m1 = M1, m2 = M2, sd1 = SD1,
sd2 = SD2, r12 = R12,
                                    low_eqbound_dz = -0.46,high_eqbound_dz
= 0.46)

# Power Analysis for ANOVA ####

# Effect size converstion.

# smallest effect size from a priori analysis: d = .59, R^2 = .08

# ANOVA test requires effect size in format 'f' to calculate pwoer
# f^2 = R^2/ (1-R^2)
# f = sqrt (R^2/(1-R^2))
f = sqrt(0.08/(1-0.08)) #.29488... ~ .295

## Correlation Among Repeated Measures

cor(data_wide$SB6_Pre,data_wide$SB6_Post) # 0.788


### ANOVA/ MIXED-EFFECTS MODEL ####

## Asusmption of normality ##
shapiro.test(data_Nal_Pre$SB6) # W = .860 - Not stat. sig. dif. from
normal(p = .057)
shapiro.test(data_Nal_Post$SB6) # W = .917 - Not stat. sig. dif. from
normal (p = .293)


shapiro.test(data_Plac_Pre$SB6) # W = .793 - Stat. sig. dif. from normal(p
= .006) <- Traditional ANOVA not possible. Assumption violated
shapiro.test(data_Plac_Post$SB6) # W = .925 - Not stat. sig. dif. from
normal (p = .290)

# Homogeneity of Variances
grp <- data %>%
  group_by(Pre_Post) %>%
  levene_test(SB6 ~ FactNP)
grp # Homogeneity of Variances assumtion not violated

## non-parametric Mixed ANOVA ##

library("nparLD")

ex.f1f1np <- nparLD(SB6 ~ FactNP * Pre_Post, data = data, subject =
"Participant_Code", description = FALSE)
plot(ex.f1f1np)

summary(ex.f1f1np)

nonpar_ANOVA <- f1.ld.f1(data$SB6, data$Pre_Post, data$FactNP,
data$Participant_Code)

nonpar_ANOVA$case2x2
#             Statistic  p-value(N)       df  p-value(T)
# Group       0.7728007  0.4396403  21.66698  0.4479892
# Time        0.4680975  0.6397149  21.99996  0.6443192
# Group:Time -2.2979330  0.0215656* 21.99996  0.0314458*
```

```
nonpar_ANOVA$ANOVA.test
# No Main Effects of Pill Type or Measurement Occasion
# Significant interaction effect (p = .022)

nonpar_ANOVA$ANOVA.test.time
# significant effect of Naltrexone


## Feys (2016) suggest that in a non-parametric, Mixed-ANOVA design with
only 2 time points (pre-post test),
## a non-parametric ANCOVA should be used instead (p. 373-374). reccomends
a few options:

{##Feys (2016) Follow-Up ####

  # The onecovahomog function from npsm
  # 'yuen', 'Kruskal-Wallis' and ' Exact Wilcoxon-Mann-Whitney'from WRS2

  ## NPSM ANCOVA results:  ###
  library("npsm")
  data_wide <-  read.csv("NalBrazil - Wide.csv", header=TRUE)
  ANCOVAdata=data_wide[,c('SB6_Post','Nal_Plac')] ## Data for ANOVA -
Post-SB6 column 1 and Group in column 2
  xcov<-cbind(data_wide['SB6_Pre']) # Covariate - in this case pre-SB6
  onecovahomog(2,ANCOVAdata,xcov,print.table=TRUE) # 2 levels, Post-SB6 by
Group, with SB6 as Covariates
  # There is a significant effect of pill type on post-SB6 response after
controlling for pre-SB6 response. F(1,23) = 4.45, p = .037


  ## WRS2 Yuen
  library("WRS2")
  yuen(SB6_Change ~ Nal_Plac, data = data_wide)
  # Two-tailed Yuen-Welch Test (timmed-mean difference) t(13.91) = 2.62, p
= .020,
  # TMD = .389 95%CI [.070, .708], d =  0.64
  # significant effect of group, where Naltrexone reduced social bonding
score by .389 compared to Placebo.

  ## KW Test
  kruskal.test(SB6_Change ~ Nal_Plac, data = data_wide)
  # chi-squared = 4.30, p = .038 - significant difference between the
groups.

  ## Exact Wilcoxon-Mann-Whitney
  library("exactRankTests")
  wilcox.exact(SB6_Change ~ Nal_Plac, data = data_wide, conf.int = TRUE,
conf.level = 0.95)
  ## W107, p = .038. Estimated difference caused by Naltrexone = .417 95%
CI [.000, .833]

  #All tests suggest significant effect of Naltrexone.


  ## Feys (2016). Nonparametric Tests for the Interaction in Two-way
Factorial Designs Using R,
  ## The R Journal Volume 8(1):367-378
  ## DOI: 10.32614/RJ-2016-027
}

### ANOVA GRAPH ####

library(ggplot2)
require(plyr)
SB6Int <- ddply(data,.(Pre_Post,FactNP),summarise, val = mean(SB6))


interaction <- ggplot(data, aes(x = Pre_Post, y = SB6, colour = FactNP)) +
  geom_boxplot() +
```

```
  geom_point(data = SB6Int, aes(y = val)) +
  geom_line(data = SB6Int, aes(y = val, group = FactNP)) +
  scale_x_discrete(limits=c("Pre", "Post")) +
  theme_bw()

interaction +
  labs(x = "When Measure Taken",
       y = "Social Bonding Measure",
       title = "Interaction plot of Social Bonding for participants in
each group at each time point")



# Hypothesis 3 ####
## Does positive affect mediate the effect of ritual on social
bonding?####

# Cannot be conducted as main effect of time was not significant.
# No main effect of time means that mediation via PANAS cannot be
conducted.

# Does Naltrexone Influence Pressure Cuff Measure? ####
# Pressure Cuff Data Assumptions ###
# ---- #

## Naltrexone ##
plotNormalHistogram(data_Nal_Pre$Pressure_Cuff,
                    main = "Histogram of Pre-Service Pressure Cuff measure
for Naltrexone",
                    xlab = "Pre-Session Pressure Cuff Measure (mmHg)")

# Doesn't look normal

plotNormalHistogram(data_Nal_Post$Pressure_Cuff,
                    main = "Histogram of Post-Session Pressure Cuff
measure for Naltrexone",
                    xlab = "Post-Session Pressure Cuff Measure (mmHg)")

# Doesn't look normal
plotNormalHistogram(data_Nal_Post$Pressure_Cuff -
data_Nal_Pre$Pressure_Cuff,
                    main = "Histogram of Change in Pressure Cuff measure
for Naltrexone",
                    xlab = "Post-Session Pressure Cuff Measure (mmHg)")

plotNormalHistogram(data_wide$Cuff_Change,
                    main = "Histogram of Change in Pressure Cuff measure
for all participants")



## Placebo ##

plotNormalHistogram(data_Plac_Pre$Pressure_Cuff,
                    main = "Histogram of Pre-Service Pressure Cuff measure
for Placebo",
                    xlab = "Pre-Session Pressure Cuff Measure (mmHg)")

# Doesn't look normal

plotNormalHistogram(data_Plac_Post$Pressure_Cuff,
                    main = "Histogram of Post-Session Pressure Cuff
measure for Placebo",
                    xlab = "Post-Session Pressure Cuff Measure (mmHg)")

plotNormalHistogram(data_Plac_Post$Pressure_Cuff -
data_Plac_Pre$Pressure_Cuff,
                    main = "Histogram of Change in Pressure Cuff measure
for Placebo",
```

```
                    xlab = "Post-Session Pressure Cuff Measure (mmHg)")

## ----------------- ##
## Shaprio-Wilk Test ####


### Naltrexone ####

    shapiro.test(data_Nal_Pre$Pressure_Cuff) # W = .899 - Not stat. sig.
dif. from normal(p = .180)
    shapiro.test(data_Nal_Post$Pressure_Cuff) # W = .901 - Not stat. sig.
dif. from normal (p = .189)
    shapiro.test(data_Nal_Post$Pressure_Cuff - data_Nal_Pre$Pressure_Cuff)
# W = .894 - Not stat. sig. dif. from normal(p = .156)

### Placebo ####
    # -------------- #
    shapiro.test(data_Plac_Pre$Pressure_Cuff) # W = .760 - Stat. sig. dif.
from normal (p = .002)
    shapiro.test(data_Plac_Post$Pressure_Cuff) # W = .868 - Stat. sig.
dif. from normal (p = .049)
    shapiro.test(data_Plac_Post$Pressure_Cuff -
data_Plac_Pre$Pressure_Cuff) # W = .916 - Not stat. sig. dif. from
normal(p = .222)



## --------------------------------------------------------------------------
------##
## Testing Link Between Naltrexone and Pain Tolerance (pressure cuff
measure) ====
## --------------------------------------------------------------------------
------##

# regression between change in pressure cuff and pill type (dummy coded)

Testlink <- lm(Cuff_Change ~ Nal_Plac, data = data_wide)
summary(Testlink) # F(1,22) = .030, p = .863
confint(Testlink)

# Unlike the wall sit test, the pressure cuff measure may not be a good
measure of central opioid release.

## --------------------------------------##
# Pre-Registered H4 - Pain Tolerance  ====
## --------------------------------------##

## Normality Test ####

shapiro.test(data_Nal_Pre$Pressure_Cuff) # W = .899, p = .180
shapiro.test(data_Nal_Post$Pressure_Cuff) # W = .901, p = .189

shapiro.test(data_Plac_Pre$Pressure_Cuff) # W = .760, p = .002
shapiro.test(data_Plac_Post$Pressure_Cuff) # W = .868, p = .049

## Placebo ####


mean(data_Plac_Pre$Pressure_Cuff) # 168.46
sd(data_Plac_Pre$Pressure_Cuff) # 81.53
median(data_Plac_Pre$Pressure_Cuff) # 140

mean(data_Plac_Post$Pressure_Cuff) # 179.23
sd(data_Plac_Post$Pressure_Cuff) # 76.42
median(data_Plac_Post$Pressure_Cuff) # 160


Hypothesis_4_Placebo <- wilcox.test(data_Plac_Pre$Pressure_Cuff,
data_Plac_Post$Pressure_Cuff, paired =  TRUE, exact = TRUE)
```

```
Hypothesis_4_Placebo

Cuff_diff <- c(data_Plac_Pre$Pressure_Cuff - data_Plac_Post$Pressure_Cuff)
#create the differences
Cuff_diff <- Cuff_diff[ Cuff_diff!=0 ] #delete all differences equal to
zero
Cuff_diff_rank <- rank(abs(Cuff_diff)) #check the ranks of the
differences, taken in absolute
Cuff_diff_rank_sign <- Cuff_diff_rank * sign(Cuff_diff) #check the sign to
the ranks, recalling the signs of the values of the differences
Cuff_ranks_P <- sum(Cuff_diff_rank_sign[Cuff_diff_rank_sign > 0])
#calculating the sum of ranks assigned to the differences as a positive,
ie greater than zero
Cuff_ranks_N <- -sum(Cuff_diff_rank_sign[Cuff_diff_rank_sign < 0])
#calculating the sum of ranks assigned to the differences as a negative,
ie less than zero

Cuff_ranks_P # used in effect size calculation (Kerby)
Cuff_ranks_N # used in effect size calculation (Kerby)

### Effect Size ####
Zstat_Cuff<-qnorm(Hypothesis_4_Placebo$p.value/2) #Z score
Zstat_Cuff #print the Z-score = -1.57
Cuff_rR <- abs(Zstat_Cuff)/sqrt(13*2)
# Effect size (Rosenthal, 1994) - more conservative effect size.
Cuff_rR # rR = 0.31
Cuff_rK <- ((Cuff_ranks_P/(Cuff_ranks_P+Cuff_ranks_N))-
(Cuff_ranks_N/(Cuff_ranks_P+Cuff_ranks_N)))
# Effect size (Kerby, 2014) - Less conservative, skewed by sample size.
abs(Cuff_rK) # rK= 53

## Naltrexone ####

H4_M2 <- mean(data_Nal_Pre$Pressure_Cuff)
H4_SD2 <- sd(data_Nal_Pre$Pressure_Cuff)

H4_M1 <- mean(data_Nal_Post$Pressure_Cuff)
H4_SD1 <- sd(data_Nal_Post$Pressure_Cuff)

H4_R12 <- cor(data_Nal_Pre$Pressure_Cuff, data_Nal_Post$Pressure_Cuff)

Hypothesis_4_Naltrexone <- TOSTER::TOSTpaired(n = 11, m1 = H4_M1, m2 =
H4_M2,
                                                        sd1 = H4_SD1, sd2 = H4_SD2,
r12 = H4_R12,
                                              low_eqbound_dz = -0.46,high_eqbound_dz
= 0.46)

### Effect Size ####
cohen.d(Pressure_Cuff ~ Pre_Post, data = data_Nal)
# d = 0.15



# Pooled data from study 4 and study 5 ####
S4S5data <- read.csv("NalAll - LONG.csv")
str(S4S5data)
S4S5data$Pre_Post <- as.factor(S4S5data$Measurement.Occasion)
S4S5data$Nal_Plac <- as.factor(S4S5data$Nal_Plac)

## subset data further ####
S4S5data_Nal <- S4S5data[S4S5data$Nal_Plac == "Naltrexone",]
S4S5data_Nal_Pre <- S4S5data_Nal[S4S5data_Nal$Pre_Post == "Pre",]
S4S5data_Nal_Post <- S4S5data_Nal[S4S5data_Nal$Pre_Post == "Post",]

S4S5data_Plac <- S4S5data[S4S5data$Nal_Plac == "Placebo",]
S4S5data_Plac_Pre <- S4S5data_Plac[S4S5data_Plac$Pre_Post == "Pre",]
S4S5data_Plac_Post <- S4S5data_Plac[S4S5data_Plac$Pre_Post == "Post",]
```

```
## normality tests ####
shapiro.test(S4S5data_Nal_Pre$SB6) # non sig
shapiro.test(S4S5data_Nal_Post$SB6)# sig

shapiro.test(S4S5data_Plac_Pre$SB6)# sig
shapiro.test(S4S5data_Plac_Post$SB6) # non-sig

## Placebo change in SB6 ####
Pooled_Placebo <- wilcox.test(S4S5data_Plac_Pre$SB6,
S4S5data_Plac_Post$SB6, paired = T)
# p = 0.043

mean(S4S5data_Plac_Pre$SB6) # 4.89
sd(S4S5data_Plac_Pre$SB6) # 1.44
median(S4S5data_Plac_Pre$SB6) # 5.58

mean(S4S5data_Plac_Post$SB6) # 5.10
sd(S4S5data_Plac_Post$SB6) # 1.40
median(S4S5data_Plac_Post$SB6) # 5.58

Pooled_diff <- c(S4S5data_Plac_Pre$SB6 - S4S5data_Plac_Post$SB6) #create
the differences
Pooled_diff <- Pooled_diff[ Pooled_diff!=0 ] #delete all differences equal
to zero
Pooled_diff_rank <- rank(abs(Pooled_diff)) #check the ranks of the
differences, taken in absolute
Pooled_diff_rank_sign <- Pooled_diff_rank * sign(Pooled_diff) #check the
sign to the ranks, recalling the signs of the values of the differences
Pooled_ranks_P <- sum(Pooled_diff_rank_sign[Pooled_diff_rank_sign > 0])
#calculating the sum of ranks assigned to the differences as a positive,
ie greater than zero
Pooled_ranks_N <- -sum(Pooled_diff_rank_sign[Pooled_diff_rank_sign < 0])
#calculating the sum of ranks assigned to the differences as a negative,
ie less than zero

Pooled_ranks_P # used in effect size calculation (Kerby)
Pooled_ranks_N # used in effect size calculation (Kerby)

### Effect Size ####
Zstat_Pooled<-qnorm(Pooled_Placebo$p.value/2) #Z score
Zstat_Pooled #print the Z-score = -2.02
Pooled_rR <- abs(Zstat_Pooled)/sqrt(18*2)
# Effect size (Rosenthal, 1994) - more conservative effect size.
Pooled_rR # rR = 0.34
Pooled_rK <- ((Pooled_ranks_P/(Pooled_ranks_P+Pooled_ranks_N))-
(Pooled_ranks_N/(Pooled_ranks_P+Pooled_ranks_N)))
# Effect size (Kerby, 2014) - Less conservative, skewed by sample size.
abs(Pooled_rK) # rK= .60

## Naltrexone change in SB6 ####
Pooled2_Naltrexone <- wilcox.test(S4S5data_Nal_Pre$SB6,
S4S5data_Nal_Post$SB6, paired = T)
# p = 0.039

mean(S4S5data_Nal_Pre$SB6) # 5.06
sd(S4S5data_Nal_Pre$SB6) # 1.11
median(S4S5data_Nal_Pre$SB6) # 5.67

mean(S4S5data_Nal_Post$SB6) # 4.69
sd(S4S5data_Nal_Post$SB6) # 1.37
median(S4S5data_Nal_Post$SB6) # 5.17

Pooled2_diff <- c(S4S5data_Nal_Pre$SB6 - S4S5data_Nal_Post$SB6) #create
the differences
Pooled2_diff <- Pooled2_diff[ Pooled2_diff!=0 ] #delete all differences
equal to zero
Pooled2_diff_rank <- rank(abs(Pooled2_diff)) #check the ranks of the
differences, taken in absolute
```

```
Pooled2_diff_rank_sign <- Pooled2_diff_rank * sign(Pooled2_diff) #check
the sign to the ranks, recalling the signs of the values of the
differences
Pooled2_ranks_P <- sum(Pooled2_diff_rank_sign[Pooled2_diff_rank_sign > 0])
#calculating the sum of ranks assigned to the differences as a positive,
ie greater than zero
Pooled2_ranks_N <- -sum(Pooled2_diff_rank_sign[Pooled2_diff_rank_sign <
0]) #calculating the sum of ranks assigned to the differences as a
negative, ie less than zero

Pooled2_ranks_P # used in effect size calculation (Kerby)
Pooled2_ranks_N # used in effect size calculation (Kerby)

### effect size ####
Zstat_Pooled2<-qnorm(Pooled2_Naltrexone$p.value/2) #Z score
Zstat_Pooled2 #print the Z-score = -2.07
Pooled2_rR <- abs(Zstat_Pooled2)/sqrt(15*2)
# Effect size (Rosenthal, 1994) - more conservative effect size.
Pooled2_rR # rR = 0.38
Pooled2_rK <- ((Pooled2_ranks_P/(Pooled2_ranks_P+Pooled2_ranks_N))-
(Pooled2_ranks_N/(Pooled2_ranks_P+Pooled2_ranks_N)))
# Effect size (Kerby, 2014) - Less conservative, skewed by sample size.
abs(Pooled2_rK) # rK= .66
```

Appendix 30 – Neurotransmitter Information

Oxytocin antagonist

At the time of planning the study and applying for ethics permission to conduct the double-blind research, there were no valid oxytocin antagonists that were appropriate for use in non-medical contexts. The best contender was in Phase 3 trials at time of planning the research. Since conducting the study those phase 3 trials have been abandoned. It does not seem that a reliable oxytocin antagonist

Dopamine antagonist

As discussed in section 2.1.2. of the main thesis, there is some early research to suggest that Dopamine plays a role in social bonding behaviour. Young et al. (2011, p. 60) suggested that it is specifically the D2-type receptors that play a role in the onset of social bonding. As such, some D2-type receptor antagonists were considered for use in the placebo-controlled trials. After researching the many options, the two antagonists with the shortest half-life and fewest reported side-effects were further considered: Prochlorperazine and Sulpiride.

Prochlorperazine, with a four-to-eight-hour half-life, is the dopamine antagonist with the shortest half-life. It is a D2-type receptor antagonist. However, it only has a middling specificity for D2-type receptors. Alongside the high affinity for D2, D3 and D4 receptors (Silvestre & Prous, 2005), it also has a low affinity for various 5-HT receptor subtypes (Silvestre & Prous, 2005), middling-to-high affinity for the alpha-1 adrenergic receptor (Richelson & Nelson, 1984) and a very high affinity for the H_1 Histamine receptor (Appl et al., 2012). This lack of specificity means it is not suitable for use in research that is specifically studying the effect of dopamine antagonism.

Sulpiride is an anti-psychotic drug with an eight-hour half-life (fairly low for dopamine antagonists), which provides its effect via D2-type receptor antagonism. It has been claimed to have a very high specificity for the D2, D3 and D4 receptors in the past, however more recent academic literature has described it as a "dirty drug" as it has multiple receptor binding affinities (Bueschbell et al., 2019). One reason it was considered initially was due to side effects tending to occur mostly from long-term use, not one-off use. However, headache or constipation possible are still possible side-effects and, though unlikely for a single use, the prevalence of akathisia and Parkinsonism is over 1% in those who take it, suggesting it is not appropriate for a study using Yoga.

After this, further dopamine antagonists were considered, but all had either too long of a half-life (12+ hours) or a prevalence of the type of side-effects that would not be appropriate for taking part in a ritual that requires movement (e.g., Parkinsonism).

Appendix 31 – Study 1 & 2 Ethics Certificate

Certificate of Ethical Approval

Applicant:

Valerie Van Mulukom

Project Title:

Synchrony, Endorphins, and Social Bonding in Religious Rituals

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

03 December 2017

Project Reference Number:

P53423

Appendix 32 – Study 1 & 2 Ethics Submission

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Appendix 33 – Study 3 Ethics Application

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Appendix 34 – Study 4 Ethics Certificate

Certificate of Ethical Approval

Applicant:

Sarah Charles

Project Title:

The role of neurotransmitter antagonists on social bonding during rituals

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as High Risk

Date of approval:

09 June 2019

Project Reference Number:

P89708

Appendix 35 – Study 4 Ethics Application

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Appendix 36 – Study 5 Ethics Certificate

Coventry University

Certificate of Ethical Approval

Applicant:

Sarah Charles

Project Title:

Double-Blind, Placebo-Controlled study looking at the role of Naltrexone on religious rituals

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

03 December 2019

Project Reference Number:

P96831

Appendix 37 – Study 5 Ethics Application

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