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Evaluation of infrared heating as an adjunct to achieve occupant thermal comfort in cars

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1.0 Introduction

A vehicle heater requires about 20 times the amount of energy to heat up a car cabin when compared to heating up an identically sized room in a house (Matsunaga et al, 2010). In electric vehicles (EV's), when the heater system is operating the cruising range is reduced to around only a third (Nakane et al, 2010) or half (Bäuml et al, 2014) of that without heating. This is a major reduction in driving range and highlights the need to develop a more energy efficient way to heat a car. By introducing an alternative heating method, and therefore decreasing the energy requirement of the heater in the car, improvements in fuel economy could be made that would enable an increased distance per unit volume of fuel. This would reduce the fossil fuel emissions per vehicle and so would increase the marketability of electric and hybrid vehicles.

Currently conventional vehicles use Heating, Ventilation and Air Conditioning Systems (HVAC) to heat occupants, via convective means, by circulating hot air throughout the cabin. The air acts as a mediator between the heater and the occupant. This results in energy losses as this hot air dissipates and escapes from the car cabin. Also the car cabin interior, including the seats, central console and the door panels act as heat sinks (Karimi et al, 2002). In conventional vehicles, excess heat which is created by the internal combustion engine (ICE) is used to fuel the heating system. Some of this heat is transferred to the car cabin and dispersed via an electric fan. As this heat is going to waste and the battery is charged when the ICE is running, this approach to cabin heating has no impact on the driving range of ICE vehicles.

However, in an EV the battery which powers the car and the associated electronic machinery only creates a relatively small amount of waste heat and, would be inadequate to heat the car cabin. Therefore EV's require a further source of heat for the vehicle cabin. A method of heating EV's is a bioethanol heater (Kohle et al, 2012). However, the efficiency of this method is questionable as it requires an extra tank to hold the fuel, adding weight to the car that will thus affect the driving range. An approach to directly heat vehicle occupants rather than the entire vehicle cabin and its contents via air could potentially save energy and also improve the time required for occupants to reach thermal comfort (TC) when entering a cold or cool vehicle. In accord, infra-red (IR) or radiant heating, which bypasses air and warms the surface to which it is incident, could be used to directly deliver heat energy to vehicle cabin occupants. This approach is currently under research for use in vehicles and is yet to be adopted by the automobile industry. Research from the built environment demonstrates that within an office space IR heating, directed to the hands, maintains TC at a lower air temperature and results in a 17% energy saving (Zeiler et al, 2013). Furthermore, using a combination of simulation and experimental work Bäuml and colleagues (2014) recently proposed that in an EV IR heaters could result in an energy saving of up to 50%. The potential for IR heating, used in conjunction with delivering heat energy via air, to deliver occupant thermal comfort in road vehicles forms the basis of the present study. Considering the sensitivity of the hands and feet to the cold (Arens et al, 2006), regional comparisons of IR heating directed at the lower and upper body areas will be explored.

Thermal comfort (TC) responses in transient conditions differ to those in steady state conditions. Local heating/cooling in the opposite direction to whole body heating/cooling can provide very high TC scores (Zhang et al, 2004). The local Thermal Sensation (TS) scores, at which the highest TC scores are achieved, shift towards cool or warm based on human thermal state. This response could be important to consider when investigating the use of IR heating in transient conditions.

The literature review will cover the following areas: Thermal comfort (TC), thermal sensation (TS), Infra-Red (IR) heating, modes of heat transfer, human thermoregulation; the thermo neutral zone and responses to heating and cooling.

2.0 Literature Review

2.1 Thermal Comfort

Thermal comfort (TC) is defined with the ASHRAE standard 55 (1992) as:

“that condition of mind which expresses satisfaction with the thermal environment”

This definition suggests that TC is a state of mind. This condition would, of course, be influenced by both physiological and psychological factors. Physiological responses provide insight into whether a person is comfortable, for example shivering or sweating suggests discomfort, however the satisfaction of the mind is paramount. TC is therefore achieved when the individual is content and wishes to be neither warmer nor cooler than they are and is therefore likely to be linked with an individual’s thermal desirability. There is a comfort zone for each individual, but this varies from person to person with no set temperature able to satisfy everyone (Olesen, 1982). As individual thermal perceptual and physiological responses vary even at a specific environmental temperature (Djongyang et al, 2010), the only way to establish TC is by gaining subjective data from the individual.

Factors known to influence TC include age (Oeffelen, 2007), gender (Karjalainen, 2007), body fat percentage (Zhang et al, 2001), metabolism (Havenith et al, 2002) and clothing resistance (De Carli et al, 2007). Due to such differences it is not possible to create a thermal environment which will satisfy everyone. The level of acceptability outlined in International Standard Organisation ISO 7730 (2005) is a 90% thermal satisfaction rating within a defined thermal environment. Values between -0.5 and 0.5 on the ASHRAE TS scale equates to 90 % of people feeling satisfied with the thermal environment (Heidari & Sharples, 2002).

2.2 Heat Transfer Mechanisms

The main methods of heat transfer used by the body's thermoregulatory response to the environment are conduction, convection, radiation and evaporation (Hanna & Brown 1983).

2.2.1 Heat Balance Equation

The amount of heat exchange between the body and the environment is shown in the following equation (Kerslake, 1972).

$$M_b + M_a + S = E \pm R \pm K \pm C$$

M_b is basal heat production which is the amount of heat produced by the body at rest. M_a is any heat produced by exercise or physical activity. S is total amount of heat storage. R is radiation, K is conduction, C is convection and E is evaporation. It is important to remember evaporation will only ever have a negative effect on heat retention within the body.

This equation describes that heat stored in the body is the direct result of the 4 methods of heat exchange (E, R, K and C), along with heat metabolism. There are obviously environment variables which can affect heat exchange such as ambient temperature (convection), thermal conductivity of the ground (conduction), wind velocity (convection), air humidity (convection) as well as the factors affecting radiative heat transfer (radiation) (Incropera, 2011). Therefore it is extremely important to have a thermal preconditioning period prior to trials so heat storage in participants is the same before each condition. Thermal steady state is when metabolic heat production is equal with heat loss to the environment (Sessler et al 1987). Differences such as sex, body fat, body shape and proportion, the thickness and composition of tissue in the body and age all affect heat exchange within the human body (Hanna & Brown 1983).

2.2.2 Conduction

Conduction is the term given to heat transfer which occurs via diffusion between a solid or stationary fluid (Bejan & Kraus, 2003). It also can be viewed as a transfer of energy from the more energetic to the less energetic particles of a substance due to interactions between the particles (Incropera, 2011). The occurrence of this type of heat transfer involves surfaces being in contact with each other. Thermal conduction relies on the differences in temperature between the surfaces, the area of the contact between the surfaces and the thermal conductivity of the surfaces (Gates, 1980). Conduction plays the major role of heat transfer from an organism's core to its surface via tissue (Precht et al, 1973).

2.2.3 Convection

Convection of air occurs when heat transfer is assisted by motion of a fluid from a wetted surface (Bejan & Kraus 2003). There are two main types of convective heat transfer, natural and forced. Natural convective heat transfer occurs when there is calm, non-moving gas or liquid which is in contact with an object whereas forced convection involves an outside force that causes the fluid to move (Hanna & Brown, 1983). When forced convection occurs, the prevalence of natural convection becomes somewhat irrelevant. So basically in environments with high air flow such as wind, natural convection does not really have an effect. Convection within the human body helps to transport heat from the core to the skin via the blood (Precht et al, 1973).

2.2.4 Radiation

Thermal heat radiation is the transfer of heat between surfaces, or between a surface and a liquid by long-wavelength electromagnetic radiation (Bejan & Kraus, 2003). Unlike the other two forms of heat transfer, radiation does not require the presence of a material mediator and actually performs most efficiently in a vacuum (Incropera, 2011). The main factors affecting radiation are: the temperature and reflectance of an object, the temperature and reflectance of objects around it, the surface area of the object and surface area of objects visible to it (Incropera & Dewhitt, 1981).

2.2.5 Environmental monitoring

In terms of monitoring different potential heat sources, air temperature, relative humidity, air velocities, mean radiant temperature and light have to be considered. Mean radiant temperature eliminates the effect air flow may elicit on ambient air temperature. It has been found that when exposed to different air velocities from 0 to 3 m s^{-1}, participants have proportionally increased the radiant heat load voluntarily to the front of their body at both exercise and rest (Gueritee & Tipton, 2015).

2.2.6 Evaporation

Evaporation is the transfer of heat which occurs when a liquid turns into a gas (Hanna & Brown 1983). This happens when sweat is produced by an individual to try and remove heat from the body. This sweat evaporates off of the skin which causes heat to be transferred from the body to the environment. There's a "latent heat of vapourisation" state change in which a water molecule is vapourised and becomes an air molecule. This method of heat exchange assists in increasing heat loss and plays a role in the cooling process.

2.2.7 Seat Heating

Comfort is a very important factor of an automobile seat (Ebe & Griffin, 2001). Temperature is an important environmental factor which affects the perception of comfort when seated in an automobile (Fazlollohtabar, 2010).

In terms of warming up, heated seat studies have shown that they can have a beneficial effect on TC at a given ambient temperature. Brookes and Parsons (1999) found that heated seats improved TS at 5, 10 and 15˚C air temperature and TC at 5 and 10˚C air temperature. Oi et al (2012) found that heated seats improve occupant comfort during a dynamic warm up phase when the air temperature is lower than 15˚ C. Another interesting finding of this study was that mean toe skin temperature either increased or did not decrease in each trial, as well as foot TS improving in the 15˚ C and 20˚C groups. However no heat was directed toward the foot region and so this must have occurred due a thermoregulatory response. Peripheral areas were affected by local heat transfer from elsewhere within the body. Zhang et al (2007) found that participants achieved whole body thermal equilibrium in 11 minutes with heated seats in all conditions, much quicker than with an air conditioning system. These conditions included being in summer conditions when warmed up from neutral to hot (25-42 ˚C) and winter conditions when being warmed from cool (15-22 ˚C). As there is a large surface area of the body in contact with the car seat, seat heating works by direct conductive heating between the mass of seat and the person. This result provides an incentive to investigate different types of heating devices within automobiles as it's possible to achieve TC faster using an alternative heating method to air conditioning alone.

One issue with the individuals who participated in Oi et al's (2012) study is that they were very similar in terms of age (22 ± 1.1years), height (175 ± 1.3 cm), mass (57.2 ± 3.2 kg) and body fat percentage (14.3 ± 0.3 %).. The participants were very similar in all the variables stated above. The findings are valid and can be applied to the specific group investigated i.e. healthy young males. Due to a decrease thermal sensitivity with age, but cold sensitivity becoming more predominant than warm sensitivity (Guergova & Dufour, 2011), this result may not be as applicable to an older population.

2.3 Human Thermoregulation

2.3.1 Core Temperature

To keep the body fully functioning, the maintenance of a core temperature between 36.5 and 38.5 °C is required (Moran & Mendel, 2002). Extreme core temperatures less than 33.5 °C and more than 41.5 °C can result in injury and death (Hensel, 1981). However these are extreme values and the thermoregulatory system tries to maintain a core temperature around 37 °C.

The human body can maintain a core temperature of approximately 36.2 to 37.7 °C in normothermic environments (Dovjak, 2013). However in extreme environments core temperature cannot be maintained in this range as the behavioural thermoregulation system is overloaded. The magnitude of changes in core temperature which initiates a thermoregulatory response is very small. An upper critical limit of 40 °C for core temperature has been suggested but this temperature is not high enough to cause any cellular damage (Hales et al, 1996).

2.3.2 Circadian Rhythms

Skin temperature and blood flow are at the lowest level in the morning and a peak in late evening (Waterhouse et al, 2005). This results in an individual gaining heat in the morning (sharpest rise in core temperature) and then losing heat at night (biggest fall in core temperature). Due to this pattern in core temperature it is important that participants in the present study are tested at the same time of day to ensure that baseline core temperature measures will be the same on each occasion. If tested at different times in the day, an individual’s thermoregulatory response could differ just because they are at a different stage in the circadian rhythm. At rest, in terms of maintenance of circadian rhythms, metabolic heat production is more involved than heat loss mechanisms (Aschoff & Heise, 1972).

2.3.3 Thermo-neutral Zone

The thermo-neutral zone is currently defined by the International Union of Physiological Sciences (IUPS) as "the range of ambient temperature at which temperature regulation is achieved only by control of sensible heat loss, i.e. without regulatory changes in metabolic heat production or evaporative heat loss" (2006). Which essentially relates to the absence of shivering or sweating. This sensible heat loss can refer to conduction, convection, radiation or evaporation. The upper and lower ambient air temperature limits of the human thermo-neutral zone are called the Upper Critical Temperature (UCT) and Lower Critical Temperature (LCT) respectively. If temperatures rise above the UCT then fall outside of the zones then the hypothalamus initiates thermoregulatory responses such as sweating and vasodilation (section 2.7). If temperatures fall below the LCT then shivering, non-shivering thermogenesis and vasoconstriction are initiated (Kingma et al, 2011). Hardy & Dubois (1937) found the lower LCT for ambient air temperature for nude humans was 28.5°C, with a skin temperature of 33.5°C. They didn't define an upper limit but stated that evaporation was markedly increased at 32°C. The LCT has since been found to be lower, at 26.4°C (Kingma et al, 2014). The TNZ for a person in a business suit doing light office work is shown in figure 5. The TNZ is shown to be from 14-24°C, equating to a skin temperature 28-34°C (Kingma et al, 2014). Between these two skin temperatures the body can maintain thermal balance without requiring either sweating or shivering. The onset of these physiological responses to the cold directly correlated to the reduction in skin temperature as well as core temperature.

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Figure 1. The TCZ for a person dressed in a business suit with resting metabolic rate (Kingma et al, 2014). Showing both ambient air temperatures and corresponding mean skin temperatures. Both TCZ reported by Gagge et al (1967) and Weiwei et al (2014) are shown. The TNZ is also labelled and responses outside this zone such as sweat, Non-shivering thermogenesis (NST) and shivering (SH).

The thermal comfort zone (TCZ) (figure 1), the range of temperatures in which TC is achieved, is not directly related to the TNZ but physiologically share the same input factors, skin temperature and core temperature (ASHRAE, 2004). The range of skin temperatures in the TCZ is narrower than the TNZ (figure 1), which results in a narrower ambient air temperature range (Kingma et al, 2014). The TCZ ambient air temperature range for a person in a business suit doing light office work is 17-24°C, with skin temperatures 32-35.5°C (Gagge et al, 1967).In steady state conditions, humans can only be in the thermo-neutral zone if heat loss and heat production are balanced. However the TCZ outlined by Gagge et al (1967) is quite large (17-24°C), which questions whether this is really a “comfort zone”. People who feel comfort at 24°C are unlikely to feel comfort at 17°C, the range of temperatures is too large to be classed as a TCZ and may not be applicable to provide comfort to a person.

2.3.4 Cooling Physiology

When exposed to cold conditions, humans elicit a thermoregulatory response in the form of cutaneous vasoconstriction in order to retain heat (Lindblad et al 1990). Thermoregulatory vasoconstriction has been found to significantly decrease cutaneous heat loss (Sessler et al 1990). This is where blood vessels constrict to reduce blood flow to certain limbs to keep the body warm. Hence this reduces the convective transfer of heat from the core to the periphery as blood flow is reduced. There is also a reduced skin blood flow in response to cooling which results in less heat being transferred from the skin to the environment (Charkoudian, 2003). Vasoconstriction is the most important thermoregulatory response during mild cool exposure, which can be identified noticeably in the upper extremity region (Zeiler et al, 2013).

An initial response to try to retain heat is horripilation. This is where the hairs on the skin retain a layer of warm air which acts as a barrier between the skin and the ambient air (Mannino & Kaufman 1986). Both the magnitude of shivering and vasoconstriction have been shown to have a linear relationship with reductions in core temperature (Cheng et al, 1995). Shivering has also been associated with a decrease in skin temperature. Peripheral vasoconstriction assists in limiting heat loss in response to a cold stimulus, whereas shivering increases metabolic heat production (Castellani et al, 2000). Muscular contractions caused by shivering increases metabolic heat production, which, alongside reduced heat dissipation allows core temperatures to be maintained even in cold environments (Charkoudian, 2003). The coldest temperature used in the current protocol is 5°C, which participants are only exposed to for 3 minutes before the temperature increases. Therefore shivering is unlikely to be a major thermoregulatory response in the study.

There have been contradicting views in the literature about the role of skin in thermoregulation. A recent review stated that some studies have suggested that skin temperature serves as a feedback system whereas others propose that it serves as a feed forward system (Nakamura, 2011). A feed forward system considers that the skin detects changes in the environmental temperature and sends feed forward signals to the brain about the ambient temperature in order to regulate body temperature before the skin has actually got cold. A feedback system involves the skin becoming cold and then sending a signal to the brain to initiate a thermoregulatory response. The review goes on to clarify that autonomic thermoregulation uses thermal feedback signals whilst other areas for example non-hairy skin can produce feed forward signals which result in behaviours which may have thermoregulatory responses. In terms of heating up, the skin would then elicit feedback signals to the brain stating the temperature is warm, which would then lead to physiological responses such as vasodilation to try and spread heat through the body. Werner (1981) states that peripheral skin temperatures decrease in a variable way when the body is cooled but in warm conditions temperatures become more stable.

At 0°C the human thermoregulatory response in terms of heat generation achieves its maximum potential, which is typically 3 to 5 times the complete amount of heat generated at basal rate (Dovjak, 2013). Heart rate and metabolic rate have been shown to increase during short bouts of exposure to cold temperatures (Marino et al 1998). In the present study the coolest temperature participants are exposed to is 5°C, and this is not a repeated bout protocol and so these responses may not occur. This pattern may only occur when the participant is being repeatedly cooled and heated.

2.3.5 Heating Physiology

In a car cabin, the HVAC system helps warm up occupants by increasing ambient air temperature. On a simple level one physiological change which occurs when the body is heated up is an increased skin blood flow without an increase in muscle blood flow (Edholm, Fox & Macpherson, 1956).

In response to heat, elevated skin and core temperatures cause cutaneous vasodilation which is activated by neural mechanisms and also local mechanisms (Kellogg, 2006). These local mechanisms occur due to the effect of the higher temperature on skin vessels. Vasodilation increases the transfer of convective heat from the core to the periphery (Charkoudian, 2003). This vasodilation requires an increased blood flow which is achieved by an increased cardiac output and redistribution of blood flow from other areas of the body. This is achieved without compromising oxygen delivery to the vital organs (Johnson & Proppe, 1996).

During normothermic conditions, skin blood flow amounts to around 5% of cardiac output but this figure can increase dramatically to as much as 60% during maximal vasodilation (Rowell 1974). This shows just how prominent and substantial vasodilation is as a thermoregulatory response in humans.

There are two main mechanisms by which temperature is regulated within the body, chemical (cell metabolism) and physical (heat dissipation) (Cheng et al, 1995). When the whole body is warmed there is an increase in the rate of chemical reactions in the body which results in an increased heat production (Havenith et al, 2002). The increase in cell metabolism is achieved via an increase in cutaneous blood flow causing an increase in the permeability of cellular and capillary vessels, which in turn increases reactions within a cell (Baker et al, 2001). Generally, the more heat which is being produced within the body means that more heat needs to be dissipated around the body. However this is dependent on other aspects of the environment and the level of metabolism.

Thermoregulatory reflex responses to heat stress include an increase in skin blood flow and sweat production in order to try and maintain thermal homeostasis (Rowell, 1977). Depending on how much heat will be applied to the body dictates whether a sweat response would occur. The sweating response from heat stress has been shown to occur before the response of vasodilation within the forearm (Love & Shanks, 1962). Heat production, sweating and heat loss are proportional to core temperature (Cabanac & Massonnet, 1977). Therefore both skin and core temperatures play an important role in thermoregulatory responses

When body parts are locally warmed or cooled core temperature initially responded in the opposite direction to skin temperature (Huizenga et al, 2004). This could be due to counter current heat exchange when warm blood is being pumped around the body. Mitchell & Myers (1968) outlined this process and states that it can occur between the arteries and veins as well as between blood vessels and the tissues which they come in contact with. Blood flows to the tissue at the artery temperature and returns through the veins at the tissue temperature from which it has just come from. So when warm blood flows around cold tissue because of vasodilation, it can lead to the blood temperature becoming cooler. Even though the body is being heated up this cooler blood flow can actually reduce core temperature initially during vasodilation. So potentially if rapid heat stress in applied to a human, they may experience a drop in core temperature initially which may cause them to elicit shivering in response. This counter current flow is interesting to note and important to consider in the dynamic warm up phase in the proposed study (section 3.3.4).

2.3.6 Regional Body Warming

In terms of applying heat regionally, there have been different findings to whole body studies. Hirata et al (1988) found that submerging one hand in water at a temperature of 35°C, then increasing this temperature to 43 °C caused a decrease in skin blood flow levels to the hand. This vasoconstriction response was not present in the control hand. In a study with a similar protocol Nagasaka et al (1986) found a vasoconstriction response in the finger when heated regionally. They suggested that this could be a method to reduce heat gain in the hand when exposed to temperatures which are above core levels. As the rest of the body wasn't being warmed then this warm blood could flow around the rest of the body where this heat could be dissipated. It's interesting to note this response is different to that employed in response to whole body warming. Other studies have found that immersing one arm in warm water (43-45°C) caused vasodilation to occur in the other arm (Gibbon & Landis 1932). The authors have also found that by immersing forearms in warm water vasodilation responses occur in the lower limbs. This response was attributed the rise in temperature of the blood being returned from the heated limb. This response is worthy of note as thermoregulatory responses can occur during the warm up phase in areas of the body which aren't even being directly heated.

Water perfusion suit studies have shown that the hands act as heat radiators and the feet resisted heat loss when locally heated (Caldwell et al, 2013). The local skin temperature changes were controlled by variations in vasoconstrictor and venoconstrictor tone. This could be relevant to conduction via steering wheel heating although this will not be investigated in this study.

The face has been found to be the most sensitive body area to temperature sensation, due to a high concentration of thermoreceptors which makes it receptive to cold and warm conditions (Stevens & Choo, 1998). Suggesting that directly heating or cooling the face can elicit an effect on thermoregulatory responses. Whilst local skin warming and whole body warming both cause cutaneous vasodilation. It has been established that the mechanisms behind the responses under these two conditions are independent (Kellogg et al, 1995).

There is a high density of thermoreceptors in the face, lips, nose, abdomen, chest, back and finger (Hensel, 1982). There is around 10 times the amount of cold receptors compared to warm receptors (Guyton & Hall, 2000). The depth of cold thermoreceptors is around 0.15-0.17mm deep in the dermis with the depth of warm receptors around 0.3-0.6mm (Hensel, 1982). The increased number of cold thermoreceptors and the shallower depth of these to the skin surface suggest that humans are more receptive to the cold than the heat.

2.4 Hypothalamus

The hypothalamus is the main organ involved in thermoregulation, which processes information gained from internal and external thermoreceptors and initiates a thermoregulatory response leading to changes in temperature (McAllen et al, 2006).

The anterior hypothalamus is responsible for initiating thermoregulatory responses, vasodilation and sweating, when the body heats up over a set temperature usually around 37 °C (Benzinger, Pratt & Kitzinger, 1961). The posterior hypothalamus is responsible for eliciting a response in the form of vasoconstriction and shivering when the body's core temperature drops below a certain level.

2.5 Skin temperature

There have been contradicting views in the literature about the role of skin in thermoregulation. Some studies have suggested that skin temperature serves as a feedback system whereas others propose that it serves as a feed forward system (Nakamura, 2011). A feedback system proposes that when skin temperature becomes hot or cold, it feedbacks this information to the brain which can then elicit a thermoregulatory response. A feed forward system considers that the skin detects changes in the environmental temperature and sends feed forward signals to the brain in order to regulate body temperature before the skin has actually got cold. This paper goes on to state that autonomic thermoregulation uses thermal feedback signals whilst other areas for example non-hairy skin can produce feed forward signals which result in behaviours which may have thermoregulatory responses. Most metabolic heat is lost through the skin (Sessler et al 1990). This shows the importance of skin to regulating body temperature, especially in terms of heat dissipation.

2.5.1 Heat Flux

Skin temperatures alone cannot be used to calculate heat loss, as temperature alone doesn't give a measure of heat transfer to the environment. So heat flux measures will be made in the current study. Heat flux sensors measure the temperature gradient between two temperature sensing discs. The sensor then divides this value by the resistance separating the discs and calculated net heat flux through the instrument (Priestley & Taylor, 1972). Also transfer of heat cannot be established from changes in central body temperature alone as this is dictated by thermoregulatory responses and redistribution of heat in the body (Sessler & Moayeri, 1990). Cutaneous heat flux, along with central temperature and tissue heat content do not determine TC (Sessler & Ponte, 1990). The poor correlation between TC and heat flux is probably due to flux only being determined by skin temperature and the environment, with TC being dictated by many other factors.

2.5.2 Contribution of skin temperature & core temperature

The contribution ratio of core temperature to skin temperature towards initiating autonomic and metabolic responses is from 2:1 to 4:1 (Frank et al, 1999), with contributions to the shivering response being 4:1 (Cheng et al, 1995). Showing core temperature has a bigger effect than skin temperature in thermoregulatory response.Skin temperature and core temperature are both equally responsible for TC (Frank et al, 1999). So as previously stated, skin temperature isn't as important in initiating autonomic and metabolic response, but it plays a big part in subjective TC.

2.6 Clothing Insulation

A "clo" is an objective value used for the insulation of clothing. In the current study one "clo" is going to be worn by the participants. For studies investigating the rate of heat transfer it is important to control the clothing insulation value. In this study one "clo" is proposed as it equates to a business suit, an outfit worn by much of the population to work every day. One "clo" requires a rate of transfer of 5.55 Kcal per square meter skin surface area per hour for a one degree centigrade difference between skin temperature and ambient air temperature (Fukazawa et al, 2007). An objective value for clothing is important to quantify insulation properties of a piece of clothing independently. Wearing one clo of insulation will have an effect on heat production and preservation as clothing is a mediator for convective as well as radiative heat exchange (Havenith et al, 2002). It is therefore important to ensure consistency of posture as well as clothing during the trials.

2.7 Thermal Comfort Models

There are two main approaches to TC, the rational approach and the adaptive approach. The rational approach, also known as the heat balance approach, is based on data obtained from environmental chambers or laboratory based studies. The two main models used in this approach are the PMV model (Fanger, 1970) and the two-node model (Gagge et al, 1986). The adaptive approach involves work which has been carried out in the “real world” via field based studies (e.g. buildings, offices).

2.7.1 Rational Approach (Heat Balance Approach)

This approach was developed by Fanger (1970) in his PMV (Predicted Mean Vote) model. This approach is applicable to steady state conditions within a room and so will not work in a dynamic situation. The PMV value is a predictor of TC based on the ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers), TS scale (ASHRAE, 2005). Fanger’s approach to TS accounts for 6 main variables involved with TS, 4 physical (environmental) and 2 personal. The environmental conditions key for this are air temperature, mean radiant temperature, air velocity and relative humidity. It also assumes these are uniform. With clothing insulation and metabolic rate (activity level), accounting for the personal variables. This model yields a “Predicted Mean Vote” (PMV) index and “Predicted Percentage of Dissatisfied” (PPD) index. The PMV is the predicted mean thermal response in a large group of people and the PPD is the predicted percentage of people who are not satisfied with the thermal environment. Both the PMV and PPD are based on scores from the ASHRAE 7 point thermal sensation scale (Figure D1). There are issues with this method though as comfort is predicted from TS. However individual differences dictate that people will report TC and different TS’s. Whilst a score of “neutral” on the sensation scale might be comfortable for some, for others comfort may only be achieved at “warm”.

2.7.1.1 Predicted Mean Vote (PMV)

The PMV is obtained through asking a group of participants for their perception of the thermal environment via the ASHRAE 7 point thermal sensation scale (ASHRAE, 2005). The model was developed by exposing participants to a range of steady state temperatures and the mean sensation from the group at each temperature became the MV (mean vote). From this data Fanger developed an equation for PMV which is as follows:

$$\mathbf{PMV= [0.303exp(-0.036M)+(0.028)L]}$$

M= Metabolic Rate

L= Thermal Load

The PMV establishes the average response from a large population and takes into account heat flow from an individual and required heat flow in order to maintain optimum comfort.

2.7.1.2 Predicted Percentage of Dissatisfied (PPD)

Fanger (1970) found that in a population of 1300, the minimum percentage of people dissatisfied with the thermal environment was 5%. Anyone who replied with a score of “2” (warm) or above, or “-2” (cool) and below on the ASHRAE 7 point thermal sensation scale was classed as being “dissatisfied”. For 95% of the population, any participant who feels “neutral”, “slightly warm” or “slightly cool” is classed as satisfied. The relationship between PMV and PPD is outlined below.

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Figure 2. Relationship between PMV and PPD adapted from Fanger (1970).

Figure 2 shows the symmetrical nature of the relationship between PMV and PPD with the lowest PPD occurring when PMV is zero. When "neutral" sensation is reported for the predicted mean vote, only 5% of the population will be dissatisfied with the environment.

2.7.1.3 Two Node Model

The other main model to assess TC in buildings is the Pierce two-node model which was developed from Stolwijk general model (Stolwijk & Hardy, 1966) by Gagge et al (1971). It includes measures of both TS and thermal discomfort, acquired from effective skin temperature and skin wetness. This concept of skin wetness is important and it can provide a source of discomfort regardless of the temperature. It is recommended that skin wetness should be below 25% (Gagge et al, 1969). This model considers the human body to be in two parts or two cylinders. The inner cylinder represent the body's core temperature (37.1ºC) whilst the outer cylinder represents the body's skin temperature (33.1 ºC).

Both the PMV model (Fanger, 1970) and the two-node model (Gagge et al, 1986) have been found to be accurate for humans in steady state conditions whilst sedentary but accuracy of the PMV model decreases as exercise intensity increases (Doherty & Arens, 1988).

Both the PMV model (Fanger, 1970) and the two-node model (Gagge et al, 1986) are effective for evaluating thermally stable environments and have been extensively used in that setting. However they do not attempt to model TC in transient dynamic situations. They could be applicable at any one point in a dynamic protocol but were not designed to predict TC in an asymmetrical dynamic environment.

2.7.2 Adaptive Approach

The adaptive approach is derived from the study of TC in more realistic environments. Using data from field based studies rather than lab based studies (Humphreys, 1978). An advantage of this is participants are more comfortable to provide feedback in their own environment, wearing normal amounts of clothing and without any other restrictions (Cena & De Dear, 2001). This approach involves the researchers intervening as little as possible to enable thermal response within everyday life to be evaluated. Different TC models have been developed that include this approach, such as the adaptive predicted mean vote (aPMV) model (Yao, Li & Liu, 2009). They developed the aPMV after finding that the predicted mean vote (PMV) is greater than the actual mean vote (AMV) in summer, but less than the AMV in winter. The PMV considers the human body a passive component of the thermal surroundings and not an active part which interacts with the thermal environment via multiple feedback loops (Brager & de Dear, 1998). The aPMV considers local climate, lifestyle, cultural background and behaviour. It was found that in cool conditions aPMV was greater than PMV and in warm conditions aPMV was less than PMV. However Yao & Li & Liu

(2009) conducted the study in China, which has a different climate to the western world. Further studies using aPMV in different climates would be warranted.

The adaptive approach differs from the rational approach as it doesn't assume that a "neutral" TS score equates to optimal TC. Instead it takes into account participants' preference about the thermal environment which explains the differences between aPMV and PMV in the different seasons as discussed above. In summer, when the environment is warmer, participants prefer to be cooler than "neutral" on the TS scale. In winter, when the environment is cooler, participants prefer to be warmer than "neutral" on the TS scale.

Adaptive work could potentially be used to investigate IR panels in vehicles but there are issues with this. In order to ensure constant temperature conditions outside, adaptive work must be carried out in a climate with consistent weather conditions. With multiple trials being used this would be difficult to conduct within the UK and another country such as Spain which has more consistent warm weather would be more appropriate. However ideally a location which has consistently cool conditions would be used to investigate IR heating and it has a greater effect at lower temperatures.

These models are predominantly for use in static environments and the current study uses a dynamic pull up in air temperature. So the models wouldn't be suited for this protocol and highlights the need for studies such as these to be carried out rather than simulated using one of these models.

2.7.3 Vehicular comfort models

There have been a few models to predict TC specifically within vehicles. Han et al (2001) developed a physiological model consisting of 16 segmental body parts and incorporated solar load, solar incident angles, glass properties, air velocity, surrounding radiant heat and air temperature on occupant thermal comfort. A different approach using a psychological model called the Virtual Thermal Comfort Engineering Model (VTCE) has also been used (Han & Huang, 2005). However this is based on a Sports Utility Vehicle (SUV) environment and may not be appropriate for all types of vehicles. Thermal manikin based models have also been used within vehicles which involve a manikin which can elicit basic processes such as breathing, heating and sweating (Rugh & Bharathan, 2005). These models appear to be in good agreement with models using human subjects, apart from the head and the feet (Alahmer et al, 2011). IR thermography has been proposed as a promising tool to predict TC in vehicle cabins and has been used to measure surface temperature in transient conditions (Qian, Ishida & Saito, 1994). However, to date there are only a limited number of studies which discuss the use of IR thermography to evaluate thermal conditions in a car. In conclusion there are some models used to predict TC within a vehicle environment, however there is disagreement over the best way to assess TC and to the authors knowledge none of the models have been used to incorporate the use of IR heat panels in a vehicle.

2.8 Thermal Sensation

Thermal sensation is the apparent feeling about the thermal environment that people have. TS has strong links with TC (figure 3) as at a certain thermal environment, dictated by people's sensation, TC is achieved (Fanger, 1970). Many researchers consider that sensation scores between "-1" (slightly cool) and "+1" (slightly warm) as "comfortable" (Zhang, 2003). The main models to predict TS are the PMV and PPD developed by Fanger (1970), the same models used for TC. This is because in steady state conditions comfort and sensation are fairly similar and it's only in dynamic situations, when the body is out the thermo neutral zone that comfort and sensation vary more (Zhang & Zhao, 2009).

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Figure 3. The relationship between thermal comfort and sensation with regards to autonomic and behavioural human temperature regulation (Hensen, 1991).

It has been suggested that very few studies have examined TS of local body parts, especially identifying TS and comfort separately (Zhang, 2003). This is interesting to note as participants may score TS as “warm” and be “comfortable” or score TS as “cool” and be “comfortable” or other combinations of the scales. The two factors are not necessarily aligned, with neutral on one scale not necessarily matching up with neutral on the other scale.

It has been suggested that individuals may not prefer to feel neutral on this ASHRAE scale, as people in warmer environments may prefer to feel cooler and people in cooler environments may prefer to feel warmer (Humphreys, 1976). This is supported by Humphreys & Hancock (2007) who found that in 57% of the cases, the assumption that neutral was the desired TS on the ASHRAE scale was incorrect. They go on to advise that as well as taking TS measures, a measure of desired TS should be taken. The current study will seek desirability scores for the seat, face, lower leg and overall air to help identify the different areas of the body, as well as the magnitude of heating/cooling, the participants desire. It will be of use to inform the design and engineering of vehicle comfort systemsas to whether IR heating has direct local effects dependant on panel position, as well as any effect on a person's optimal TC, TS, desirability or magnitude of desirability.

Experimental studies still need to evaluate specific local inputs (IR) and potentially provide data to incorporate into a model which could calculate how the local body areas affected by IR relate to overall TC and TS.

2.8.1 Transient Thermal Sensation

Under steady state conditions, it is generally considered that TS scores further away from neutral are perceived as being uncomfortable. In transient conditions there is a different response. Participants who have been exposed to the heat (hyperthermia) or cold (hypothermia), perceive an additional heat or cooling source (in the opposite direction to the overall environment) aimed towards the hand, forehead and neck as being pleasant (Cabanac 1972; Attia & Engel, 1981). Also Zhang et al (2004) found that locally TC votes of "very comfortable" for the foot were only achieved when the whole body was either warm or cold and heating or cooling was applied to the foot in the opposite direction which helped relieve discomfort. Local comfort was shifted on the TS scale to either cooler or warmer than neutral depending on the body's thermal state. Locally high levels of comfort can be achieved in transient conditions even if the whole body is being heated/cooled. Using a ramp protocol

2.8.2 Desirability

As well as obtaining information about current TS, a need to find out about desired TS has led to a 3 point thermal preference scale being developed (McIntyre, 1980). It is therefore important in the present study to utilise a scale of thermal desirability. Oi et al (2012) used a similar 3 point scale to McIntyre (1980) to identify whether participants desired a "warmer" or "cooler" temperature. However, an expanded version of this scale, informed by consistent participant feedback during previous automotive thermal based work in our laboratory, is used in the current investigation (Appendix D3).

2.8.3 Acceptability

Another consideration is thermal acceptability i.e. how acceptable is the total thermal environment to an individual. Thermal acceptability has been found to be closely correlated to TC with scores of "comfortable" and "slightly uncomfortable" on the comfort scale falling into the "acceptable" range on the thermal acceptability scale (Zhang & Zhao, 2008).Acceptability of the thermal environment was reported prior to TC being reported for both uniform and non-uniform environments. TC is not necessarily required for an environment to be considered thermally "acceptable".

2.9 Infra-Red (IR) Heating

Using infrared as a heat source to improve human TC has not been widely reported in literature to date. In the built environment, Zeiler Vissers & Boxem (2013) conducted a study which investigated the use of infra-red heating systems on comfort to try and improve energy efficiency within a building environment. The Infra-red heat source was directed at the hands in an office style environment. The study found that local radiant heating at an power output of 98 W could maintain TC whilst the air temperature was dropped from 22 to 19.5ºC, resulting in a potential energy saving of 17%. In this study perceptual TC improved with a "human-in-the-loop" comfort strategy in place. This control strategy included a feedback loop which meant the radiant heat source was turned on when fingertip temperature dropped below 29 °C and was turned off when skin temperature exceeded 31.5 °C. Between these values it was hypothesised that TS would remain neutral or higher due to the participant remaining in the “thermo-neutral zone”. This demonstrates the potential for IR heating to be used within a vehicle.

The main gender differences in Zeiler et al’s (2013) study were that for some of the trial the female participants’ sensation dropped below neutral and also a warmer environment was preferred. The IR heating was activated for longer periods of time for the female compared to the male due to the finger skin temperature dropping below 29 ºC for much of the trial. A limitation of this study is that the protocol was only conducted using one male and one female participant. This means the data being collected for each gender is only from one person and so even an average across participants is not possible. There wasn’t a clothing insulation value (clo) reported for the participants in the study which could have affected thermal perceptions. These results cannot be said to be applicable across a certain population, office workers, as the sample size is too small to be an accurate representation of this population.

Zeiler’s study (2013) is one of the first studies to investigate IR heating on participant TC shows the proof of concept that IR has a positive influence on maintain TC with potential for energy savings in an office environment. The current study is trying to build on these findings and establish whether IR works in vehicles. One participant of each sex may have been used as there are known gender differences with cold extremities with women having higher thermal discomfort with cold extremities (TDCE) scores compared to men (Mozaffarieh et al, 2010). This variation is controlled for in the current study as only male participants were recruited. However the validity of Zeiler’s study may be compromised due to the small sample size.

IR heating within vehicles has only been shown to effectively warm up an occupant from a cold environment (-7 ºC) when used alongside convective heaters (Bäuml et al, 2014). When IR heaters were used in isolation, the areas of the body these were aimed at warmed up to comfortable levels quickly, with air temperature only rising to a maximum of 2 ºC. Other areas of the body, such as the feet, felt cold as IR panels only focused on the thigh and knee. TC was not achieved with IR heaters being used in isolation. Even with the convective heaters on, the feet still took nearly 30 minutes to be regarded as comfortable. This agrees with Arens et al (2006) who found foot temperature to be the coolest body part of the body in different conditions and to cause the main source of discomfort under cool conditions. However these tests were completed in an environmental chamber and not in a vehicle simulation. In relation to the PMV model mentioned earlier, until a point where the foot gets too hot, if foot TS increases this will increase foot TC. The feet are the main cause of overall discomfort in the cool so by eliminating this cold sensation overall TC can be improved.

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Degree Kelvin (K)

Figure 4. The position of the IR panels used in Bauml et al's (2014) stud . In t i image the 'dummy is b ing exposed to IR heating in isolation.

When IR heating in isolation was tested on a dummy, skin temperature did not reach comfortable levels. Although these results were validated on real people, the number of participants was not reported and so the reliability and validity of these findings is limited. In the Bäuml (2014) study, combination of IR and convective heating (section

2.5) was suggested to be the most efficient way to heat the car air cabin and achieve holistic TC (Figure 4). This was because skin temperatures were higher and feet became less cold. Although there was an IR panel toward the lower leg region, it highlights the potential for an IR heat source in the footwell area to be directed at the feet. Simulation results show the addition of IR potentially reduced the energy consumption of the vehicles heating system by 50%.

Figure 5 shows how TC can be maintained at lower ambient air temperatures with the use of IR heating. Less convective heating is potentially required which could result in a substantial energy saving. However they go on to state that only a combination of convective and radiant heating is effective for TC to be attained. It has to be stated that comfort is multi-factorial and factors such as conduction from the seat must also be considered.

Figure 5. Diagram representing the relationship between radiation/convective heating and thermal comfort (Bäuml et al, 2014)

2.10 Aims

The aim of the study is to evaluate the potential contribution of an infrared (IR) heat source to a car cabin occupant's thermal comfort during a dynamic warm up. In addition the impact of positioning the IR panel towards the upper compared to the lower body will be evaluated.

2.11 Hypothesis

It is hypothesised that during a dynamic car cabin warm up scenario (5-25°C) that IR heating, aimed towards the upper or lower body, compared to no IR heating will warm occupants quicker with TS values increasing at a greater rate. Accordingly it is hypothesised that IR heating will improve occupant TC compared to no IR heating. Likewise the occupant's desirability to change their thermal environment will be lower in the IR conditions compared to no IR. Finally it is hypothesised that local skin temperatures, incident to the IR heating, will be greater throughout the trial compared to NoIR. Therefore IR panel position dependent differences in local thermal sensation and comfort are hypothesised.

3.0 Methods

3.1 Experimental Design

8 healthy male participants (mean ± sd; age, 27±8 years; height, 176.0±0.05 meters; mass, 76.5±11.2kg; body mass index, 24.6±3.5 kg·m^2) volunteered to take part in the study. Each participant signed an informed consent form for the study. Ethical approval for this study was granted by Coventry University Ethics Committee. They were deemed healthy via a health questionnaire (Coventry University Sport Science and Physiology health screen questionnaire), on arrival prior to participation at each laboratory visit. In preparation for each visit participants were required to avoid alcohol for 24 hours before each trial and abstain from caffeine, avoid strenuous exercise and not smoke for 2 hours before the trial. None of the participants were smokers. Participants clothing was standardised to one "clo" of insulation, equivalent to a person wearing a business suit (Oi et al, 2012). In general the outfit people wore consisted of an undershirt, a long sleeved shirt, a jacket or sweat shirt, underpants, trousers, socks and training shoes. Participants wore exactly the same clothing on each occasion to ensure they were exposed to the same level of insulation across the three trials.

On arrival at the laboratory participants were instrumented according to sections 2.5.3, 2.5.4 and 2.5.5. Participants were required to make 3 separate visits to the environmental chamber. Each consisted of instrumentation, a 15 minute preconditioning period followed by a 40 minute experimental trial. The three conditions are listed below.

- NoIR- No Infra-red heating.
- IRV- IR heating in a panel situated in the visor position of a vehicle
- IRF- IR heating in a panel situated in the foot well position of a vehicle

Participants visited the chamber at the same time of day for each trial; either 9am, 12pm or 4pm.

The NoIR and IRV trials took place in a balanced cross-over design in Nov/Dec 2015. A ‘single blind’ approach was applied to the trials (Figure 6A). The IRF trial was conducted in Jan 2015 using the same participants (Figure 6B).

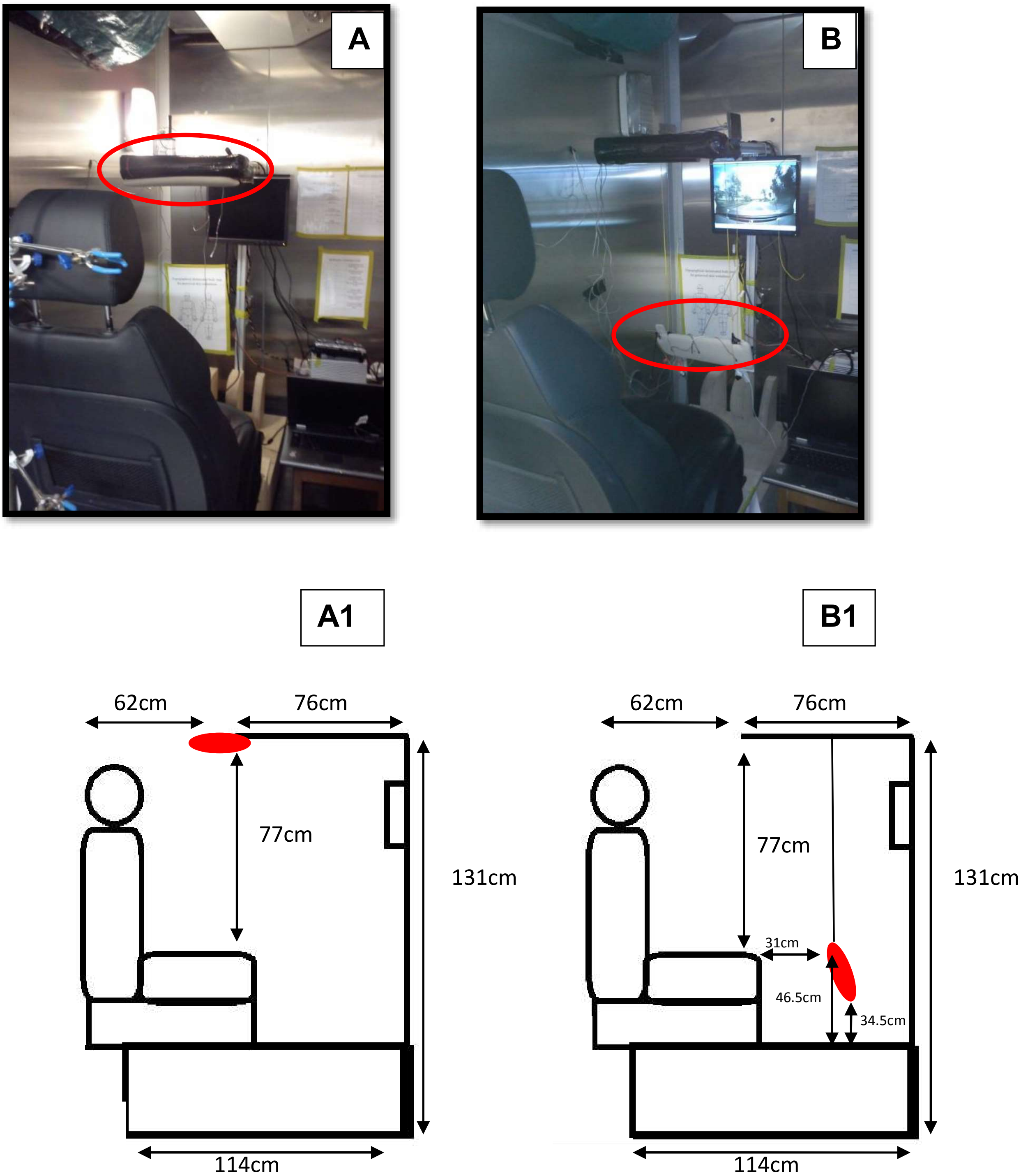

Figure 6. Instrumented environmental chamber, A) IRV (Infra-Red Visor) trial photo, A1) IRV trial schematic, B) IRF (Infra-Red Footwell) trial photo and B1) IRF trial schematic. IR (Infra-Red) panel position and dimensions are indicated for each trial.

3.2 Physiological Measures

3.2.1 Heart Rate

Heart rate was monitored with a chest strap and recorded via telemetry on a wrist watch (Polar FT1, Sweden). HR was taken at 5 minute intervals during preconditioning (section 3.3) and at 2 minute intervals during the 40 minute experimental trials (section 3.3.1).

3.2.2 Core temperature

Core temperature was measured by a rectal thermistor and an aural thermistor. On arrival to the chamber participants were instructed to privately insert the medical grade rectal thermistor (FF, Edale, Instruments Ltd, Cambridge, UK) 10cm past the rectal sphincter. Each participant used the same rectal thermistor on each visit after it had been cleaned with disinfectant (Virkon). The aural thermistor(FF, Edale, Instruments Ltd, Cambridge, UK) was cited in the participants' ear canal and again was kept consistent throughout the trials. Both thermistors were attached a to an Eltek Gen II wireless data logging system (Eltek Ltd, Cambridge, UK). Data were logged at 10 second intervals.

3.2.3 Skin Thermistors

Skin thermistors were sited on 20 sites around the body (figure 7) and fixed on with medical grade breathable tape (MED5560, PolarSeal, Saxmundham, UK). The cites used were as follows; Nose, forehead, chest, forearm (right), upper arm (right), hand (right), 2nd finger (right), upper back (right and left), lower back (right and left), buttocks (right and left), posterior thigh (right and left), anterior thigh (right), lower leg (medial and lateral), foot (right) andtoe (right). The thermistors were connected to a Squirrel data logger (2020 Series, Grant Instruments Ltd, Shepreth, UK). Data were logged at 10 second intervals.

Two methods of calculation mean skin temperature were used (Ramanathan, 1964; Oi et al, 2012). Ramanathan's calculation was as follows:

msk = 0.3 (chest + arm) + 0.2 (thigh + lower leg)

Oi et al's (2012) calculation, as shown below, uses 15 different body parts including areas which were in contact with the seat.

T_{sk} = {7(T1) + 17.5(T2) + 14(T3) + 5(T4) + 9.5(T5) + 13(T6) + 7(T7)

+ 3.375(T8) + 3.375(T9) + 3.375(T10) + 3.375(T11) + 3.375(T12)

+ 3.375(T13) + 3.375(T14) + 3.375(T15)}/100

Where component temperatures are: T1, forehead; T2, chest; T3, forearm (left); T4, hand (left); T5, anterior thigh (left); T6, leg (left); T7, foot (left); T8, upper back (right); T9, upper back (left); T10, lower back (right); T11, lower back (left); T12, buttocks (right); T13, buttocks (left); T14, posterior thigh (right); and T15, posterior thigh (left).

3.2.4 Heat Flux

Four heat flux sensors (gSKIN –XB 26 9C, greenTEG, AG, Zurich, Switzerland) were attached to the participants using microporous tape (figure 8) . They were cited on the forehead, nose and lower leg (medial and lateral). The sensors were connected to a Squirrel data logger (2020 Series, Grant Instruments Ltd, Shepreth, UK). Data were logged at 10 second intervals. They were sited so that they would give a positive value indicating heat transferred from the body to the environment as opposed to a negative value which would indicate net heat gain to the body from the environment. Each heat flux value was multiplied by a specific calibration factor supplied by the manufacturer to obtain a precise value.

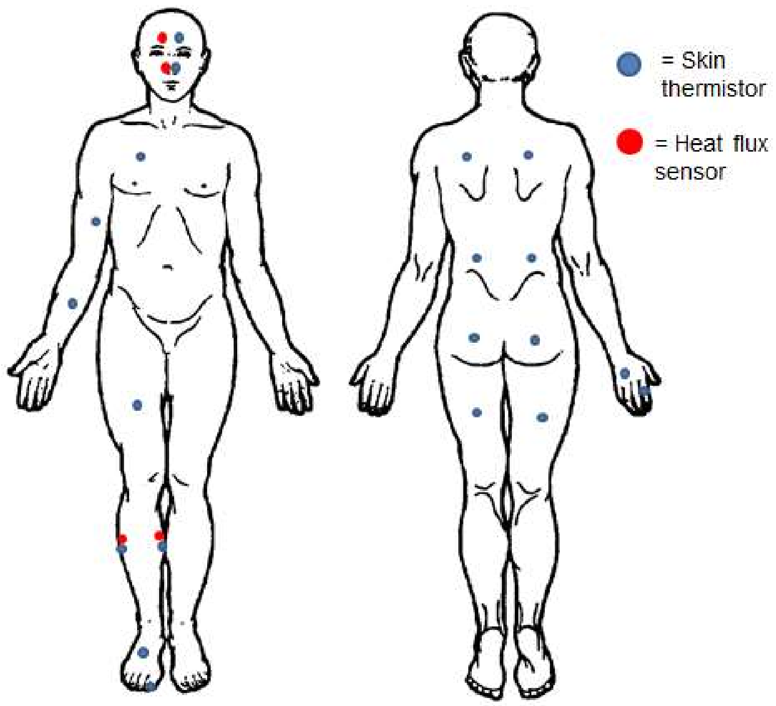

Figure 7. Skin thermistors and the heat flux sensors on the participant.

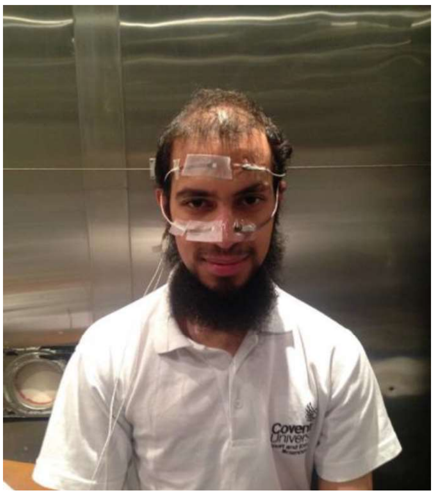

Figure 8. A participant instrumented with skin thermistors and heat flux sensors.

3.3 Subjective Measures

Subjective measures were collected at -15 -10 and -5 minutes in preconditioning and at 2 minute intervals throughout the 40 minute experimental trial. Desirability and acceptability measures were only collected during the 40 minute “pull up” protocol(section 3.3.4) and not during preconditioning (section 3.3.2).

3.3.1 Thermal Comfort

TC measures were verbally reported on a 7 point scale (ASHRAE, 2004). The scale was as follows; -3, very uncomfortable; -2, uncomfortable; -1, slightly uncomfortable; 0, neutral; +1, slightly comfortable; +2, comfortable; and +3, very comfortable (appendix D1). TC was sought for head, face, nose, chest and arms, hands, area of the body in contact with the seat back, area of the body in contact with the cushion, lower leg, feet, toes and overall.

3.3.2 Thermal Sensation

TS measures were sought immediately after all the TC questions. An adapted 9 point version of the ASHRAE scale was used which included measures of very cold and very hot. The scale was as follows: -4 very cold; -3, cold; -2, cool; -1, slightly cool; 0, neutral; +1, slightly warm; +2, warm; +3, hot; +4 very hot (appendix D2). TS was sought for the head, face, nose, chest and arms, hands, area of the body in contact with the seat back, area of the body in contact with the cushion, lower leg, feet, toes and overall. An average TS was also calculated from the different body parts.

3.3.3 Thermal Desirability

Thermal desirability was taken on a 7 point desirability scale for the face, lower leg, the seat and the ambient air (appendix D3).The face and lower leg were selected as these areas were considered to potentially be effected by the IRV and IRF trials.The scale was as follows; -3, “a significantly higher temperature would be better”; -2, a “higher temperature would be better”; -1, “a slightly higher temperature would be better”; 0, “the current temperature is fine”; and +1, “a slightly lower temperature would be better”; +2, “a lower temperature would be better”; +3 “a significantly lower temperature would be better”. The scale was expanded from Oi’s (2012) 3 point desirability scale which only included a warmer, cooler or temperature is fine options. The 7 point scale used indicates the magnitude of heating/cooling participants feel they require

3.3.4 Acceptability

Thermal acceptability was noted on a visual analogue scale (used by Zhang et al, 2007). The scale runs from; -1 ‘Clearly unacceptable’ to 0 ‘Just unacceptable’ and 0 ‘Just acceptable’ to +1 ‘Clearly acceptable’ (appendix D4). The participants noted how acceptable the total thermal environment was on the scale with a pen. The same scale was used within each trial and enabled participants to track their change in perception over time.

3.4 Equipment

3.4.1 Environmental Chamber

The trials were conducted in an environmental chamber (figure 9 ; dimensions; 2.5m wide by 3m long by 2.1m high), located within the Engineering and Computing Building at Coventry University. The chamber consisted of 2 separate rooms, chamber 1 and 2. Chamber 1 (used for preconditioning) was around twice the size of chamber 2 (experimental trial). To negate and possible radiant heat from the lights, 4 temporary LED lights were fixed to the walls. This helped to illuminate the chamber and enabled participants to clearly have sight of the subjective scales used.

Figure 9. The environmental chamber used in the study.
Chamber 1 and chamber 2 are clearly indicated on the figure.

3.5 Procedure

3.5.1 Preconditioning

Participant instrumentation, as outlined in 3.5, took place in chamber 1 prior to preconditioning. Chamber 1 was also used for the 15 minute preconditioning period (environmental conditions; temperature 22°C and relative humidity (RH) 35%). Participants were seated on a cushioned office chair throughout this period. The total time participants spent at 22°C was approximately 30-45minutes.

3.5.2 Experimental Protocol

After the 15 min preconditioning period participants were escorted to chamber 2 (temperature 5°C and RH 35%), to stand for 3 minutes in order to simulate the transition period from moving from a building to a vehicle (Oi et al, 2012). After this 3 minute period participants were seated on an ‘XVS’ seat fixed to plywood ‘buck’. Prior to the trials each participant moved the seat into a comfortable position and this was then noted on the buck with a pencil and kept the same across the 3 trials. The dimensions of the pedals were aligned to those in a Range Rover Evoque. The buck incorporated a seat with a battery power supply to enable it to be moved to the participants preferred position (figure 10). Participants were instructed to rest their feet on the pedals. The plywood buck enabled the IR panel to be placed in the visor position for the IRV trial (figure 6A) and suspended near the foot well position for the IRF trial (figure 6B), according to the geometry of the Range Rover Evoque.

Figure 10. The buck with the car seat used in the study (supplied by Jaguar Land Rover).

3.5.3 Pull Up

Immediately after the 3 minutes standing exposure, participants were seated and exposed to a dynamic “pull up” protocol where the ambient air temperature rose from 5°C to 25°C over a 40 minute period. This equated to a rise of 1°C every 2 minutes.

The participant was seated throughout the 40 min period and watched a driving simulation video to maintain a forward gaze throughout. This was to ensure the IR panels would have an equal effect on both sides of the body to ensure a consistent symmetric exposure.

A dynamic protocol was used in order to simulate how a vehicle currently heats up and to help identify a precise temperature TC was achieved. Static temperatures could also have been used to test this device, but this isn't as realistic within a car cabin situation in cold conditions in a warm up phase.

3.5.4 Environmental conditions

Environmental conditions within the chamber were recorded by temperature data loggers (EL-USB-2-LCD, Lascar electronics, UK). Two of these loggers were placed in chamber 1 to measure the temperature which was set at 22°C. Three loggers were placed in chamber 2 (Head height, chest height, foot level) to record the temperature rise from 5°C to 25°C over a 40 minute period. To establish globe temperature, a thermistor (EUL, Edale, Instruments Ltd, Cambridge, UK), cited within a black plastic casing, was attached to an Eltek Gen II wireless data logging system (Eltek Ltd, Cambridge, UK). All this environmental data was logged at 10 second intervals. During preliminary work, numerous different chamber heating programs were run to enable a reliable "pull-up" protocol to be established.

3.5.5 IR Panel Instrumentation

The IR panel had a surface area of approximately 0.55m^2 and was positioned within a sun visor (Qpunkt, Germany). The visor was fitted with three thermistors (EUL, Edale, Instruments Ltd, Cambridge, UK) attached to an Eltek Gen II wireless data logging system (Eltek Ltd, Cambridge, UK). One thermistor was cited in the centre of the visor with the other two being positioned 10cm either side (figure 11). A heat flux sensor (gSKIN –XB 26 9C, greenTEG, AG, Zurich, Switzerland) was also attached to the centre of the visor. This was also sewn on and connected to a data logger (Squirrel 2020 Series, Grant Instruments Ltd, Shepreth, UK). It was positioned so it would produce a positive heat flux value when measuring the heat being transferred from the panel to the environment. The IR panel was powered via a 12V regulated DC power supply and controlled via DSPACE control hardware according to the 'IR Heater Setup User Guide' supplied by Jaguar Land Rover (JLR). The IR panel drew 4 amps at 12V and thus had a power usage of 48 Watts. The temperature of the IR panel within the visor was controlled to reach a maximum temperature of 90°C. However during Instrumentation the surface visor temperature heated up to a maximum temperature of 60°C. Participants were informed to not touch the visor at any point during the trial. At 60°C the panel was hot to touch but if accidental contact did occur, no serious harm would be caused. No such events occurred. The IR panel was a prototype and was not an optimised system in regards to heating up. There was approximately a 15 minute lag to reach optimum temperature. Therefore, in the IR trials, the panel was turned on 15 minutes prior to participants sitting down on the chair. If the panel had only been turned on once participants were seated then the potential benefit of the IR heating would have been lost at the lower temperatures of the dynamic "pull up" protocol.

Figure 11. The IR panel used in the study with three thermistors and a heat flux sensor attached.

3.5.6 Seat Instrumentation

Four thermistors (EUL, Edale, Instruments Ltd, Cambridge, UK) were fixed to the seat and attached to an Eltek Gen II wireless data logging system (Eltek Ltd, Cambridge, UK). Two thermistors were placed on the seat cushion, to correspond with the left and right buttock when sitting, and two on the seat back to correspond with the left and right lower back when seated.

3.6 Data Management and Statistical Analysis

3.6.1 Temperature data

After downloading all the logged data files (skin temperatures, core temperatures, heat flux, seat temperatures, air temperatures and visor temperatures), relevant data were manually selected and moved to Microsoft excel (Microsoft Office 2010). A preconditioning master file and an experimental trial master file were created. Both incorporated columns where mean skin temperatures and heat flux values were calculated. Mean values and standard deviations for temperature data at each time point to correspond with the timing of subjective data were calculated and graphs were plotted.

3.6.2 Subjective Data

The subjective data (thermal comfort, sensation, acceptability and desirability) was typed into Microsoft Excel from the raw data sheets. Only one master file was created, with different tabs for preconditioning and experimental trials. Mean and SD were calculated and graphs for the subjective data were created.

3.6.3 Statistical Analysis

The data were imported to Minitab version 17. Initially normal probability plots were created to check the data for normality. One factor repeated measures of variance (ANOVA) was used on the data from the last minute of preconditioning in order to ensure participants started the experimental trials at the same physiological state each time.

Experimental trial data were analysed using a two factor repeated measures ANOVA. Effect sizes (partial eta-squared, η_p^2) were calculated from the ANOVA table sum of squares (η_p^2 = SS effect/(SS effect + SS error). This attributes the proportion of the variance in the dependant variable to the factor in question. This approach helps give context to any significant differences resulting from collecting data at multiple time points where differences are actually very small. Effect sizes greater than 0.50 were interpreted as large, effect size of 0.50-0.30 as medium, effect size of 0.30-0.10 as small, and those < 0.10 as trivial. It is however noted that effect sizes should be interpreted dynamically (Fröhlich et al, 2009).

Regression equations were calculated to estimate the average time taken for a "0" score (neutrality) to be reported. The data used for this were determined by visual inspection. A regression equation for the whole 40 minute trial would not have provided an accurate estimation of the time a "0" score was reported. For overall comfort, overall sensation and total acceptability, data indicated a linear response over the first 24 min period in all trials. For thermal desirability a linear response was present throughout the 40 minute period and so regression was calculated for the full trial for this response. Linear regression was undertaken on average subjective data (Overall thermal comfort, sensation, air desirability and total acceptability) in excel.Graphs with lines of best fit in excel were created for all the variables mentioned with regression equations and r^2

values noted on the graphs. The data was then imported into Minitab where it was statistically analysed using a general linear model via a univariate ANOVA.

4.0 Results

Preconditioning data are shown at 5-minute intervals (table A1- A3) with data from the experimental trial for 2-minute intervals (table B1-B9).

4.1 Participant Preconditioning

Air temperature (21.8±0.4°C) and relative humidity (36.2±7.1%) at chest level (whilst seated) were consistent throughout the 15 minute preconditioning period of each experimental trial (Table A1).

TC scores throughout the preconditioning period are shown in table A2 with end values shown in table 1. Mean values for all areas of the body were generally between "1" and "2" (slightly comfortable and comfortable).Values for the lower leg, feet and toes were slightly less comfortable with end values between "neutral" and "slightly comfortable". End point TC scores varied between individuals for all areas of the body ($P \leq 0.001$).

TS scores for the preconditioning period are outlined in table A3 along with the SD's with the end values highlighted in table 1. TS scores did not vary between trials ($P>0.05$). Generally scores fell between 0 ("neutral") and 2 ("warm"). End point TS scores as also varied between participants across all body areas except the hands ($P<0.01$ to $P<0.05$). Mean heart rate at the end of the 15 minutes preconditioning for all trials (73±9 $b \cdot min^{-1}$) was consistent but varied between participants ($P<0.05$).

Core temperature, mean skin temperature and heat storage data for the end of preconditioning are shown in Table 2 (table A4). Rectal temperature was significantly different between trials (mean end points: NoIR, 37.3°C; IRV, 37.2°C; IRF 37.1°C) with post hoc tests revealing a difference between NoIR (n=8) and IRF (n=6; $P<0.05$). There was a medium effect size (η_p^2 =0.43). In absolute terms the mean differences in rectal temperature were <0.2°C across all conditions. Across the entire data set it was considered that any differences were of no biological significance differences and within normal variation.

These data indicate that participants were consistently preconditioned by the end of the 15 minute period.

Table 1. Thermal comfort and sensation (mean ± SD) after 15 min preconditioning; No Infra-Red (NoIR), Infra-Red Visor (IRV) & Infra-Red Footwell (IRF).

Subjective Response	Time (min)	Trial	Head	Face	Nose	Chest & Arms	Hands	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
Thermal Comfort	0	NoIR	1.5±0.9	1.4±1.1	1.3±1.2	1.6±0.9	1.4±1.1	1.6±0.9	1.6±0.9	1.0±1.2	1.1±1.4	1.1±1.4	1.4±1.2	1.4±1.0
		IRV	1.5±0.9	1.5±0.9	1.3±0.9	1.4±1.1	1.3±0.9	1.3±0.9	1.3±0.9	1.1±0.8	1.0±0.9	1.0±0.9	1.3±0.9	1.3±0.8
		IRF	1.3±1.0	1.2±1.0	1.0±1.1	1.3±0.8	1.0±1.1	1.2±1.0	1.3±0.8	0.8±1.3	0.7±1.5	0.8±1.5	1.0±1.1	1.1±1.1
Thermal Sensation	0	NoIR	1.0±0.9	1.1±0.8	1.0±0.9	1.3±0.9	1.0±1.2	1.3±0.9	1.3±0.9	0.6±1.1	0.6±1.4	0.5±1.3	1.1±1.0	1.0±0.9
		IRV	0.5±1.1	0.6±0.9	0.5±1.1	0.9±1.0	0.8±0.9	0.9±0.8	1.0±0.9	0.4±1.1	0.3±1.2	0.3±1.2	0.6±0.9	0.6±0.9
		IRF	0.8±0.8	0.8±0.8	0.7±0.8	0.8±0.8	0.5±0.8	1.2±0.4	1.0±0.6	0.3±1.2	-0.2±1.2	0.5±1.4	0.7±0.8	0.7±0.7

Table 2. Core temperature, mean skin temperature and heat storage (mean ± SD) after 15 min preconditioning; No Infra-Red (NoIR), Infra-Red Visor (IRV) & Infra-Red Footwell (IRF). Mean skin temp[1] Ramanathan, [2] Oi et al.; Heat storage[1,2] Ramanathan using rectal and aural temp, Oi et al.[3,4] using rectal and aural, respectively.

Time (min)	Trial	Rectal (°C)	Aural (°C)	Mean skin temp[1] (°C)	Mean skin temp[2] (°C)	Heat storage[1] ($J \cdot g^{-1}$)	Heat storage[2] ($J \cdot g^{-1}$)	Heat storage[3] ($J \cdot g^{-1}$)	Heat storage[4] ($J \cdot g^{-1}$)
0	NoIR	37.3±0.2	36.1±0.5	32.2±0.5	32.1±0.3	0.1±0.2	1.2±2.0	0.1±0.2	1.2±2.0
	IRV	37.2±0.3	36.0±0.5	32.2±0.7	31.9±0.4	0.2±0.4	0.4±0.5	0.1±0.2	0.3±0.3
	IRF	37.1±0.2	35.6±0.7	31.8±0.6	32.1±0.6	0.1±0.4	0.2±0.4	0.2±0.3	0.3±0.3

4.2 Experimental Trial

4.2.1 Environmental conditions

Temperature and humidity data throughout the experimental trial are shown in table B1. There was a significant difference ($P<0.001$) between trials during the dynamic pull up for globe temperature (mean: NoIR, 4.0°C to 23.6°C; IRV, 4.5°C to 23.4°C; IRF, 4.1°C to 23.9°C). Although on visual inspection the globe temperatures (figure 12) appear similar, statistically there were significant differences between conditions (table B1). There were vertical air temperature differences of around 1.5-2°C, with the hottest temperatures being recorded at head level and the coolest temperatures at foot level. Relative humidity was about 60% at the beginning of the trial and 40% at the end of the 40 minutes. However it peaked about 80% with the highest scores falling between 8°C and 20°C. However humidity did follow the same trend throughout the different trials. The effect sizes for all environmental data were all <0.2 which is considered to be a small effect. This analysis confirms the reproducibility of the environmental conditions between trials.

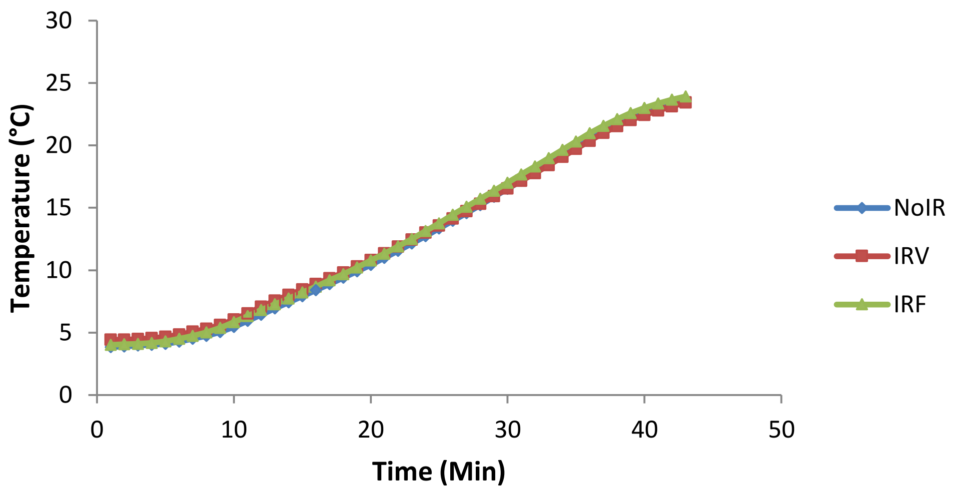

Figure 12. Mean globe temperature throughout the experimental trials (3 min standing at ≈5°C followed by 40 min "pull up"); No Infra-Red (NoIR), Infra-Red Visor (IRV) & Infra-Red Footwell (IRF). Error bars are omitted for clarity. For values ± SD's see table B1.

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4.2.1.1 Water Vapour Pressure

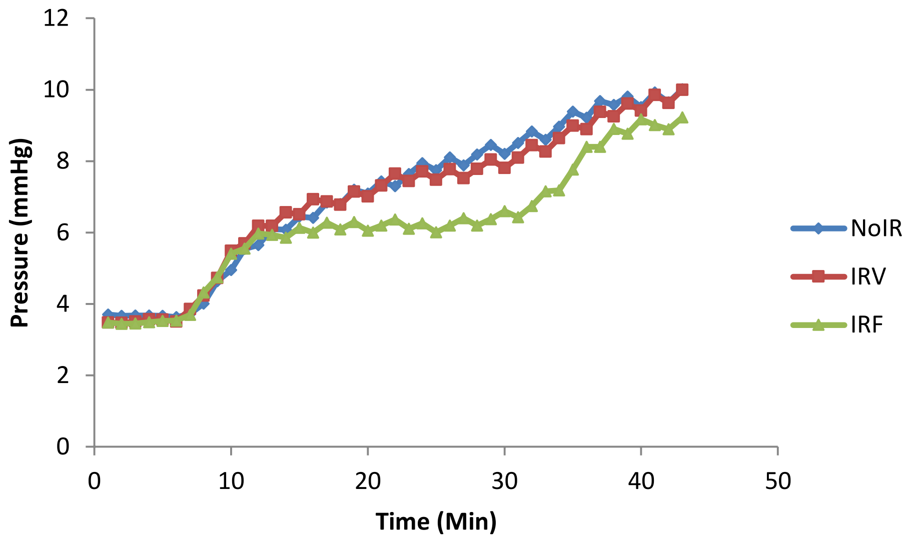


Figure 13. Mean vapour pressure throughout the experimental trials (3 in stan ing at ≈5°C followed by 40 in “pull up” · Infra-Red (NoIR), Infra-Red Visor (IRV) & Infra-Red Footwell (IRF). Error bars are omitted for clarity.

Vapour pressure increased as the temperature increased and followed the same pattern for all conditions. However between 15-35min vapour pressure tended to be lower in IRF but was only ≈2mmHg difference.

4.2.2 IR Panel Visor Temperatures

IR panel temperatures varied for all sites across the panel (left, middle and right) between the trials but generally followed the same trend ($P<0.001$; refer to table B2 for values ± SD). Values for the middle of the panel tended to be greater than those closer to the extremity of the panel and are shown in figure 14. In the NoIR trial the temperature rose in line with the ambient air temperature. In both IR trials the panel temperature was clearly greater than in the NoIR trial ($P<0.001$). Panel temperatures in the IR trials also increased with air temperature to around 68°C, with slightly higher values recorded in IRV compared to IRF ($P<0.001$) and also reflects the vertical air temperature difference noted above.

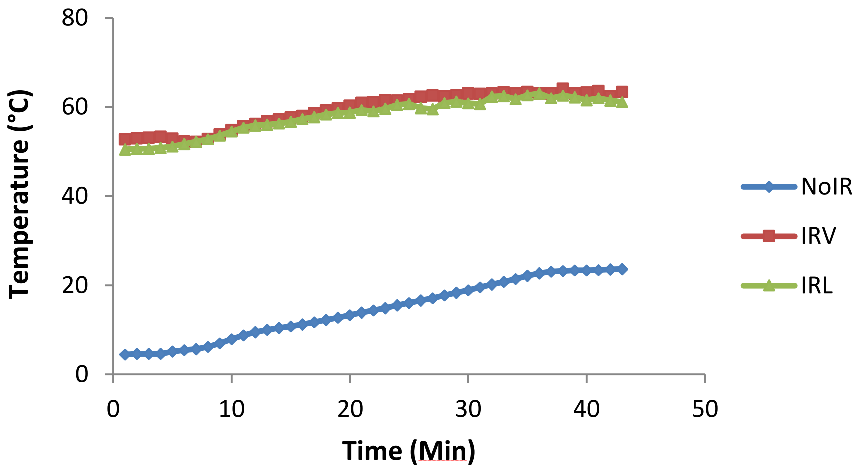


Figure 14. Middle of the visor temperatures (mean) throughout the experimental trials; No Infra-Red (NoIR), Infra-Red Visor (IRV) & Infra-Red Footwell (IRF itted for cla it . lues ± SD's see table B2.

4.2.3 IR Panel Heat Flux

IR panel heat flux (HF) values are given in table B2 and are shown in figure 15. Due to instrument error/malfunction there was no usable data for the IRF trial. Heat flux from the visor declined within the exposure with the highest heat flux levels in the IRV trial (≈1100 W·m^2) occurring at 6 minutes and gradually declining in the final 20 minutes of the trial with the final value ≈870 W·m^2. However, due to the slightly lower visor temperature scores in IRF (due to vertical air temperature differences), along with the presumption that heat production was the same for both IR trials, it can be assumed that heat flux for IRF would be slightly higher to IRV.

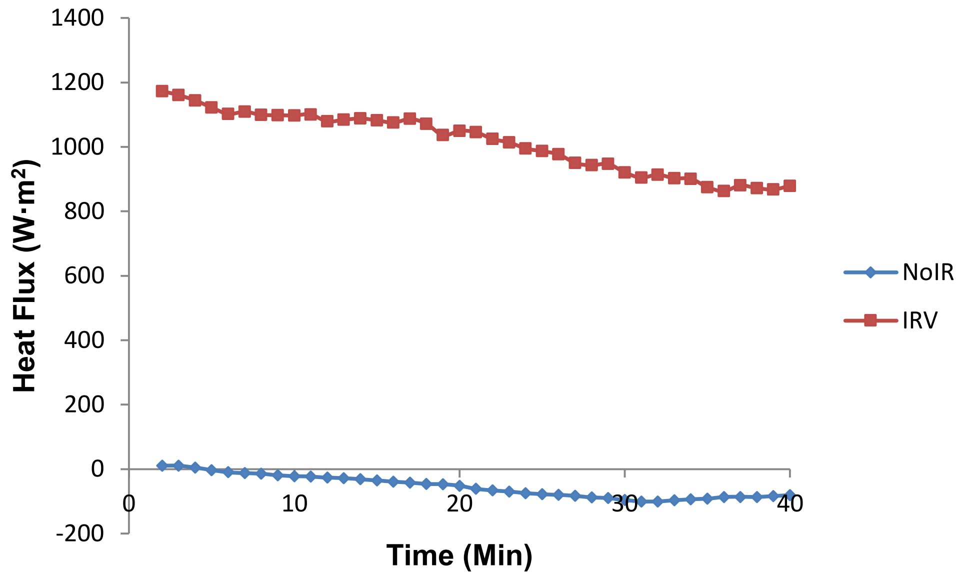


Figure 15. Mean middle of the visor heat flux values throughout the experimental trials; No Infra-Red (NoIR) & Infra-Red Visor (IRV) & Infra-Red Footwell (IRF). IRF values are not useable and so are omitted for clarity. Error bars are o itted for cla it . lues ± SD's see table B .

4.2.4 Car Seat

Car seat temperatures initially matched that of the air temperature (≈5°C) for the initial 3 minute period for which the participants were standing (table B2). Once the participants were seated, as expected the seat temperatures rose rapidly in the first 10 minutes and continued to rise throughout the trial, peaking at 40 minutes (≈27-31°C) for all trials. The hottest area of the seat was the area in contact with the left buttock and the coolest part of the seat was the area in contact with the left lower back. There were IR dependant panel differences with slightly higher values for the seat left lower back in the IRV condition. There were significant differences for car seat temperature between all trials (P<0.001). For seat left buttock, seat right buttock and seat right lower back there were small/trivial effect sizes (η_p^2 = 0.04, η_p^2 =0.19 and η_p^2 =0.10 respectively) with a large effect size for seat left lower back (η_p^2 =0.51).

4.3 Rectal, Aural & Mean Skin Temperatures

Rectal temperature decreased from ≈37.1-37.2°C to ≈36.9°C throughout all trials (figure 16; table B6). The greatest reduction occurred in the final 20 minutes of the trial. There was a significant difference between IRV and IRF for rectal temperature ($P<0.05$) however the effect size (η_p^2 =0.01) confirmed this to be trivial. Rectal temperature for NoIR and IRV were higher for the first 20 minutes of the trial compared to IRF with temperatures converging towards the end. Aural temperature was more variable with a decrease of ≈0.3-0.5°C in the first 20 minutes of the trial and an increase in line with ambient air temperature in the second half of the trial with all trials finishing 0.3°C higher compared to the first two minutes of the trial (table B6). Although aural temperatures in NoIR and IRV were slightly higher than IRF these differences were confirmed to be trivial (η_p^2 =0.03).

Both calculations of mean skin temperature, 4 site method and 15 site method, showed an initial decrease in temperature to ≈30°C after around 10 minutes in all trials (figure 17). This was followed by a steady increase in temperature for the final 30 minutes of the trial with the 40 minute temperature around 1-2°C warmer compared to initial values at the start of the trial. Mean skin temperature was higher in NoIR compared to both IR trials for each method ($P<0.001$). However the effect size (η_p^2 =0.24) was small. Significant differences were noted between all trials for both methods ($P<0.001$) apart from between the two IR trials in Oi's 15 site method ($P>0.05$).

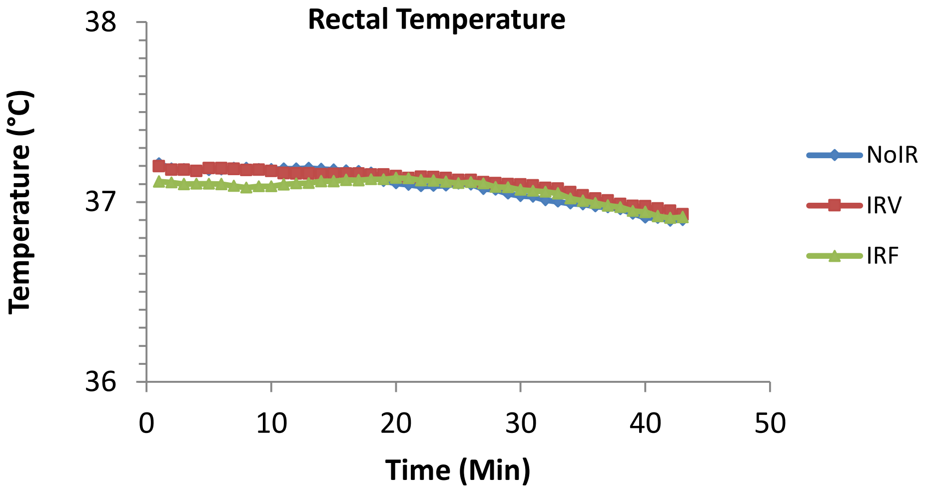


Figure 16. Mean rectal temperature throughout the experimental trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Error bars are omitted for cla it . lues ± SD's see table B .

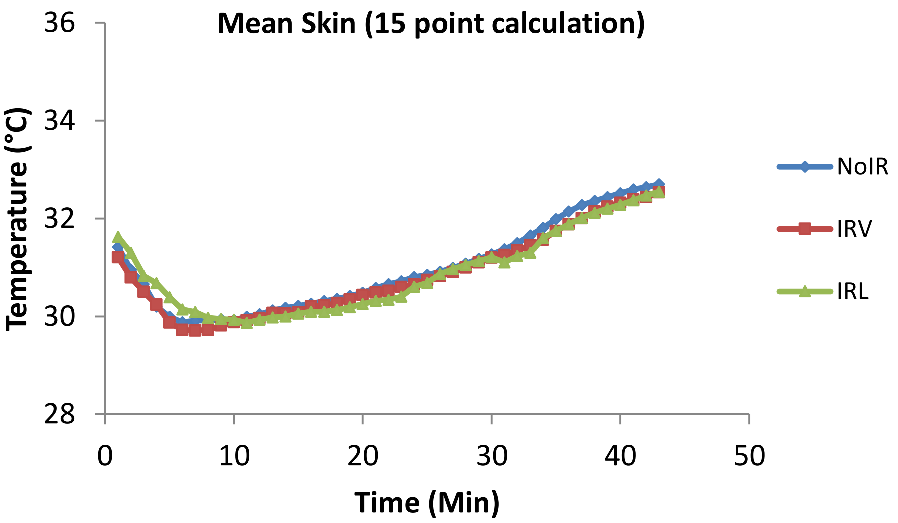


Figure 17. Mean s in temperature calculated u ing i's 15 ite method throughout the experimental trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Error bars are omitted for clarity. For values ± SD's see table B .

4.4 Body Area Temperatures

Upper body skin temperatures are reported in table B7 and lower body skin temperatures in table B8. Skin temperatures decreased in the initial phase of the trial and then after 40 minutes had increased either back to initial values or higher. All skin temperatures were significantly different between trials ($P<0.05$) apart from the hands ($P>0.05$). Post hoc tests revealed that inner lower leg temperature was warmer in the IRF trial compared to IRV and NoIR (IRF vs IRV, $P<0.001$; NoIR vs IRF, $P<0.001$) However the outer lower leg temperature was warmer in NoIR, and similar in IRV, compared to IRF. In the IRF condition inner lower leg temperature was higher than outer lower leg temperature whereas for NoIR outer lower leg temperature was higher than inner lower leg. For IRV the inner and outer lower leg temperatures were similar. Toe temperature was consistently the coolest lower body temperature throughout the trials. Anterior thigh values followed the same pattern with an initial decrease in the first ≈5-10 min and then an increase for the rest of the trial. Again there were differences between trials ($P<0.001$) with post hoc tests revealing highest values for IRV ($P<0.001$) and lowest values for IRF ($P<0.001$).

In terms of upper body temperature, the hands, finger and nose were the coldest, although these temperatures improved and ended up a lot warmer than the lower body extremities (e.g.≈5-9°C warmer compared to toe temperature). Finger temperature initially decreased from ≈27-28°C to ≈20-23°C in all trials and then increased to ≈30-34°C by the end of the trial for all conditions. Highest finger temperature values were in IRV ($P<0.001$) with end values ≈6°C higher than initial temperatures. Areas of the body in contact with the seat back declined during the initial 5-10minutes of the protocol and then increased, often reaching initial values by the end of the 40 minute trial. Lower back (left & right) temperatures were significantly warmer in the IRF condition compared to NoIR and IRV ($P<0.01$ to $P<0.001$) Initial lower back values were around 1°C warmer in the IRF condition but by the end on the trial temperatures were similar across all conditions.

4.5 Heat Flux

Heat flux data are reported in table B9. Heat flux for all body areas (forehead, nose, inner lower leg and outer lower leg) decreased throughout the trial as ambient air temperature increased. Forehead and inner lower leg heat flux were both higher in NoIR compared to the other conditions. Forehead heat flux was also significantly different between all combinations of trials (Figure 19: $P<0.001$). NoIR had the highest heat flux values and IRF the lowest. Outer Lower Leg Heat flux was significantly higher in IRF compared to IRV and NoIR (IRF vs IRV, $P<0.001$; NoIR vs IRF, $P<0.001$). Nose heat flux declined at the greatest rate in the first 10 minutes of the trial (≈600 to ≈200 $W \cdot m^2$) before steadying out around 150 to 200 $W \cdot m^2$ across all conditions. There were significant differences between all conditions for inner lower leg heat flux ($P<0.001$ to <0.05) with NoIR consistently higher than both IR trials (Figure 18).

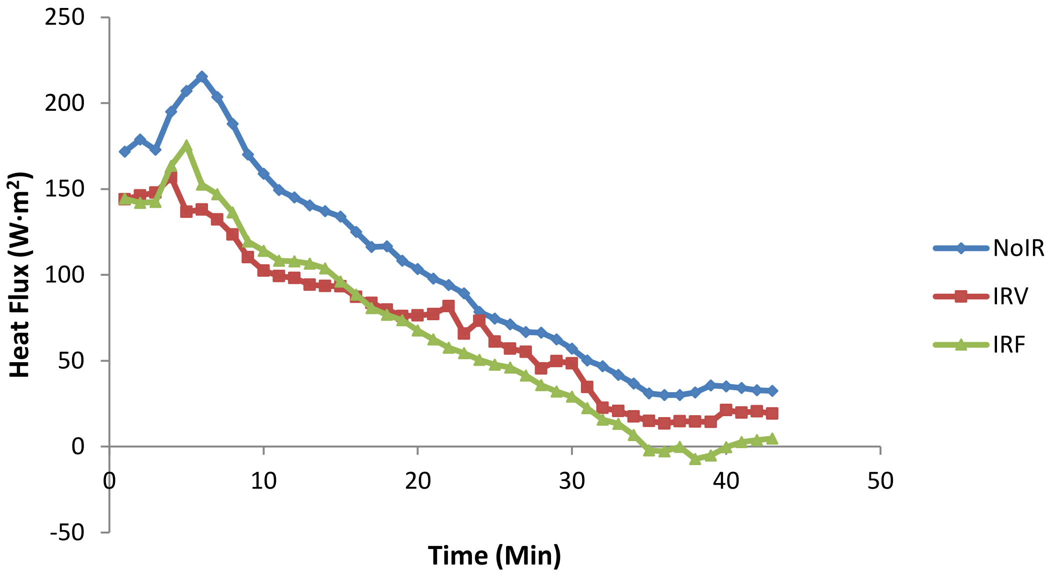


Figure 18. Mean Inner lower leg heat flux throughout the experimental trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Error bars are omitted for cla it . lues ± SD's see table B .

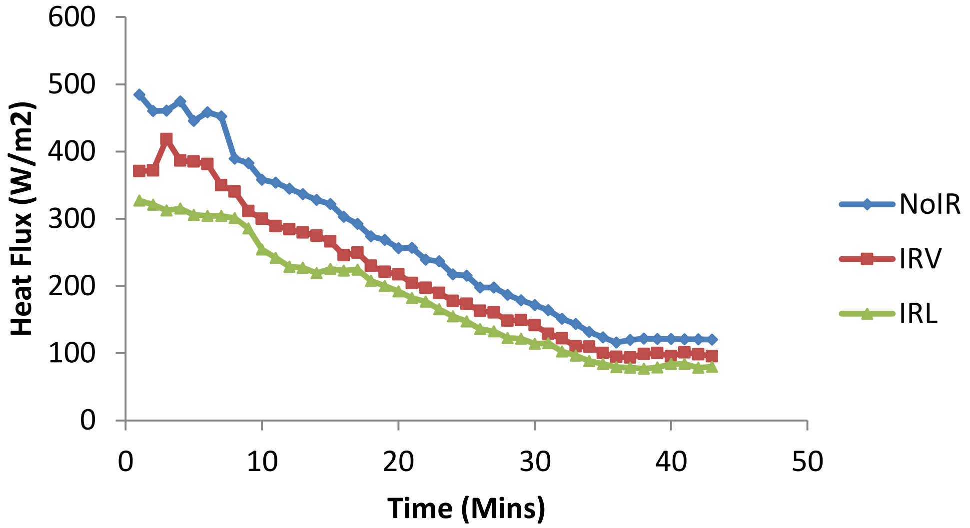


Figure 19. Mean forehead heat flux throughout the experimental trial for the three conditions NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell itted for cla it . lues ± SD's see table B .

4.6 Subjective Data

Individual responses for TC, TS, overall air desirability and total acceptability did vary for each variable throughout the conditions (Table B4: P<0.001).

4.6.1 Thermal Sensation

The initial mean sensation values, taken at two minutes seated after the 3 minutes of standing at 5°C, were generally "slightly cool" or "cool" for all body areas (head, face, nose, chest & arms, hands, seat back, seat cushion, lower leg, feet, toes and overall) . Visually, the trend of TS was fairly similar to TC with a steady linear increase from 0-24 minutes (figure 20). The IR trials initially showed a sharper rise compared with NoIR. This is confirmed using linear regression to the linear component of the response (neutrality reported ≈3-4 min earlier in IR trials).

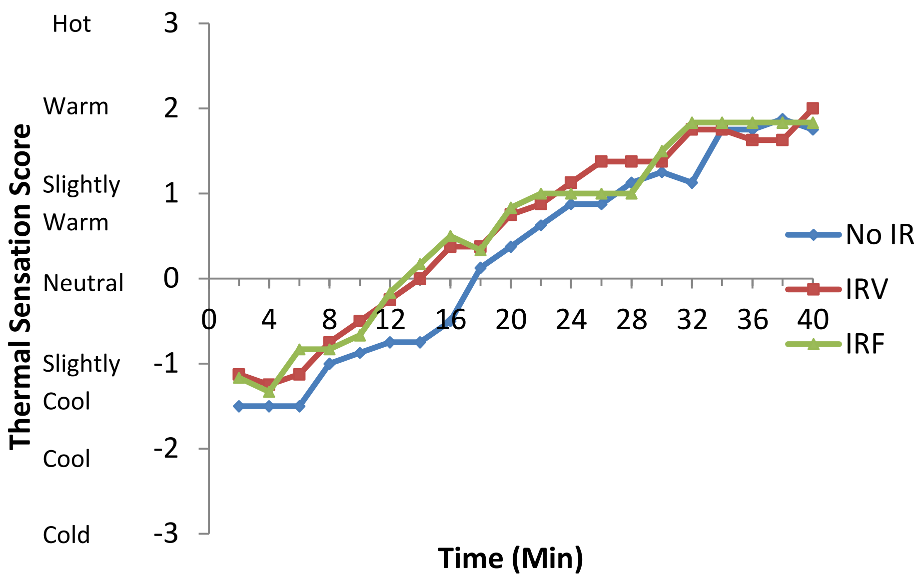


Figure 20. Mean overall thermal sensation scores throughout the experimental trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell itted for cla it . lues ± SD's see table B4.

Overall TS was significantly different between trials (P<0.001) with post hoc tests revealing higher scores in the IR trials (NoIR vs IRV, P<0.01 and NoIR vs IRF, P<0.001: η_p^2 =0.05). TS scores were not significantly different between groups for the head, face and nose (P>0.05). However for all other body areas (chest & arms, hands, seat back, seat cushion, lower leg, feet and toes) there was variation in TS scores between trials (P<0.05 to P<0.001). Post hoc results revealed IR panel position dependant differences for sensation, similar to the comfort findings.

In summary IRV improved TS for the chest & arms, hands and seat back compared to NoIR (Figure 25: P<0.05 to P<0.001). IRF improved TS for the hands, seat back, seat cushion, lower leg, feet and toes (Figure 26: P<0.01 to P<0.001). IRF improved lower leg, feet and toe sensation compared to NoIR (Figure 26: P<0.05 to P<0.001). These improvements are aligned to the direction of the IR heating provided by the panel in the different trials. The hands were the coldest body area (i.e. lowest mean TS) throughout all the conditions.

4.6.1.2 Sensation Linear Regression

For the first 24 minutes of the trial, linear regression analysis was carried out for TS (Figure 21). There were still significant differences in TS between trials (P<0.001) over this time period with an improvement in both IR trials compared with NoIR, but no difference between the two IR trials for the first 24 min (NoIR vs IRV, P<0.01, NoIR vs IRF, P<0.001, IRV vs IRF, P>0.05). TS followed the same trend as comfort with a "0" score (neutral) occurring earlier and at lower air temperatures (Table 1) in both IR trials compared to NoIR (NoIR 11.0°C, IRV 9.3°C and IRF 9.2°C).

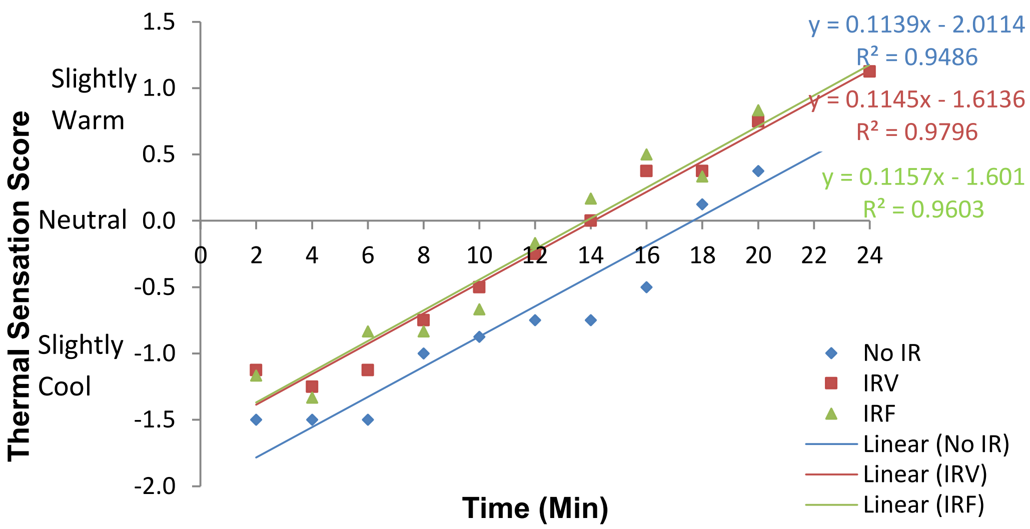


Figure 21. Mean overall thermal sensation scores for the first 24 minutes of the trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Lines of best fit for each condition have been added.

4.6.2 Thermal Comfort

For all conditions TC values for all areas of the body initially declined from preconditioning levels of "slightly comfortable" and "comfortable" (table B2) to "slightly uncomfortable" and "uncomfortable" after 3 minutes of standing at 5°C (table B3; figure 22). Responses for all areas varied between participants (P<0.001). The TC scores generally increased throughout trials (P<0.001, main effect for time for all body areas). The trend of overall TC, as seen in figure 2, was an increase until ≈24-28 minutes and then a plateau. This generally represents the response for all body areas sought. This decline in the rate of increase in comfort occurs concurrently to high TS scores i.e. the participant was getting too warm (section 4.6.1; figure 20).

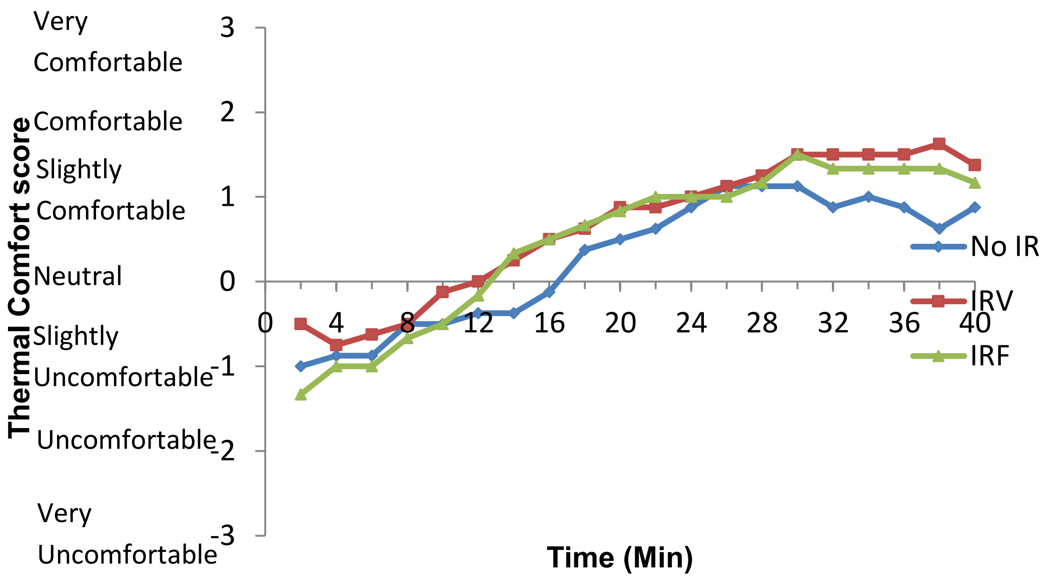


Figure 22. Mean overall thermal comfort scores throughout the experimental trials; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Error bars are o itted for cla it . lues ± SD's see table B .

Comfort scores for the head, chest and nose did not vary between trials (P>0.05). For all other body areas there were significant differences between trials (P<0.05 to P<0.001) in TC with post hoc tests (Table C1) indicating higher overall comfort scores in IR trials compared to NoIR (NoIR vs. IRV, P=0.001 and vs. IRF, P<0.05). The effect size was trivial (η_p^2 = 0.04). There was no significant difference between the IR trials (P>0.05). The IRV trial provided higher comfort scores for the chest & arms, hands and lower leg compared to NoIR (Figure 25: P<0.05 to P<0.001). With the IRF trial improving comfort in the lower leg (compared to NoIR and IRV), foot and toe region, compared to NoIR (Figure 26: P<0.05 to P<0.001). Post hoc tests revealed that body areas in contact with the seat back and seat cushion were both higher in the IR trials (P<0.01 to P<0.001) compared with NoIR.

6.2.2 Comfort Linear Regression

Linear regression analysis conducted on the first 24 minutes of the trial after visual inspection of the graph showed the linear portion of the data were from 0-24 minutes before a plateau was observed (Figure 23). The regression equation for each condition was used to calculate the mean time at which a "0" score was reported (Table 3). A TC score of "0" was reached sooner in the IR trials compared to NoIR. For the first 24 minutes, TC was significantly different between conditions (P<0.01) with post hoc tests revealing a difference between NoIR and IRV (P=0.001). The differences between the other trials (NoIR and IRF & IRV and IRF) were close to significance (P=0.11 to P=0.12). A neutral score was reported earlier (NoIR 15.2 min, IRV 11.4 min, IRF, 13.2 min) and at lower air temperatures (globe temperature) in both IR trials compared to NoIR (NoIR 9.4°C, IRV 8.0°C and IRF 8.7°C). The linear regression equations are also reported on figure 3 and the response in IRF was clearly steeper i.e. Thermal comfort improved at a quicker rate, compared to IRV and NoIR. NoIR and IRV tend to follow a similar pattern to each other but with IRV comfort values being consistently higher throughout the 24 minute period.

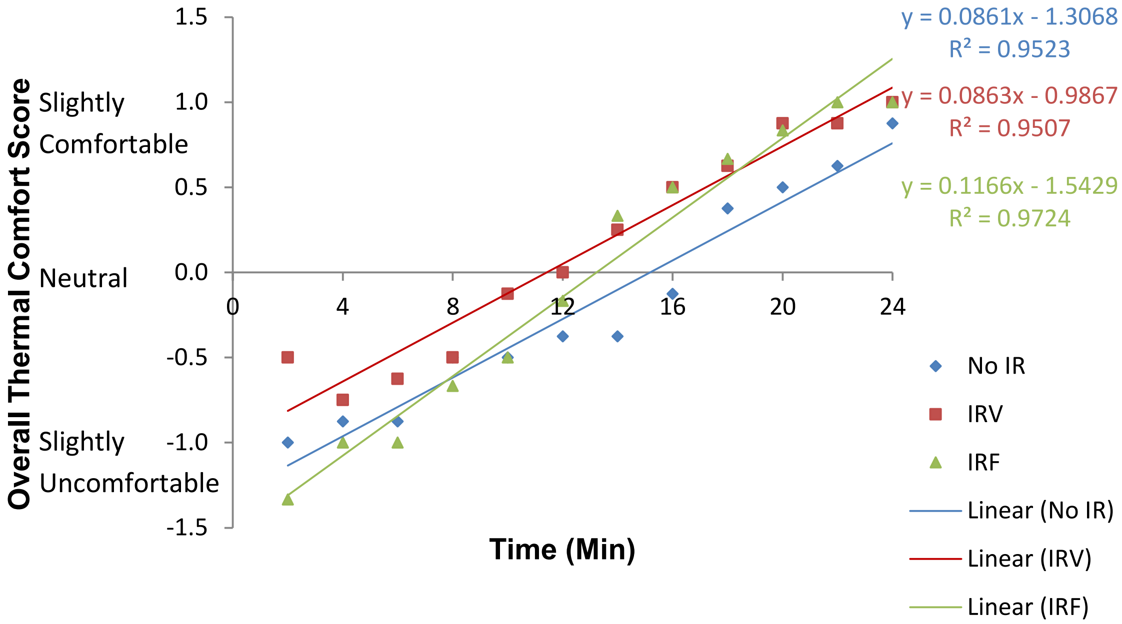


Figure 23. Mean overall thermal comfort scores for the first 24 minutes of the trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Lines of best fit for each condition have been added.

Overall TC in the IRV condition was higher than NoIR due to improvements in chest & arms and hands TC and TS scores during the trial (figure 25). The sharp improvement in TC regression was due to an improvement in lower leg, foot and toe TC and TS seen throughout the trials (figure 26).

Correlations between mean TC and mean TS scores for each body area in each condition are shown in table C3. There was a strong positive correlation (r=0.96) between mean overall TC and mean overall TS in all trials (Figure 24). With these values for the three trials very similar (NoIR, r=0.94, IRV, r=0.99 and IRF, r=0.97). The hand and areas in contact with the seat back had the highest correlation between comfort and sensation (r=0.98). Only one body area for one trial had a correlation of less than 0.9 (Chest & arms, NoIR, 0.89). Using the overall regression equation, TS was calculated as -0.1 when TC was 0.

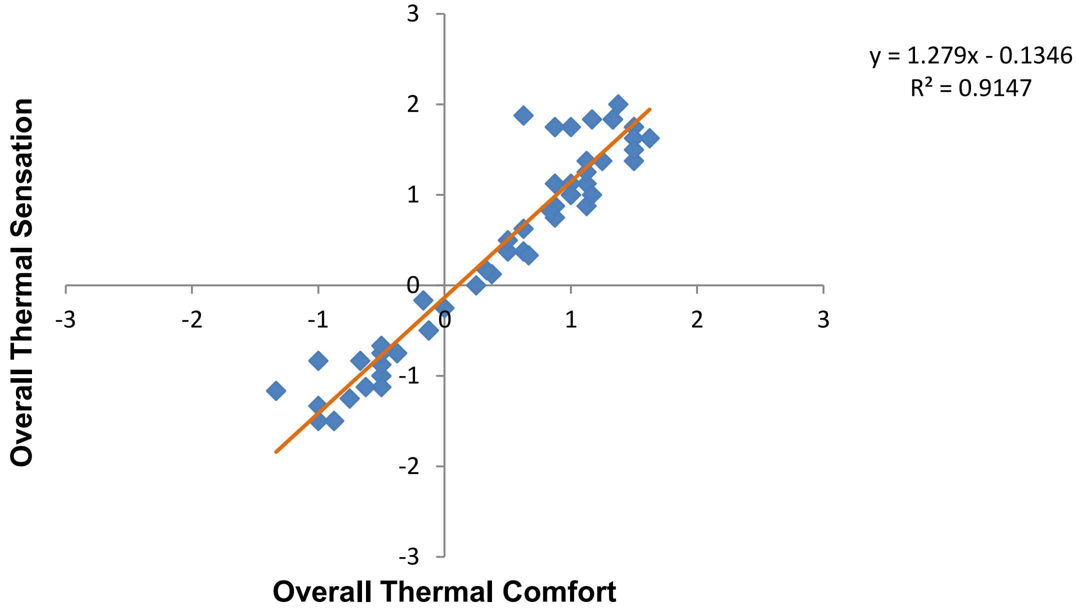


Figure 24. Mean overall thermal comfort scores correlated against mean overall thermal sensation scores for all conditions (r=0.96). An overall line of best fit has also been added.

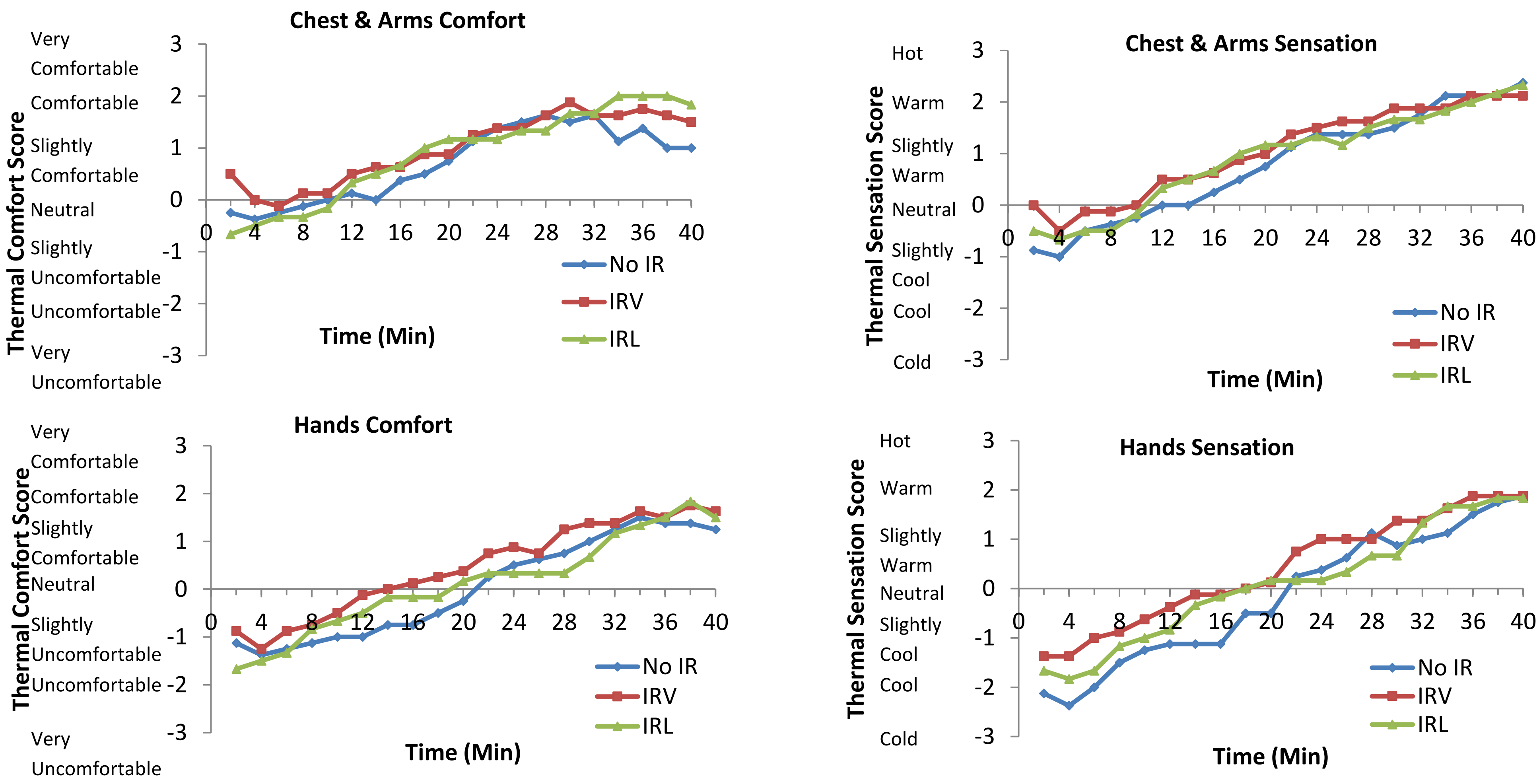
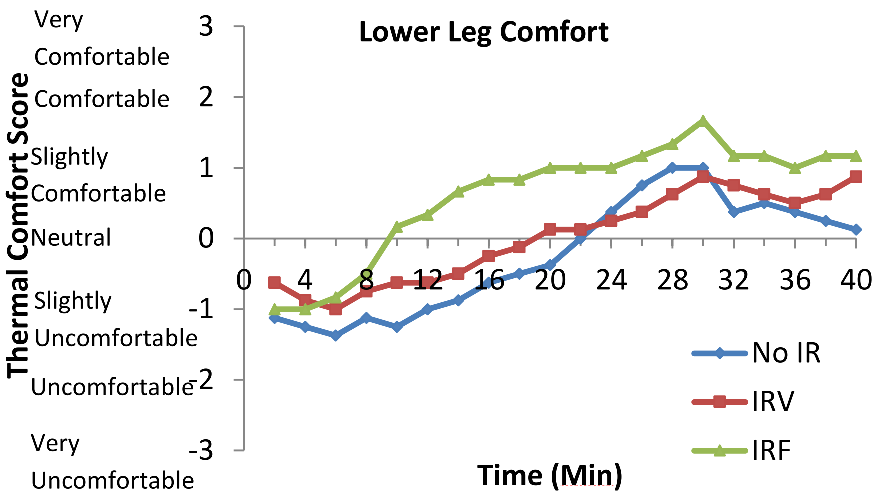
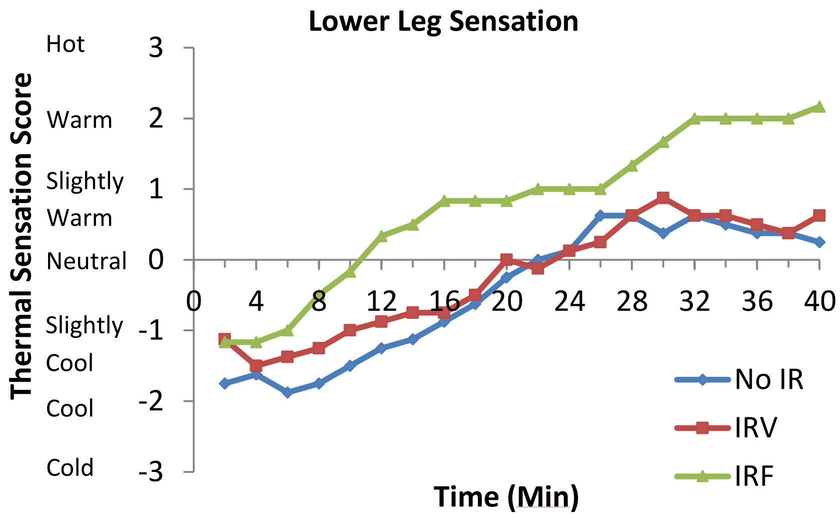
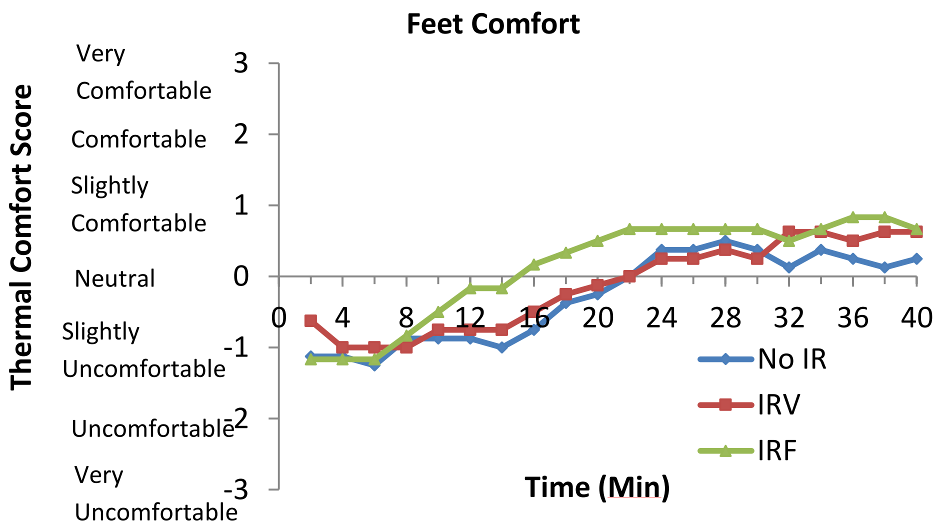
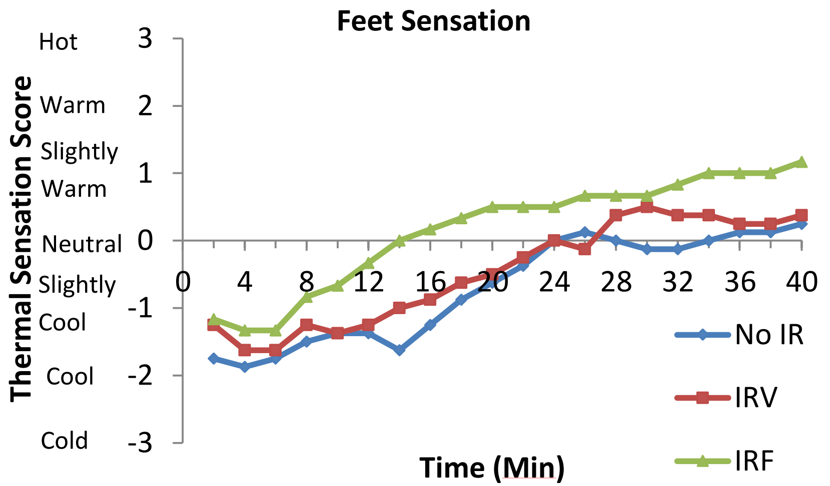


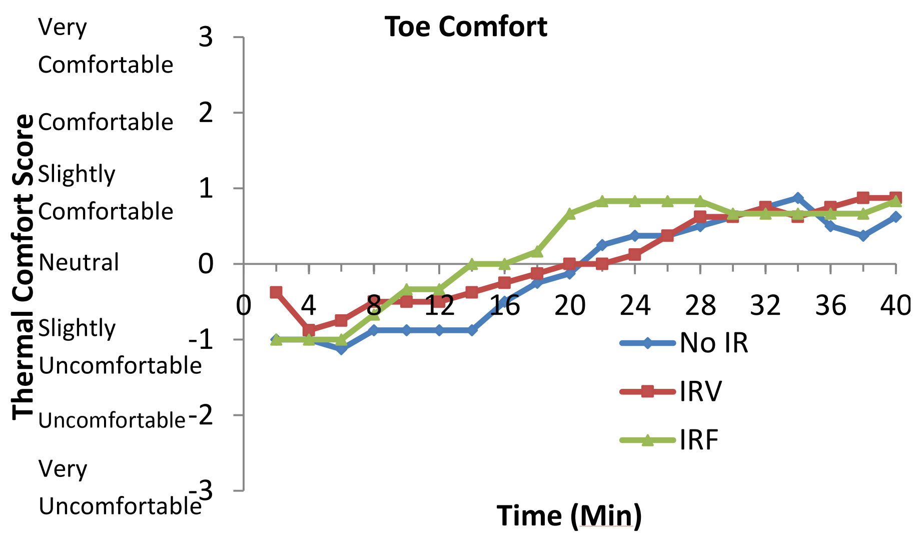
Figure 25. Mean thermal comfort and sensation scores for the chest & arms and hands throughout the experimental trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Error bars are omitted for clarity. For values ± SD's see table B3 & B4.


Lower Leg Comfort
Thermal Comfort Score
Very Comfortable
Comfortable
Slightly Comfortable
Neutral
Slightly Uncomfortable
Uncomfortable
Very Uncomfortable
3
2
1
0
-1
-2
-3
0 4 8 12 16 20 24 28 32 36 40
Time (Min)
No IR
IRV
IRF


Lower Leg Sensation
Thermal Sensation Score
Hot
Warm
Slightly Warm
Neutral
Slightly Cool
Cool
Cold
3
2
1
0
-1
-2
-3
0 4 8 12 16 20 24 28 32 36 40
Time (Min)
No IR
IRV
IRF


Feet Comfort
Thermal Comfort Score
Very Comfortable
Comfortable
Slightly Comfortable
Neutral
Slightly Uncomfortable
Uncomfortable
Very Uncomfortable
3
2
1
0
-1
-2
-3
0 4 8 12 16 20 24 28 32 36 40
Time (Min)
No IR
IRV
IRF


Feet Sensation
Thermal Sensation Score
Hot
Warm
Slightly Warm
Neutral
Slightly Cool
Cool
Cold
3
2
1
0
-1
-2
-3
0 4 8 12 16 20 24 28 32 36 40
Time (Min)
No IR
IRV
IRF



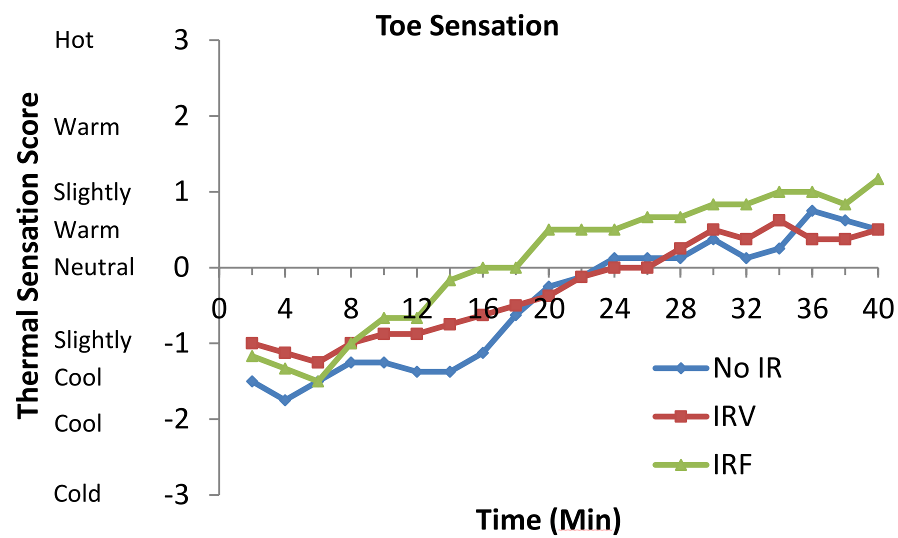


Figure 26. Mean thermal comfort and sensation scores for the lower leg, feet and toe throughout the experimental trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Error bars are omitted for clarity. For values ± SD's see table B3 & B4.

4.6.3 Thermal Desirability

Overall thermal desirability scores are reported in table B5. Face and overall air temperature desirability scores exceeded “0” at around 28 minutes (figure 29) in all trials and by 40 minutes, participants were reporting scores of “1” (a slightly cooler temperature is desired). Throughout the 40 minute trial seat and lower leg desirability increased to a score around “0” which translates to “the current temperature is fine” (Figure 29). There were significant differences in thermal desirability between trials for the seat, lower leg and air temperature ($P<0.01$ to $P<0.001$: $\eta_p^2=0.03$, 0.20 and 0.05 respectively) but not the face ($P>0.05$: $\eta_p^2=0.01$).

In summary post hoc tests revealed that the IR trials improved desirability compared to NoIR. IRV improved seat desirability and overall air desirability compared to NoIR ($P<0.01$). IRF improved seat and overall air desirability compared to NoIR ($P<0.05$ to $P<0.001$) and lower leg desirability to both NoIR ($P<0.001$) and IRV trials ($P<0.001$).

Linear regression was calculated for overall air desirability to help calculate when a score of “0” (“the current air temperature is fine”) was reached as well as helping compare the responses across the trials (Figure 27). Linear regression was calculated for the full 40 minute trial as there was a linear response in desirability throughout this period. Participants in the IR trials reported “0” values earlier than in the NoIR condition (table 3). This equated to a lower air temperature in both IR trials compared to NoIR (NoIR, 17.8°C, IRV 15.9°C, IRF 16.4°C).

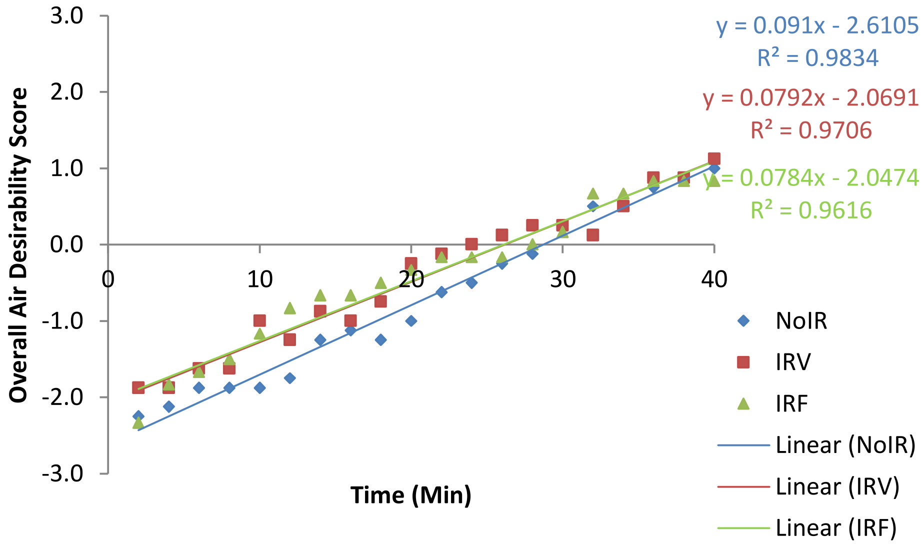


Figure 27. Mean overall air desirability scores for the first 40 minutes of the trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Lines of best fit for each condition have been added.

There was a strong positive correlation (r=0.92) between mean overall TC and mean overall air desirability in all trials (Figure 28). With these values for the three trials very similar (NoIR, r=0.88, IRV, r=0.96 and IRF, r=0.95). Using the overall regression equation, overall air desirability was calculated as -1.1 when TC was 0.

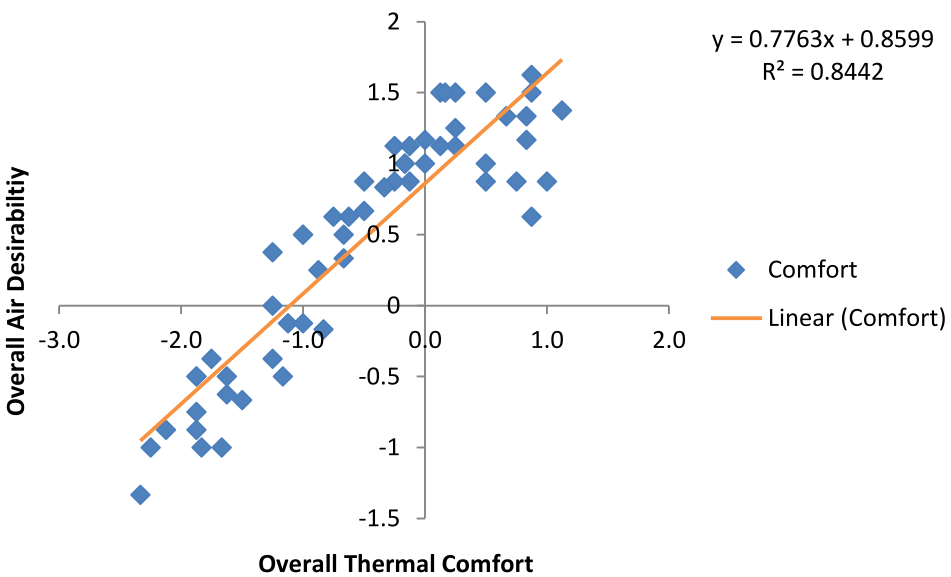


Figure 28. Mean overall thermal comfort scores correlated against mean overall air desirability scores for all conditions (r=0.92). An overall line of best fit has also been added.

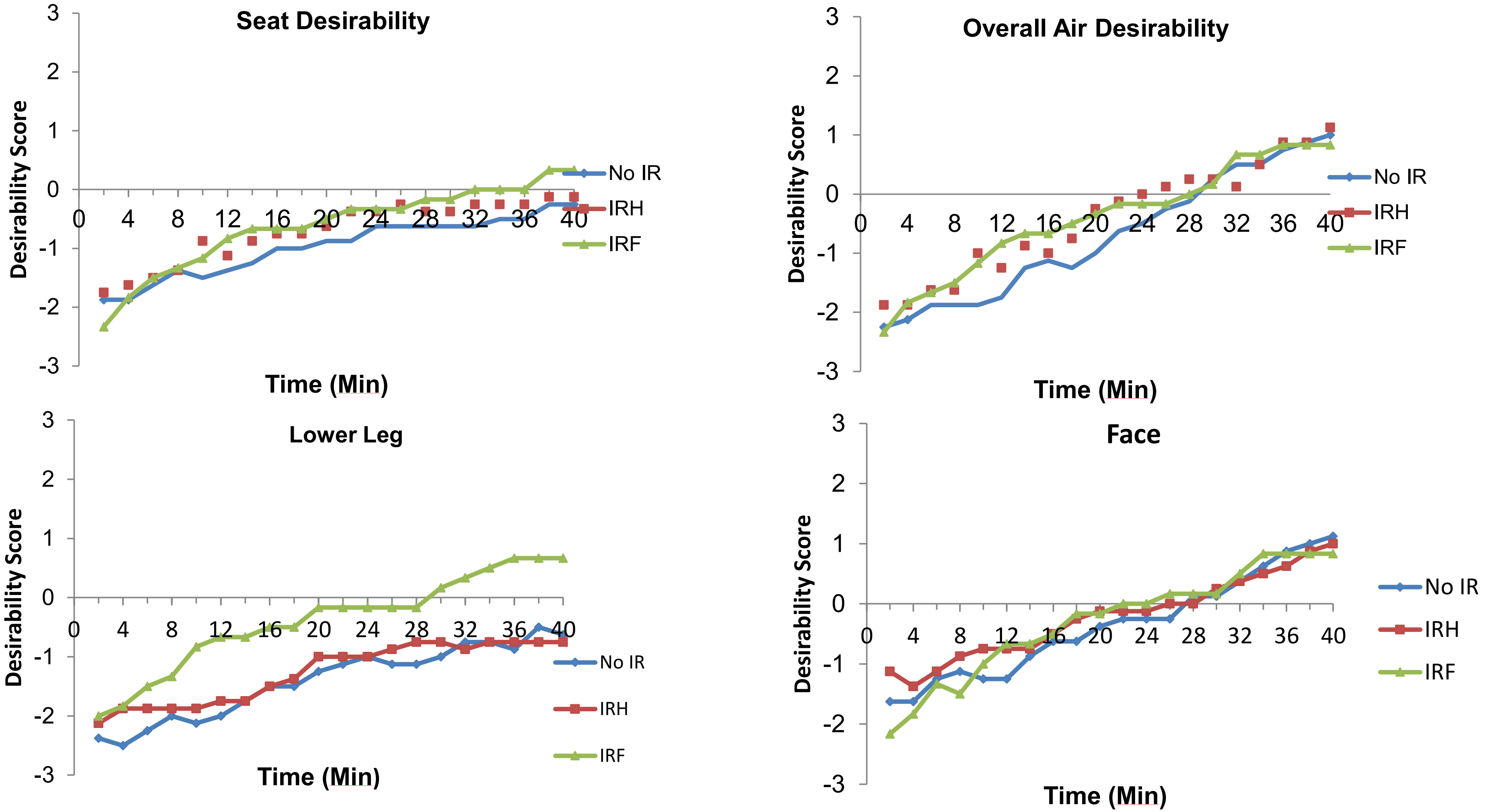


Figure 29. Mean desirability scores for the seat, overall air, lower leg and face throughout the experimental trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Error bars are omitted for clarity. For values ± SD's see table B5.

4.6.4 Acceptability of the total thermal environment

Acceptability of the total thermal environment increased with the rise in air temperature until around ≈28 min (figure 30, table B5) and then levelled off which was temporally aligned to TS scores rising from “slightly warm” to “warm”. Overall acceptability scores varied between trials ($P<0.001$: $\eta_p^2=0.05$) with post hoc analysis revealing higher acceptability scores in IR trials compared to NoIR (NoIR vs IRV, $P<0.001$, NoIR vs IRF, $P<0.05$).

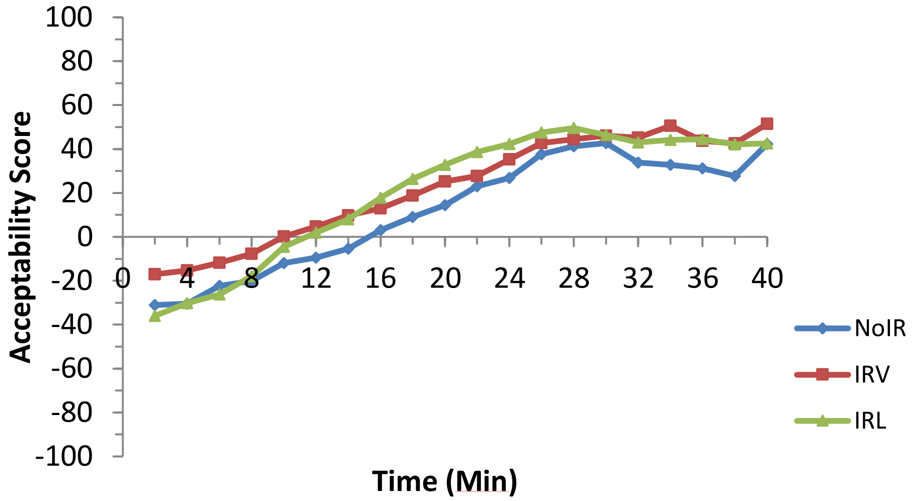


Figure 30. Mean acceptability of the total thermal environment scores throughout the experimental trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Error bars are omitted for clarity. For values ± SD’s see table B .

Linear regression over the first 24 minutes is shown in figure 31. There were differences between the trial ($P<0.001$). The rate of increase in acceptability scores was higher in IRF compared to NoIR and IRV as shown by the gradients of the lines of best fit. A “0” score reported when participants felt the total thermal environment was “just acceptable” occurred around ≈3-5minutes earlier in the IR trials compared to NoIR. This equated to a globe temperature difference of 1-2°C (NoIR; 9.4°C, IRV; 7.6°C & IRF; 8.2°C).

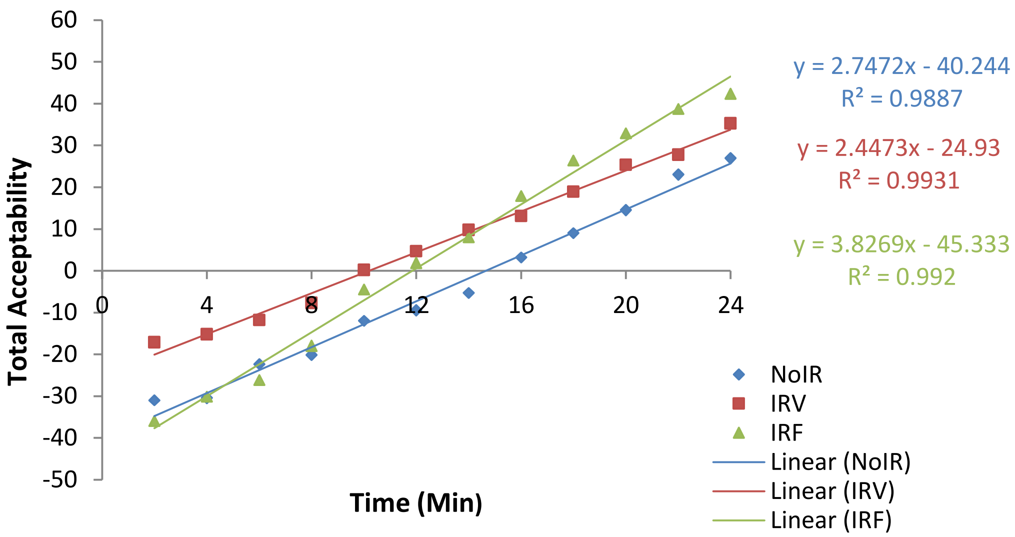


Figure 31. Mean acceptability of the total thermal environment scores for the first 24 minutes of the trial; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Lines of best fit for each condition have been added.

Table 3. Trial times and corresponding air temperatures at which "0" was reported for TC, sensation, overall air desirability and total thermal acceptability; NoIR- No Infra-Red; IRV- Infra-Red Visor & IRF -Infra-Red Footwell. Temporal data are calculated linear regression, for example refer to figure 3.

Subjective Response	**Condition**	**Time (Mins)**	**Temperature (°C)**
Overall Thermal Comfort	NoIR	15.2	9.4
	IRV	11.4	8.0
	IRF	13.2	8.7
Overall Thermal Sensation	NoIR	17.7	11.0
	IRV	14.1	9.3
	IRF	13.8	9.2
Overall Air Desirability	NoIR	28.7	17.8
	IRV	26.1	15.9
	IRF	26.1	16.4
Total Thermal Acceptability	NoIR	14.6	9.4
	IRV	10.2	7.6
	IRF	11.8	8.2

4.7 Summary

The main difference between trials was an improvement in TC in IRV and IRF compared to NoIR. Neutrality was reported for TC and TS earlier and at lower ambient air temperatures in both IR trials compared to the control trial. These changes were apparent despite limited differences in physiological measures between conditions.

5.0 Discussion

The main finding of the current study was that IR heating (surface area $0.55m^2$ consuming 48W of power), independent of panel position, improved TC in a car cabin environment during a 40 min dynamic pull up (ambient air temperature from 5°C-25°C). The potential for a relatively small IR panel to deliver occupant TC at lower air temperatures was also evident. Therefore radiant heating has the potential to provide major energy savings and a consequent improvement in fuel economy and driving range in electric vehicles.

5.1 Subjective Responses

5.1.1 Overall Thermal Sensation

The first subjective measures were taken after 2 minutes and it is assumed that at 0 minutes, participants were at the same state on each occasion due to the environment being kept consistent between trials. TS improved in the IR trials for the first 24 minutes (ambient air ≈17°C) and then scores for all trials converged. This is in agreement with Oi et al (2012) who found an improvement in TC with heated seats during a dynamic warm up phase up to 15°C, but then no benefit above this temperature. Therefore it is apparent that both IR (radiant) and seat heating (conduction) follow the same trend in that they are mostly beneficial to TS at low ambient air temperatures during a warm up phase. There is the same qualitative trend with seat heating (Oi et al, 2012) and IR heating(present study), however energy consumption and output are not comparable due to lack of data, although it is likely that the IR panel consumed less than the seat heating.

Previous IR heating research in vehicles has found that occupants still had cold feet due to the direction of the IR panel (Bäuml et al, 2014). To address this issue it was suggested that only a combination of IR and convective heating could deliver comfort. The present study found a significant improvement in foot TC and sensation in the IRF trial, with participants reporting foot comfort around 7 minutes earlier compared with the other trials. Showing IR heating panels can be effectively positioned toward the feet in a vehicle. This is an important finding as the feet are the main cause of discomfort in cold conditions (Arens, 2006). Eliminating foot discomfort with IR heating may have been a big factor in the improvement in overall TC and TS. However the suggestion that a combination of heating systems may still be valid as in the current study there was no improvement in foot temperature with IR heating directed towards the feet. There are also issues with the distance and intensity of the IR. The use of heated seats has been shown to improve ore prevent a decrease in toe temperature, whilst significantly increasing foot TS (Oi et al, 2012). This is interesting as there is no heat directed towards this region. This has also been found by Gibbon & Landis (1932) and could be due to a vasodilation response in the indirectly heated region (section 2.6.6). A combination of seat heating and IR may increase this thermal response in the foot region.

5.1.2 Overall Thermal Comfort

Overall TC followed a similar trend to TS, with an increase in all trials in a linear fashion for the first 24 minutes, with a clear improvement in both IR trials.

In a dynamic thermal environment, IR heating improved TC compared to NoIR for approximately the first 24 minutes of the trial or, until an air temperature of 17°C was reached. The fact that overall TC ("0" score) was achieved at relatively low air temperatures (NoIR; 9.4°C, IRV; 8.0°C and IRF; 8.7°C), and around 1°C-2°C lower in IR trials compared to NoIR, suggests that IR heating is most effective during cool temperatures. Zeiler et al (2013) found that comfort with IR heating could be maintained at an air temperature of 19.5°C (2.5°C lower than without IR). However, this is a much higher temperature compared to the current study, it was in an office environment with the air temperature was reduced from 22°C to 19.5°C. This will elicit a different response of comfort compared to a warming protocol due to a "hysteresis" effect in the TC response discussed below. Also the Zeiler (2013) study a direct subjective measure of TC was not recorded; instead comfort was calculated using Fanger's model (Fanger, 1970) using TS values. The IR heater was controlled by finger temperature being in a certain temperature range (29-31.5°C), so included a feedback system not used in the present study. Participants in the Zeiler (2013) study were in a relatively 'stable' environment compared to the current study.

The temperature at which TC was achieved for each condition (8-9.4°C) may not have been the same if a cooling protocol with IR heating had been used. This is due to a phenomenon known as "hysteresis". This is where a comfortable ambient air temperature when being heated up from the cold may be different to a comfortable temperature when being cooled from a hot condition. This has been attributed to an "anticipatory" sensation and comfort response by participants (Gagge, 1967). This hysteresis effect is more prominent in the cold when being warmed, where the rate of heat transfer to the body predominates over the low skin temperatures which cause discomfort itself. The sensation of being warmed therefore leads participants to report comfort due to the sensation of "warming" rather than actually when they are at a comfortable level. This must be taken into consideration in the current study as the low ambient air temperatures where participants reported comfort may not be the same temperatures at which comfort is reported when being cooled. Also overall TC (a mean score of 0) was achieved ≈1-2 minutes earlier than TS in all trials. This could be due to this "anticipatory" effect where participants can feel the environment improving (especially with the added IR heat source) and therefore report that they are "comfortable" whilst they are still reporting that they are slightly cool on the TS scale. TC was reported at "neutral" when TS was between "slightly cool" and neutral for all trials. For IRV and NoIR this score was -0.3 and for IRF this was achieved at -0.1 sensation score. Comfort was still achieved before sensation was neutral, although the difference is very small. Comfort was asked prior to sensation, resulting in a difference of around 30 seconds between the two subjective responses. Had both TC and TS been collected at exactly the same point this finding may have been slightly greater but potentially still trivial. Also it has been found that comfort can be perceived by humans when they are being released from thermal stress (Kuno, 1995). This occurs when subjectively a participant can evaluate comfort without a recovery in physiological condition. This was again attributed to this "anticipation" response reported by Gagge (1967). Kuno (1995) has argued that "anticipation" is just a description, and that actually a situation where an uncomfortable stimulus is removed creates a pleasant psychological state even when a physiological state is just returned to neutral.

This poses the question of whether the participants were actually feeling "neutral" comfort when they reported it, or if because the environment was improving and warming up they perceived an improved comfort. It is unlikely that the ambient air temperatures at which comfort was reported would also be the same if a cooling or steady state protocol was used, as mentioned above. Brooke & Parsons (1999) investigated the effect of seat heating on comfort at steady state conditions. Their main finding was that overall comfort was improved at 5°C and 10°C but not 15°C or 20°C. Although the method of heating is different, the improvement in comfort at lower ambient air temperatures suggests that alternative heating systems to HVAC may play a role in improving comfort during very cold conditions immediately after occupants have entered the vehicle. This agrees with the current finding in the study even though a static and not dynamic protocol was used. The main mode of heat transfer from seat heating is conduction, which might potentially provide a larger energy transfer compared with IR. However this mode of heat transfer can only affect areas of the body in contact with the seat but does not directly heat exposed areas, as IR does.

As it took ≈11-13 minutes for TC to be achieved in both IR trials, IR heating in isolation may not be sufficient to provide TC in vehicles. This agrees with (Bäuml et al, 2014) who found that only a combination of IR and convective heating was sufficient to provide TC as IR alone did not heat up the air temperature in the car cabin. The only thing heating the cabin would be the occupant as IR heating is a mode of heat transfer which does not require a material mediator such as air (Incropera, 2011). However the ambient temperature used in the Bäuml et al (2014) study was -7°C, significantly cooler than the initial temperature in the current study (5°C). The rate of heat transfer would have been greater in theBäuml et al (2014) study due to a greater temperature gradient between the IR heat source and the cool occupant. Also due to the current study involving a rise in ambient air temperature alongside IR heating, it can only be speculated on that IR heating alone cannot provide comfort. In the present study, if TC was reported straight away at ambient air temperatures of 5°C, then IR heating alone may be sufficient but this was not the case. However there may be a greater potential for IR heating to provide TC in isolation if; multiple IR panels were combined creating a larger surface area (than ≈0.55m^2), a higher intensity of radiant heating (than 48W) per panel was used and if the panels were located closer to the occupant.

5.1.3 Local improvements in TC and TS

It is interesting to note that locally, there were greater improvements in the IRF trial compared with IRV. For IRV there were local improvements for the chest & arms and hands TC and TS. For IRF these improvements in TC and TS were recorded in the lower leg, feet and toes. With local effects greater in the IRF condition. This could be due to the positioning of the IR panel, in IRF it was located a lot closer to the body compared to when it was in the visor position. Other studies which are not car based have found a preference for the head to be cool in hot environements, and comfortable in cool environments (Arens et al, 2006). In the current study this may be applicable as the participants prefer heating toward the lower leg region compared to the upper body. The improvement in lower leg comfort and sensation in the IRF condition could be attributed to the increase in inner lower leg temperature. However it is interesting that IRF had a reduced outer lower leg temperature compared to NoIR.

Overall TC tends to align to the most uncomfortable body parts (Arens et al, 2006) and so it is important that all body areas are heated and made as comfortable as possible rather than focusing just on one body area (e.g. hands). There is no benefit of making one body area “very comfortable” if others area are still “uncomfortable” as overall TC would be considered “uncomfortable”. This suggests that people are least comfortable when the range of TS scores are greatest across the body and find either a warm or cold condition more comfortable than a combination of different TS scores at different body areas.

Head, face and nose TC and TS were not significantly different between conditions showing that when the IR panel is in the visor position, there is no heat directed to this region of the body. The heat in IRV mainly fell onto the chest, hands and thigh. An IR panel directed toward the head region may improve TC although in cold conditions the head is perceived as warmer and more comfortable compared to the rest of the body (Arens et al, 2006). So the head will probably not benefit from IR heating as much as other body parts. Hand TC and sensation was significantly improved in the IRV trial but interestingly there was no difference in hand skin temperature between trials. This could be due to counter current heat exchange taking place (section 2.6.5)

5.1.4 Thermal Desirability

To evaluate TC the ASHRAE definition was applied. However if TC is considered to be achieved when participants are feeling ‘just right’ then it may be more logical to focus on the desirability scores rather than comfort *per se*. It’s not been identified clearly whether a “neutral” score on the ASHRAE scale is classed as TC or whether a score of “comfortable” is when TC is achieved. A score of “0” on the desirability score equates to “neither a warmer nor cooler environment would be desired”. TC may be reported prior to comfort being achieved due to the sensation of “warming” felt by participants (section 5.1). Using the average data from all conditions, a “0” score on the TC scale was achieved when overall air desirability was -1.1, or “a slightly warmer temperature would be desired”. This would support th idea that TC can be reported prior to a comfortable environment being provided, due to this “warming” sensation and the fact the environment is improving. According to the overall air desirability scales, a comfortable environment was achieved ≈1-2°C earlier in the IR trials compared to NoIR. However the ambient air temperatures are all a lot higher compared to analysing when “0” was achieved on the TC scale, around 16-18°C. These temperatures closer to the air temperature comfort could be maintained with IR heating in Zeiler et al's (2013) study. It also suggests that reporting "neutral" on the ASHRAE scale may not be when TC is achieved and a higher value on this scale is more representative of comfort.

For lower leg desirability IRF was the only condition where participants actually wanted a "slightly lower temperature". For the other trials participants did not report that the current temperature was fine. This shows the benefit of IR heating towards the lower leg and the effectiveness of the panel toward this region.

It has been found that with seat heating, optimal TS for areas in contact with a car seat are higher at lower air temperatures (Oi et al, 2012). These authors combined when participants reported "the current temperature is fine" on the desirability scale with the TS scores at that point. At 10°C and lower TS scores were between "slightly warm" and "warm" when desirability was neutral and at 20°C TS scores were around "neutral". In the present study, a score of "the current temperature is fine" for overall air desirability was achieved earlier and at lower ambient air temperatures in the IR trials (IRV & IRF≈16°C, NoIR ≈18°C). For all conditions this neutral desirability score occurred when TS was reported between around "slightly warm" and "warm" for all trials. The addition of IR heating did not seem to reduce the TS score when the current air temperature was reported as "fine", it did however appear to increase the rate at which a "fine" air temperature was reported. This suggests that IR increases the rate of warming in the current protocol as desirability was reported earlier in IR trials. But there was no apparent difference with IR heating on the TS score at which desirability was reported.

5.1.5 Acceptability

A "just acceptable" score of thermal acceptability was reported at ≈1-2 minutes earlier than "neutral" on the TC scales. This finding agrees with that of Zhang & Zhao (2008) who also found acceptability was reported at TC scores of "slightly uncomfortable. These author report that the range of TS at which acceptability was reported is from “0” (neutral) to “1.5” (slightly warm to warm). However in the current study acceptability was reported prior to a neutral TS being reported. So participants were cold but still reported the environment as acceptable. A potential explanation for this difference being Zhang & Zhao’s (2008) finding applies to sedentary participants being exposed to uniform environments for 30 minute exposures (28°C, 32°C and 35°C) and not a dynamic pull up in ambient air temperature used in the present study.

5.2 Environmental Conditions

5.2.1 Chamber Temperatures

The slight variation in ambient air temperature between conditions may be attributed to the investigator being in the vicinity of the lascar temperature sensors. Although the investigator as situated in a similar place for all trials if there was slight variation in positioning this could have affected the temperature loggers. As confirmed by the small effect size, the observed differences were of no ‘real’ significance. The temperature gradient difference between head and foot level (≈1.5-2°C) was consistent throughout so would not have affected the results. The differences in mean globe temperature between conditions were so small (<≈0.5°C) they were considered negligible.

The lascar temperature sensors logged data every 10 seconds. The loggers were observed as reacting instantaneous to the change in environment. However even if there was a small difference with the real temperature due to lag time, in absolute terms the same protocol was used on each occasion and the rise in temperature was consistent.

The RAMP increase in temperature (5-25°C) resulted in a lack of control the RH. However when vapour pressure was calculated although it increased over time, it was a lot more stable than RH. Vapour pressure was slightly lower in IRF compared to the other two trials, but this difference was never more than ≈2mmHg and so was not considered to be of any practical difference.

5.2.2 Car Seat Temps

Car seat temperatures were higher prior and for the first 2 minutes of both IR panels due to the panel being turned on for 15 minutes and radiant heat from the panel being incident to the seat. The IR panels were turned on prior to the trial starting so they could heat up to their maximum potential (section 3.4.1). For the first couple of minutes both seat cushion temperatures (seat l buttock and seat r buttock) were higher in IRV compared to IRF with the seat back temperatures similar between IR trials. This is due to heat from the IR panel in IRV falling directly onto the seat cushion. Some of the differences between participants in car seat temperature could have been due to postural differences when seated. Participants were instructed to sit comfortably and adjust the seat to how they would have it within a car in relation to where the pedals were on the buck.

Areas in contact with the seat back were warmer in the IR trials (especially IRV). This is probably not a thermoregulatory response and due to the IR panels being turned on prior to the trial and heating the seat. This is supported by the higher car seat temperatures recorded in the IR trials compared to NoIR.

5.2.3 IR Panel

Improvements in TC and TS were evident in both IR trials even though the IR panel used in the present study had a relatively small surface area (0.55m^2) and a power usage of 48 W. The visor surface temperature, in which the IR panel was stored, was slightly higher in the IRV trial compared to the IRF trial. This was due to the vertical air temperature difference in the environmental chamber with the temperature at head level 1.5°C warmer than foot level.

5.3 Physiological Response

When participants entered the cold chamber they were normothermic and only were briefly exposed to a cold temperature in order to simulate transfer from a building to a vehicle (3 mins at 5°C). This may have elicited some regional cooling (hands and face), shown with the initial low TC and TS scores when in the seat. The forehead heat flux data also decreases as soon as participants enter the chamber, indicating vasoconstriction to the forehead. If participants were not normothermic (e.g. elevated/ reduced core and skin temperatures), then thermal perceptions would be altered. However participants were confirmed to be normothermic for each trial when entering the cold, as indicated by consistent preconditioning data.

Whilst there were clear differences between conditions for the subjective data, differences in the physiological data were not as clear.

5.3.1 Core Temperature

Rectal temperature decreased by around 0.2°C -0.3°C by the end of 40 minute trial even though ambient air temperature was increasing. This is likely to be due to convection and counter current heat exchange as discussed previously (section 2.6.5). When vasodilation occurs in response to warming, the cold tissue at the periphery (hands and feet) cooled the blood which was returned to the core. For the first 15 minutes rectal temperature was stable so it is speculated that at this time point vasodilation starts. Rectal temperature was decreasing whilst mean skin temperature was increasing, showing a regional variation response to the temperature between the core and periphery as the body warms. This was due to cool blood returning to the core from the cold periphery after vasodilation occurs. So the skin temperatures are increasing as the environment gets warmer whilst core temperature is still decreasing.

Aural temperature followed the same trend as rectal temperature but was a lot more variable. Initially it decreased by ≈0.3-0.5°C in the first 20 minutes of the trial (for all conditions) and then increased to initial values or above by the end of the 40 minute trial. When tympanic temperature is measured accurately, it has been shown to be a good indicator of core temperature and reflect changes in brain temperature (Brinnel & Cabanac, 1989). However external cooling, especially to the face, has been shown to affect aural temperature to a greater extent than core temperature (Cabanac, Germain & Brinnel, 1987). Thus this bigger variation in aural temperature compared to rectal temperature would be expected.

5.3.2 Skin Temperatures

IR heating directed towards the face has been shown to increase skin surface temperature of the hand (Tannam, 2012). This response has also been recorded when IR heating was directed towards the alternate hand. A proposed mechanism is that the heat must have caused a vasodilator response within the hand, increasing blood flow to the skin to help assist heat dissipation to the environment. In the current study both hands were exposed and positioned symmetrically in relation to the IR panel. Hand temperature initially decreased and plateaued in the current study, before rising in the last 10 minutes of the trial. However interestingly there was no difference between conditions for hand temperature. The intensity of the IR heating in the current study may not have been sufficient to elicit a thermoregulatory response. However there was an increase in finger temperature in the IRV condition which is probably a result of the direct radiant heating to this area. If a thermoregulatory response had occurred in the IRV condition it would be expected that hand temperature would have also increased. Anterior thigh temperature was highest in the IRV group as this is predominantly where the IR heat is being directed.

When convective heating was used alongside IR, body parts exposed directly to the IR panels warmed up quickly and other body parts warmed up slower with feet taking 30 minutes to warm up (Bäuml et al, 2014). In the current study foot temperature decreased for the first 30 minutes of the trial and then started to warm up slightly. However for all conditions foot temperature at the end of the trial was ≈1°C lower than the initial value. Thus even the positioning of the visor in the IRF trial, may not have been optimum to warm the feet. The increase inner lower leg temperature in the IRF condition suggests that more of the radiant heat fell on this area and less directly towards the foot. This response is similar to that observed by Bäuml and colleagues (2014) study.

5.3.3 Heat Flux

Heat flux values for the forehead were highest in the NoIR group and lowest in IRV. More heat is being transferred from the occupant to the environment without any IR heating. As there is no IR heating directed toward the face region there should be very little difference between the groups. This was due to measurement variability and the sensitivity of the heat flux sensors.

For the inner lower leg there is a similar trend with NoIR heat flux being the highest throughout the trial and lower values in both IR conditions with IRV the lowest for most of the trial. This shows that with the addition of IR heating directed toward the lower leg, less heat is lost to the environment locally compared with the control trial. Heat flux has been shown to be directly related to temperature, when hand temperature increases so does hand HF (Tannam, 2012). However this isn't the case as in the IRF condition, participants had the highest inner lower leg temperature, but the lowest inner lower leg heat flux values throughout.

5.3.4 Thermal Comfort Zone

Mean skin temperature was initially around 31.5°C for all conditions. It then decreased during the 3 minute transition period and around the first 5 minutes of the trial for the three trials. Skin temperature did not reach 31.5°C again until around 30 minutes into the trial. This is interesting as around 31.5°C is the lower limit of the TCZ for a person in a business suit at a resting metabolic rate suggested by Gagge et al (1967). Theoretically when mean skin was outside this temperature participants should not feel comfortable. However comfort was reported a lot earlier in all conditions at mean skin temperatures ≈30-30.5°C. The ambient air temperature range for the TCZ suggested by Gagge (1967) is ≈18-24°C. TC was reported at air temperatures a lot lower than this (8-9.5°C) for all trials. These zones are used in steady state conditions and may not be applicable for the dynamic protocol used in the current study. Also the TCZ was not developed to incorporate external heat sources (IR) into the model, and so is only applicable for the NoIR condition. Suggesting that they dynamic “pull up” protocol used does not fit the model.

It is difficult to evaluate the effect of IR on the TCZ or the TNZ due to the dynamic increase in ambient air temperature used in this investigation instead of a steady state protocol being used.

5.4 Limitations

One potential limitation of the study was that only young male participants were recruited. It is likely that an older population would be the main market for purchasing luxury vehicles. It is predicted that in an older population, as thermal sensitivity decreases with age (Guergova & Dufour, 2011), IR would elicit a positive perceptual response and may only improve TC to a lesser extent. Also body fatness of the participants was not accounted for, which is a limitation as body fat percentage influences TC (Zhang et al, 2001).

Static globe temperature measurements were not taken in the seat where the participant was sat. As environmental measures show that the conditions were consistent throughout trials, it is assumed that the radiant load on the participant would have been higher in the two IR trials as the IR panel was the only variable changed between trials.

Another limitation is that air velocity was not assessed during trials. Air velocity within the environmental chamber was measured during the ramp protocol during instrumentation and was less than 0.1m.sec^{-1}. Air velocity was therefore considered minimal and consistent throughout and between trials. No participants or experimenters noticed any air flow within the chamber and the same protocol was used for all trials ensuring consistency between conditions

Due to equipment failures (second IR panel breaking) it was not possible to include a combined IRV and IRF trial. It would have been of benefit to see the combined effect of these panels on participants' TC. The controlled rise in ambient air temperature (5-25°C) may not have been representative of the rate of rise in a vehicle. The dynamic protocol was the most controlled rise in air temperature which could be accurately reproduced using the environmental chamber. In different conditions vehicles will warm up at different rates. The use of IR in steady state conditions has not been addressed which is another limitation of the study.

5.5 Conclusion

In conclusion the present study has demonstrated that a relatively small IR panel can improve TC and TS in a dynamic "pull up" protocol. The added radiant heat meant that TC was achieved at lower ambient air temperatures which could reduce the energy requirement of the heating system in an electric vehicle, leading to a potential improvement in fuel economy. The hypothesis that IR would improve TC is therefore accepted due to higher values in the IR conditions and a "neutral" score being reported earlier and at lower ambient air temperature in IR trials compared to NoIR.

As TS and desirability scores improved quicker and a "neutral" score was reported earlier in the IR conditions, it is accepted that IR heating improves perceptual response in a warm up protocol. There were local subjective differences between the two IR trials, with IRV improving TC and TS in the chest & arms and hands, and IRF improving TC and TS in the lower leg, feet and toe. Also IR heating improved the acceptability of the total thermal environment.

The hypothesis that IR heating would warm up occupants' skin temperature is accepted on a local level. Anterior thigh temperatures were significantly warmer in the IRV trial and inner lower leg temperature was significantly warmer in the IRF trial.

Practical applications based on the current findings indicate that IR heating, targeted at the lower extremities or towards the hands and chest & arms, can improve TC within a vehicle. However there may be a safety issue with the temperature of the IR heat source. The visor which encased the IR panel reached temperatures over 60 which could be dangerous when directed towards humans..

5.6 Further Work

The current study is one of the first to investigate IR heating in vehicles. The initial finding of a positive effect of a single IR panel on TC and TS provides justification to further develop work in this area. Firstly it would be beneficial to investigate whether a combination of IR panels aimed at various body areas would result in a greater perceptual response due to a 'cumulative' effect. Using a steady state protocol would help detect if IR heating improves TC at certain ambient air temperatures. From this it would be of benefit to try and identify which optimal body areas IR heating can affect. This could be achieved by having a steady state protocol (ambient air ≈15°C) with participants entering a vehicle which is fitted with individual IR panels directed at different body areas. One of the panels will then be turned on and time to TS measured, with participants also reporting the regions they can feel 'warmth' from the panel.

In order to include a feedback system, occupant feedback should be used to tailor which IR panels to use to achieve TC. This could be achieved by using a variety of steady state temperatures (10°C, 15°C, 18°C and 22°C) with the participant seated in a vehicle with all 5 IR panels switched on. Over the course of a 30 min protocol participants will inform the investigator which panels they want warmer and which they want cooler. This will indicate how TC is affected over the temperature range and which IR panels they report as being more effective.

Due to the positive effect seat heating can have on TC, using a combination of this and IR to improve TC could be examined. With a view to developing a heating system to provide TC compromised of radiant, conductive and air based (convective) heating. It is hypothesised that increasing the surface area of the IR panel would increase the perceptual and thermal responses. Further work using a combination of IR and convective heating methods is also warranted as this may be the only way to achieve comfort with a radiant heat source (Bäuml et al, 2014).

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7.0 Appendix

APPENDIX A

Table A1: Environmental variables (mean ± SD) during preconditioning.

Time (min)	Trial	Air Head Level (°C)	Humidity Head Level (%)	Air Chest Level (°C)	Humidity Chest Level (%)
	NoIR	21.9±0.4	38.1±8.1	21.7±0.4	38.5±7.8
-15	IRH	22.0±0.4	38.6±10.5	21.5±0.5	37.6±8.1
	IRF	21.7±0.3	33.4±0.5	21.7±0.4	34.2±0.6
	NoIR	21.8±0.4	38.3±8.2	21.7±0.4	38.3±7.7
-10	IRH	21.8±0.6	38.1±10.3	21.5±0.5	37.2±7.8
	IRF	21.7±0.4	33.6±1.0	21.7±0.4	34.1±0.5
	NoIR	21.8±0.4	38.4±8.5	21.7±0.4	38.3±7.9
-5	IRH	21.8±0.6	37.5±10.8	21.5±0.5	36.5±8.1
	IRF	21.7±0.4	33.1±1.5	21.7±0.4	33.6±0.9
	NoIR	21.8±0.5	37.9±9.2	21.6±0.4	37.8±8.6
0	IRH	21.8±0.6	37.0±11.3	21.5±0.5	36.0±8.3
	IRF	21.7±0.3	32.7±1.6	21.7±0.4	33.4±1.0

Table A2: Thermal comfort (mean ± SD) responses during preconditioning (arbitrary units).

Time (min)	Trial	Head	Face	Nose	Chest & Arms	Hands	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
	NoIR	1.4±1.1	1.4±1.1	1.3±1.2	1.5±1.1	1.1±1.1	1.5±1.1	1.4±1.2	1.1±1.0	1.1±1.4	1.1±1.4	1.5±1.1	1.3±1.1
-15	IRH	1.5±0.9	1.5±0.9	1.4±1.1	1.4±1.1	1.4±1.1	1.4±1.1	1.5±0.9	1.5±0.9	1.1±1.2	1.1±1.2	1.4±1.1	1.4±1.0
	IRF	1.2±1.0	1.2±1.0	1.0±1.1	1.3±0.8	1.3±0.8	1.5±0.5	1.5±0.5	1.0±1.1	0.7±1.5	1.0±1.3	1.3±0.8	1.2±0.9
	NoIR	1.4±1.1	1.5±0.9	1.4±1.1	1.6±0.9	1.4±1.1	1.6±0.9	1.6±0.9	1.3±1.0	1.0±1.4	1.0±1.4	1.5±1.1	1.4±1.0
-10	IRH	1.4±1.1	1.4±1.1	1.4±1.1	1.3±1.2	1.4±1.1	1.4±1.1	1.4±1.1	1.3±1.2	1.3±1.2	1.3±1.2	1.4±1.1	1.3±1.1
	IRF	1.2±1.0	1.2±1.0	1.0±1.1	1.5±0.5	1.2±0.8	1.5±0.5	1.5±0.5	0.8±1.3	0.8±1.3	1.0±1.3	1.0±1.1	1.2±0.9
	NoIR	1.4±1.1	1.4±1.1	1.3±1.2	1.6±0.9	1.4±1.1	1.5±1.1	1.6±0.9	1.0±1.2	1.0±1.4	1.0±1.4	1.4±1.2	1.3±1.0
-5	IRH	1.5±0.9	1.5±0.9	1.4±1.1	1.3±1.2	1.4±1.1	1.4±1.1	1.4±1.1	1.3±1.2	1.3±1.2	1.3±1.2	1.4±1.1	1.4±1.0
	IRF	1.2±1.0	1.2±1.0	1.0±1.1	1.5±0.5	1.2±1.0	1.5±0.5	1.5±0.5	0.8±1.3	0.8±1.3	0.8±1.3	1.0±1.1	1.2±0.9
	NoIR	1.5±0.9	1.4±1.1	1.3±1.2	1.6±0.9	1.4±1.1	1.6±0.9	1.6±0.9	1.0±1.2	1.1±1.4	1.1±1.4	1.4±1.2	1.4±1.0
0	IRH	1.5±0.9	1.5±0.9	1.3±0.9	1.4±1.1	1.3±0.9	1.3±0.9	1.3±0.9	1.1±0.8	1.0±0.9	1.0±0.9	1.3±0.9	1.3±0.8
	IRF	1.3±1.0	1.2±1.0	1.0±1.1	1.3±0.8	1.0±1.1	1.2±1.0	1.3±0.8	0.8±1.3	0.7±1.5	0.8±1.5	1.0±1.1	1.1±1.1

Table A3: Thermal sensation (mean ± SD) responses during preconditioning (arbitrary units).

Time (min)	Trial	Head	Face	Nose	Chest & Arms	Hands	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
	NoIR	0.9±0.8	0.9±1.0	0.8±0.9	1.1±1.0	0.8±1.0	0.9±1.0	1.1±0.8	0.5±1.1	0.5±1.4	0.4±1.3	0.9±1.0	0.8±0.9
-15	IRH	0.6±1.2	0.9±1.0	0.5±1.1	1.0±1.2	0.6±0.9	0.8±0.9	0.9±0.8	0.6±0.9	0.3±1.2	0.3±1.2	0.9±1.0	0.6±0.9
	IRF	0.7±1.0	0.8±0.8	0.7±0.8	1.0±0.6	0.7±0.5	1.0±0.6	1.2±0.4	0.3±1.2	0.2±1.5	0.3±1.4	0.7±0.8	0.7±0.8
	NoIR	1.0±0.9	1.0±1.1	0.9±1.0	1.3±0.9	1.1±1.1	1.1±1.0	1.3±0.9	0.6±1.1	0.6±1.4	0.5±1.3	1.0±1.1	0.9±0.9
-10	IRH	0.6±1.2	0.9±1.0	0.6±1.2	0.9±1.0	0.6±0.9	0.9±0.8	0.9±0.8	0.5±0.9	0.1±1.2	0.1±1.2	0.8±0.9	0.6±0.9
	IRF	0.8±0.8	0.8±0.8	0.7±0.8	1.2±0.4	0.7±0.5	1.2±0.4	1.2±0.4	0.3±1.2	0.0±1.3	0.5±1.4	0.7±0.8	0.7±0.7
	NoIR	1.0±0.9	1.1±1.0	0.9±1.0	1.3±0.9	1.0±1.1	1.3±0.9	1.3±0.9	0.6±1.1	0.5±1.4	0.4±1.3	1.0±1.1	0.9±0.9
-5	IRH	0.6±1.2	0.9±1.0	0.6±1.2	0.8±0.9	0.6±0.9	0.9±0.8	0.9±0.8	0.5±0.9	0.3±1.2	0.3±1.2	0.8±0.9	0.6±0.9
	IRF	0.8±0.8	0.8±0.8	0.7±0.8	1.2±0.4	0.7±0.5	1.0±0.6	1.2±0.4	0.3±1.2	-0.2±1.2	0.3±1.4	0.7±0.8	0.7±0.7
	NoIR	1.0±0.9	1.1±0.8	1.0±0.9	1.3±0.9	1.0±1.2	1.3±0.9	1.3±0.9	0.6±1.1	0.6±1.4	0.5±1.3	1.1±1.0	1.0±0.9
0	IRH	0.5±1.1	0.6±0.9	0.5±1.1	0.9±1.0	0.8±0.9	0.9±0.8	1.0±0.9	0.4±1.1	0.3±1.2	0.3±1.2	0.6±0.9	0.6±0.9
	IRF	0.8±0.8	0.8±0.8	0.7±0.8	0.8±0.8	0.5±0.8	1.2±0.4	1.0±0.6	0.3±1.2	-0.2±1.2	0.5±1.4	0.7±0.8	0.7±0.7

Table A4: Core temperature, mean skin temperature and heat storage (mean ± SD) during preconditioning.

Time (min)	Trial	Rectal (°C)	Aural (°C)	Mean skin temp[1] (°C)	Mean skin temp[2] (°C)	Heat storage[1] ($J \cdot g^{-1}$)	Heat storage[2] ($J \cdot g^{-1}$)	Heat storage[3] ($J \cdot g^{-1}$)	Heat storage[4] ($J \cdot g^{-1}$)
	NoIR	37.4±0.3	36.0±0.3	31.9±0.5	31.8±0.6	0.0±0.0	0.0±0.1	0.0±0.0	0.0±0.1
-15	IRV	37.3±0.2	35.9±0.5	31.8±0.6	31.7±0.4	0.0±0.1	0.0±0.1	0.0±0.1	0.0±0.1
	IRF	37.2±0.2	35.6±0.7	31.8±0.7	31.9±0.7	0.1±0.3	0.1±0.3	0.1±0.2	0.1±0.1
	NoIR	37.3±0.2	36.1±0.3	32.1±0.5	32.0±0.4	0.1±0.1	0.6±0.8	0.1±0.8	0.6±0.8
-10	IRV	37.3±0.2	35.9±0.5	31.9±0.5	31.8±0.4	0.1±0.1	0.1±0.2	0.1±0.2	0.1±0.2
	IRF	37.2±0.2	35.7±0.7	31.9±0.6	32.1±0.6	0.2±0.4	0.3±0.4	0.2±0.4	0.3±0.2
	NoIR	37.3±0.2	36.2±0.3	32.1±0.5	32.1±0.4	0.1±0.2	0.9±1.5	0.1±0.2	1.0±1.5
-5	IRV	37.3±0.3	36.0±0.4	32.1±0.6	31.9±0.4	0.2±0.3	0.3±0.4	0.1±0.2	0.2±0.3
	IRF	37.2±0.2	35.7±0.8	31.9±0.6	32.1±0.6	0.2±0.4	0.3±0.5	0.2±0.3	0.3±0.3
	NoIR	37.3±0.2	36.1±0.5	32.2±0.5	32.1±0.3	0.1±0.2	1.2±2.0	0.1±0.2	1.2±2.0
0	IRV	37.2±0.3	36.0±0.5	32.2±0.7	31.9±0.4	0.2±0.4	0.4±0.5	0.1±0.2	0.3±0.3
	IRF	37.1±0.2	35.6±0.7	31.8±0.6	32.1±0.6	0.1±0.4	0.2±0.4	0.2±0.3	0.3±0.3

Mean skin temp[1] Ramanathan, [2] Oi et al.; Heat storage[1,2] Ramanathan using rectal and aural temp, Oi et al.[3,4] using rectal and aural, respectively.

APPENDIX B

Table B1: Environmental variables (mean ± SD) throughout each condition. P relates to the 3 min standing period prior to sitting.

(ANOVA main effect $^{\#}P<0.05$, $^{*}P<0.01$, $^{**}P<0.001$; superscript[1] indicates P is equal to $^{\#,\ *,\ **}$).

Time (min)	Trial	Globe Temperature (°C)**	Air Head Level (°C)**	Humidity Head Level (%)**	Air Chest Level (°C)**	Humidity Chest Level (%)**	Air Foot Level (°C)**	Humidity Foot Level (%)**
	NoIR	3.8±0.6	4.5±0.9	59.6±7.3	4.4±0.7	59.4±7.0	3.6±0.4	63.1±6.8
P1	IRV	4.4±0.8	4.2±0.8	56.0±6.7	4.0±0.8	55.4±6.3	2.8±0.4	59.7±6.5
	IRF	4.0±0.8	3.3±1.5	56.8±5.3	6.9±6.2	53.3±4.0	1.8±0.9	61.0±3.4
	NoIR	3.9±0.5	4.6±0.9	58.5±7.6	4.6±0.6	58.9±7.2	3.8±0.3	62.9±6.9
P2	IRV	4.4±0.7	4.4±0.8	55.1±7.2	4.1±0.7	55.4±6.7	2.9±0.4	60.0±6.5
	IRF	4.1±0.7	3.5±1.3	55.8±4.6	7.0±6.1	52.9±3.3	2.0±1.0	60.8±2.5
	NoIR	4.0±0.4	4.7±0.8	58.9±7.7	4.8±0.5	59.0±7.1	3.8±0.4	62.9±7.3
P3	IRV	4.5±0.7	4.5±0.8	55.8±8.3	4.1±0.8	56.1±7.1	2.9±0.5	60.6±6.4
	IRF	4.1±0.7	3.7±1.3	55.9±3.9	7.1±6.1	52.8±3.2	2.0±1.0	61.3±2.0
	NoIR	4.1±0.3	4.9±0.6	58.8±6.9	4.9±0.4	58.7±6.2	3.8±0.4	62.8±5.8
2	IRV	4.7±0.7	4.8±0.9	56.3±6.2	4.3±0.8	56.8±6.2	3.0±0.6	62.0±6.1
	IRF	4.3±0.6	3.9±1.2	56.9±4.2	7.2±6.1	53.7±4.0	2.1±0.7	62.6±3.3
	NoIR	4.5±0.3	5.0±0.6	58.7±5.5	4.9±0.3	59.3±5.0	3.8±0.5	64.9±4.3
4	IRV	5.1±0.6	4.8±0.9	56.0±4.3	4.4±0.8	57.4±4.8	3.0±0.7	64.4±5.0
	IRF	4.7±0.6	3.9±1.0	59.0±4.1	7.3±6.0	56.1±4.3	2.3±0.9	66.4±3.3

Time (min)	Trial	Globe Temperature	Air Head Level	Humidity Head Level	Air Chest Level	Humidity Chest Level	Air Foot Level	Humidity Foot Level
	NoIR	5.0±0.3	5.2±0.6	67.7±2.2	5.2±0.3	68.7±2.4	4.1±0.5	77.7±3.5
6	IRV	5.6±0.5	5.1±0.9	68.7±3.9	4.7±0.9	69.1±3.4	3.4±0.8	80.6±3.6
	IRF	5.4±0.6	4.4±1.0	71.8±4.7	7.5±5.9	65.6±8.2	2.9±0.7	81.6±2.8
	NoIR	5.9±0.4	5.9±0.5	76.4±1.6	5.9±0.4	76.0±1.9	5.0±0.4	84.9±3.5
8	IRV	6.5±0.5	5.8±0.8	78.7±4.1	5.5±0.9	76.9±3.2	4.5±0.7	88.5±3.7
	IRF	6.3±0.5	5.2±0.7	78.7±5.4	8.1±5.6	71.0±11.0	4.0±0.5	88.0±3.8
	NoIR	7.0±0.4	6.7±0.4	79.2±4.3	6.8±0.4	78.3±3.9	6.1±0.3	86.2±5.7
10	IRV	7.6±0.4	6.7±0.7	79.5±4.6	6.4±0.8	78.8±4.4	5.5±0.7	89.3±5.1
	IRF	7.3±0.5	6.2±0.6	78.5±4.7	8.8±5.3	71.7±11.6	5.1±0.3	87.1±4.2
	NoIR	7.9±0.4	7.6±0.4	79.1±6.7	7.7±0.3	78.0±6.2	7.1±0.3	84.8±8.0
12	IRV	8.4±0.4	7.6±0.6	78.2±5.8	7.1±0.7	78.4±6.0	6.5±0.7	87.6±7.0
	IRF	8.2±0.4	7.2±0.5	76.0±5.5	9.4±4.9	70.7±11.6	6.1±0.3	83.3±5.4
	NoIR	8.9±0.4	8.6±0.3	77.9±8.5	8.6±0.3	77.4±8.5	8.1±0.3	83.4±10.4
14	IRV	9.3±0.3	8.4±0.6	76.7±7.8	7.9±0.7	77.4±7.9	7.3±0.6	85.3±9.4
	IRF	9.2±0.3	8.2±0.4	72.1±6.1	10.2±4.6	68.2±11.2	7.2±0.3	78.6±6.8
	NoIR	9.9±0.4	9.6±0.3	76.5±10.5	9.6±0.4	76.4±10.9	9.2±0.4	81.8±13.1
16	IRV	10.3±0.3	9.4±0.6	74.6±9.7	8.8±0.7	75.8±10.0	8.3±0.6	82.7±11.9
	IRF	10.2±0.2	9.4±0.4	67.4±6.1	11.0±4.2	64.8±10.0	8.3±0.3	73.0±7.5

Time (min)	Trial	Globe Temperature	Air Head Level	Humidity Head Level	Air Chest Level	Humidity Chest Level	Air Foot Level	Humidity Foot Level
	NoIR	11.0±0.4	10.7±0.4	74.4±12.4	10.8±0.3	74.5±12.8	10.4±0.4	78.7±14.7
18	IRV	11.3±0.4	10.5±0.5	71.6±11.2	9.8±0.7	73.4±11.8	9.3±0.6	79.0±13.8
	IRF	11.3±0.2	10.7±0.4	61.9±5.5	11.9±3.7	60.8±8.1	9.5±0.3	66.9±7.2
	NoIR	12.1±0.4	11.9±0.4	71.5±13.4	12.1±0.3	71.5±13.6	11.7±0.4	75.1±15.8
20	IRV	12.4±0.4	11.6±0.5	67.8±12.4	10.9±0.7	70.1±13.0	10.5±0.6	74.6±15.1
	IRF	12.5±0.2	12.0±0.4	56.6±4.6	12.8±3.3	56.8±5.9	10.9±0.3	60.9±6.3
	NoIR	13.3±0.4	13.2±0.5	68.6±14.0	13.4±0.4	68.2±13.9	13.0±0.6	70.7±15.6
22	IRV	13.6±0.4	12.8±0.6	64.1±13.2	12.1±0.7	66.3±13.4	11.7±0.6	70.0±15.7
	IRF	13.8±0.2	13.5±0.5	52.0±3.8	13.9±2.8	53.0±4.0	12.2±0.3	55.8±5.1
	NoIR	14.6±0.5	14.5±0.7	65.3±14.0	14.8±0.5	64.6±13.7	14.3±0.7	67.0±15.3
24	IRV	14.7±0.4	14.1±0.6	60.3±13.1	13.3±0.8	62.5±13.5	13.0±0.6	65.3±15.8
	IRF	15.1±0.3	15.1±0.6	48.1±2.9	14.9±2.3	49.9±2.5	13.5±0.3	51.9±3.9
	NoIR	15.9±0.5	15.9±0.7	62.0±13.7	16.2±0.6	60.9±13.2	15.5±0.9	63.5±14.8
26	IRV	15.9±0.5	15.4±0.7	57.0±13.2	14.6±0.9	59.0±13.2	14.3±0.7	61.4±15.3
	IRF	16.4±0.3	16.7±0.6	44.7±2.2	16.1±1.8	47.1±2.0	14.8±0.4	48.8±3.2
	NoIR	17.2±0.6	17.4±0.8	58.3±13.7	17.7±0.7	57.3±12.9	16.5±1.1	60.4±14.2
28	IRV	17.2±0.6	16.8±0.7	53.8±13.0	15.9±0.9	55.8±12.8	15.5±0.7	57.9±14.3
	IRF	17.7±0.3	18.3±0.6	41.9±1.6	17.4±1.4	44.8±2.3	16.1±0.5	46.3±2.6

Time (min)	Trial	Globe Temperature	Air Head Level	Humidity Head Level	Air Chest Level	Humidity Chest Level	Air Foot Level	Humidity Foot Level
	NoIR	18.5±0.7	18.9±0.9	55.0±12.8	19.2±0.8	53.7±12.0	17.4±1.2	57.8±13.1
30	IRV	18.4±0.7	18.2±0.9	51.3±12.1	17.4±0.9	53.1±11.8	16.7±0.8	55.5±13.1
	IRF	19.0±0.3	19.9±0.7	40.9±2.5	18.6±1.0	43.4±3.1	17.4±0.5	45.7±2.4
	NoIR	19.9±0.7	20.4±1.1	52.8±10.1	20.8±0.9	51.6±9.1	18.2±1.4	56.6±10.9
32	IRV	19.7±0.8	19.7±1.0	49.3±10.9	18.8±0.9	51.0±10.3	17.9±0.8	53.8±11.7
	IRF	20.3±0.4	21.7±0.8	41.7±1.3	20.1±1.0	44.4±3.0	18.7±0.6	47.0±1.7
	NoIR	21.2±0.8	21.9±1.2	50.2±8.6	22.3±1.0	49.0±7.7	19.0±1.6	56.2±9.4
34	IRV	21.0±0.8	21.1±1.1	47.9±8.9	20.3±0.9	49.4±8.3	18.9±0.9	53.1±10.2
	IRF	21.6±0.5	23.3±0.9	41.9±2.4	21.4±1.4	44.5±2.6	20.0±0.7	48.3±2.5
	NoIR	22.2±0.8	23.1±1.2	47.7±7.1	23.4±1.1	46.6±6.2	20.0±1.8	54.3±8.4
36	IRV	22.0±0.9	22.2±1.2	46.3±7.1	21.4±0.9	47.7±6.6	20.0±0.9	51.6±8.5
	IRF	22.6±0.6	24.5±0.8	41.3±2.1	22.4±1.8	44.0±3.0	21.2±0.7	47.6±2.6
	NoIR	23.0±0.8	24.0±1.1	45.4±6.0	24.2±1.1	44.4±5.2	21.2±1.8	51.2±7.5
38	IRV	22.8±0.9	23.1±1.2	44.7±6.0	22.3±0.9	45.9±5.6	20.9±0.9	49.5±7.1
	IRF	23.4±0.6	25.3±0.7	40.0±1.8	23.1±1.9	42.6±3.3	22.1±0.6	45.6±2.2
	NoIR	23.6±0.8	24.7±1.0	43.4±5.5	24.9±1.0	42.5±4.7	22.2±1.9	48.2±7.0
40	IRV	23.4±0.8	23.8±1.1	42.8±5.2	23.0±0.9	44.0±4.6	21.7±1.0	47.1±5.7
	IRF	23.9±0.6	25.8±0.6	38.6±1.6	23.5±2.1	41.4±3.6	22.9±0.6	43.6±2.0

Table B2: Car seat temperature and infrared panel (visor) temperature and heat flux (mean ± SD). P relates to the 3 min standing period prior to sitting(ANOVA main effect #P<0.05, *P<0.01, **P<0.001; superscript[1] indicates P is equal to #, *, **).

Time (min)	Trial	Seat left buttock (°C)**	Seat right buttock (°C)**	Seat right lower back (°C)**	Seat left lower back (°C)**	Right visor (°C)**	Middle visor (°C)**	Left visor (°C)**	Visor heat flux ($W \cdot m^2$)**
	NoIR	5.0±1.0	5.2±1.1	4.8±0.9	4.8±0.8	4.5±0.9	4.5±0.9	4.0±0.7	
P1	IRV	5.9±0.8	6.3±0.8	5.5±0.6	5.5±0.7	56.3±2.1	52.7±3.6	44.2±5.7	
	IRF	5.3±0.5	5.6±0.6	5.3±0.4	5.6±0.5	51.9±2.3	50.5±3.1	43.9±3.1	
	NoIR	5.1±1.0	5.3±1.0	4.9±0.8	4.9±0.8	4.7±0.8	4.7±0.8	4.1±0.5	
P2	IRV	6.0±0.7	6.4±0.7	5.7±0.5	5.7±0.7	56.7±1.9	52.9±3.8	44.6±6.0	
	IRF	5.4±0.4	5.7±0.6	5.4±0.4	5.7±0.4	52.2±2.2	50.6±2.9	44.1±2.6	
	NoIR	5.1±0.9	5.4±1.0	4.9±0.8	5.0±0.7	4.7±0.7	4.6±0.6	4.1±0.4	
P3	IRV	6.1±0.7	6.5±0.7	5.8±0.5	5.8±0.7	57.0±2.3	53.1±4.3	44.9±6.6	
	IRF	5.5±0.4	5.8±0.5	5.5±0.4	5.9±0.4	52.3±2.0	50.7±3.0	44.2±2.4	
	NoIR	12.7±2.0	11.7±2.3	9.1±1.9	8.6±1.6	5.1±0.6	5.1±0.6	4.6±0.4	12±24
2	IRV	13.2±3.5	12.4±3.5	9.5±2.7	9.9±2.5	57.2±2.1	52.9±4.2	45.7±5.1	856±529
	IRF	14.3±2.6	14.0±2.1	9.2±1.3	10.4±2.1	52.5±1.9	51.1±2.7	44.2±2.5	-
	NoIR	21.8±0.9	20.1±2.6	15.9±2.9	14.1±2.9	5.8±0.7	5.7±0.8	5.2±0.5	3±21
4	IRV	21.3±2.3	19.7±3.1	16.4±3.6	15.5±3.3	57.2±1.6	52.1±3.9	45.5±3.0	983±429
	IRF	21.3±1.7	21.3±2.0	16.5±3.7	16.8±3.0	52.7±2.0	52.2±2.8	44.1±2.1	-

`Time (min)	Trial	Seat left buttock	Seat right buttock	Seat right lower back	Seat left lower back	Right visor	Middle visor	Left visor	Visor heat flux
	NoIR	24.8±0.6	23.6±2.4	19.7±2.4	17.3±3.4	6.8±0.8	7.0±0.9	6.4±0.7	-13±21
6	IRV	24.2±2.0	22.7±3.1	19.9±3.7	18.5±3.8	58.6±1.4	53.8±3.7	47.0±2.2	1103±102
	IRF	24.3±1.2	24.2±1.6	19.5±3.3	20.0±3.0	54.1±2.2	53.6±2.8	45.7±2.1	-
	NoIR	26.3±0.6	25.4±2.1	22.1±2.1	19.3±3.6	8.5±0.8	8.8±0.9	8.2±0.7	-19±24
8	IRV	25.7±1.8	24.4±2.9	22.1±3.5	20.3±4.0	60.1±1.3	55.7±3.7	49.4±1.1	1100±56
	IRF	25.8±1.1	25.7±1.4	21.9±3.1	22.0±2.6	55.4±2.2	55.3±3.1	47.2±2.3	-
	NoIR	27.2±0.6	26.4±1.9	23.7±1.9	20.8±3.7	9.6±0.6	10.0±0.7	9.5±0.5	-27±18
10	IRV	26.7±1.7	25.4±2.8	23.6±3.2	21.5±4.0	61.1±1.4	56.8±4.0	50.8±1.0	1098±54
	IRF	26.8±1.1	26.6±1.2	23.6±3.1	23.4±2.3	56.5±2.2	56.0±2.8	48.2±2.3	-
	NoIR	27.8±0.6	27.2±1.7	24.8±1.7	21.9±3.6	10.5±0.6	10.8±0.6	10.4±0.5	-31±15
12	IRV	27.3±1.6	26.1±2.6	24.7±3.0	22.4±3.9	61.7±1.3	57.6±4.1	51.5±0.9	1079±51
	IRF	27.5±1.0	27.3±1.1	24.7±3.0	24.3±2.1	57.2±2.0	56.7±2.6	49.2±2.3	-
	NoIR	28.4±0.6	27.7±1.6	25.7±1.6	22.7±3.5	11.3±0.6	11.7±0.8	11.3±0.6	-38±14
14	IRV	27.8±1.6	26.7±2.5	25.4±2.8	23.1±3.8	62.6±1.3	58.6±4.0	52.6±0.8	1088±48
	IRF	28.0±1.0	27.8±1.0	25.6±2.9	25.0±1.9	58.2±1.7	57.7±2.7	50.4±2.1	-
	NoIR	28.8±0.6	28.2±1.5	26.3±1.5	23.3±3.4	12.3±0.6	12.8±0.8	12.4±0.6	-47±14
16	IRV	28.2±1.6	27.1±2.4	26.1±2.6	23.6±3.7	63.5±1.2	59.7±3.9	54.1±0.6	1075±40
	IRF	28.4±1.0	28.2±1.0	26.2±2.9	25.6±1.9	59.3±2.0	58.7±2.2	51.5±2.0	-

Time (min)	Trial	Seat left buttock	Seat right buttock	Seat right lower back	Seat left lower back	Right visor	Middle visor	Left visor	Visor heat flux
	NoIR	29.2±0.6	28.5±1.4	26.8±1.5	23.9±3.3	13.3±0.6	13.9±0.8	13.5±0.6	-53±14
18	IRV	28.6±1.5	27.5±2.3	26.6±2.5	24.0±3.5	64.7±1.1	60.9±3.5	55.1±0.7	1087±42
	IRF	28.8±1.1	28.5±1.0	26.7±2.7	26.0±1.8	60.0±1.5	59.4±1.3	52.3±2.1	-
	NoIR	29.5±0.7	28.9±1.3	27.4±1.4	24.4±3.2	14.3±0.6	14.9±0.8	14.7±0.6	-61±13
20	IRV	28.9±1.5	27.9±2.2	27.0±2.4	24.4±3.4	65.6±1.0	61.5±3.4	55.7±1.2	1050±80
	IRF	29.1±1.1	28.8±0.9	27.2±2.6	26.3±1.9	60.1±1.5	59.6±2.5	52.6±2.6	-
	NoIR	29.8±0.7	29.1±1.2	27.8±1.3	24.8±3.1	15.4±0.6	16.0±0.9	15.8±0.6	-66±10
22	IRV	29.2±1.5	28.2±2.0	27.5±2.2	24.7±3.4	65.6±1.0	61.7±2.8	56.8±1.3	1025±60
	IRF	29.3±1.2	29.0±1.0	27.6±2.6	26.5±1.9	61.2±1.4	60.7±1.6	53.9±2.2	-
	NoIR	30.0±0.7	29.4±1.2	28.0±1.4	25.2±3.0	16.5±0.7	17.1±0.9	17.0±0.7	-75±12
24	IRV	29.5±1.5	28.5±1.9	27.8±2.1	25.1±3.3	66.2±0.7	62.5±3.1	57.7±1.5	995±73
	IRF	29.5±1.2	29.3±0.9	27.7±2.5	26.8±1.9	60.7±1.2	59.6±2.2	53.9±2.5	-
	NoIR	30.2±0.7	29.6±1.2	28.3±1.6	25.5±2.9	17.7±0.7	18.4±1.0	18.3±0.8	-80±14
26	IRV	29.7±1.4	28.7±1.8	28.1±2.0	25.3±3.2	66.2±1.2	62.6±2.8	58.0±1.8	977±60
	IRF	29.7±1.2	29.5±0.9	27.9±2.3	27.0±1.7	61.9±1.4	61.2±0.5	54.9±2.1	-
	NoIR	30.4±0.8	29.7±1.3	28.5±1.6	25.8±2.9	18.8±0.7	19.5±1.1	19.5±0.9	-88±10
28	IRV	29.9±1.4	29.0±1.7	28.3±1.9	25.7±3.1	66.5±1.1	62.9±3.2	58.2±1.5	943±57
	IRF	30.2±1.0	29.7±0.9	28.2±2.3	27.3±1.7	61.6±1.1	60.7±2.0	54.5±2.1	-

Time (min)	Trial	Seat left buttock	Seat right buttock	Seat right lower back	Seat left lower back	Right visor	Middle visor	Left visor	Visor heat flux
	NoIR	30.6±0.8	29.9±1.2	28.8±1.5	26.1±2.8	20.0±0.7	20.8±1.0	20.8±1.0	-96±10
30	IRV	30.2±1.4	29.3±1.4	28.6±1.9	26.0±3.0	67.3±1.2	63.4±2.7	58.4±1.7	921±69
	IRF	30.4±1.0	29.9±0.9	28.7±2.0	27.6±1.6	63.0±0.7	62.5±0.9	55.8±2.1	-
	NoIR	30.8±0.9	30.1±1.3	29.1±1.4	26.5±2.7	21.2±0.6	22.1±0.9	22.2±1.0	-101±13
32	IRV	30.5±1.4	29.6±1.2	28.9±1.9	26.4±2.8	67.4±1.0	63.4±1.8	58.4±2.0	914±45
	IRF	30.6±1.0	30.1±0.9	29.2±1.7	27.9±1.4	63.2±1.1	62.6±1.7	56.0±2.1	-
	NoIR	31.0±0.8	30.3±1.2	29.4±1.3	26.8±2.6	22.2±0.5	23.1±0.9	23.3±0.9	-94±10
34	IRV	30.7±1.4	29.8±1.1	29.1±1.9	26.8±2.6	66.8±0.5	63.1±2.3	58.6±1.8	901±58
	IRF	30.7±1.1	30.2±0.9	29.5±1.7	28.2±1.3	63.2±0.5	62.0±1.5	56.2±2.2	-
	NoIR	31.0±1.1	30.4±1.3	29.7±1.2	27.1±2.5	22.7±0.6	23.3±1.0	23.7±1.0	-87±11
36	IRV	30.9±1.4	30.0±1.1	29.3±1.8	27.1±2.5	66.5±1.1	63.0±2.9	58.8±1.5	863±56
	IRF	30.8±1.1	30.3±0.9	29.8±1.6	28.4±1.2	63.5±0.8	62.2±2.1	56.5±1.8	-
	NoIR	31.1±1.3	30.5±1.4	29.9±1.2	27.3±2.5	23.0±0.6	23.4±1.1	23.9±1.0	-87±9
38	IRV	31.0±1.4	30.2±1.1	29.6±1.8	27.4±2.4	66.8±0.8	63.6±2.8	59.0±1.6	872±38
	IRF	30.9±1.1	30.5±0.9	30.0±1.6	28.6±1.2	63.1±0.9	62.0±1.1	56.4±2.0	-
	NoIR	31.2±1.3	30.7±1.3	30.2±1.1	27.6±2.4	23.3±0.6	23.6±1.0	24.2±0.8	-81±10
40	IRV	31.2±1.4	30.3±1.0	29.9±1.7	27.6±2.4	66.4±1.0	63.4±3.3	58.7±1.7	879±65
	IRF	31.1±1.1	30.6±0.9	30.1±1.5	28.7±1.1	62.6±0.7	61.1±1.3	55.8±2.2	-

Table B3: Thermal comfort (arbitrary units, mean ± SD) responses during the trial (not collected during 3 min stand prior to being seated; ANOVA main effect $^{\#}P<0.05$, $^{*}P<0.01$, $^{**}P<0.001$; superscript^{1} indicates P is equal to $^{\#, *, **}$).

Time (min)	Trial	Head	Face	Nose	Chest & Arms*	Hand**	Seat Back Contact**	Seat Cushion Contact**	Lower Leg**	Feet#	Toes#1	Overall**1	Average#
	NoIR												
P1	IRV												
	IRF												
	NoIR												
P2	IRV												
	IRF												
	NoIR												
P3	IRV												
	IRF												
	NoIR	-0.5±1.2	-0.6±1.3	-0.5±1.3	-0.3±0.7	-1.1±1.2	-0.8±1.3	-0.8±1.0	-1.1±1.1	-1.1±1.2	-1.0±1.2	-1.0±1.2	-0.8±1.0
2	IRV	-0.5±1.3	-0.5±1.3	-0.6±1.1	0.5±1.4	-0.9±1.2	-0.1±1.2	-0.3±1.4	-0.6±1.4	-0.6±1.3	-0.4±1.4	-0.5±1.3	-0.4±1.1
	IRF	-0.8±1.3	-1.0±1.5	-1.3±1.2	-0.7±1.2	-1.7±0.8	-0.7±1.2	-0.7±1.2	-1.0±0.9	-1.2±1.3	-1.0±1.3	-1.3±0.8	-1.0±1.1
	NoIR	-0.8±1.4	-0.8±1.4	-0.9±1.4	-0.4±1.2	-1.4±0.9	-0.9±1.4	-0.9±1.1	-1.3±1.2	-1.1±1.6	-1.0±1.5	-0.9±1.6	-0.9±1.2
4	IRV	-0.9±1.5	-0.6±1.4	-0.8±1.4	0.0±1.6	-1.3±1.2	-0.4±1.6	-0.6±1.4	-0.9±1.7	-1.0±1.5	-0.9±1.4	-0.8±1.6	-0.7±1.3
	IRF	-0.8±1.3	-1.3±1.2	-1.3±1.2	-0.5±1.0	-1.5±0.8	-0.7±1.2	-0.7±1.0	-1.0±0.9	-1.2±1.3	-1.0±1.4	-1.0±0.9	-1.0±1.0

Time (min)	Trial	Head	Face	Nose	Chest & Arms	Hands	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
	NoIR	-0.6±1.4	-0.6±1.3	-0.8±1.3	-0.3±1.2	-1.3±1.0	-0.8±1.2	-0.9±1.1	-1.4±1.1	-1.3±1.4	-1.1±1.4	-0.9±1.6	-0.9±1.1
6	IRV	-0.6±1.3	-0.4±1.4	-0.5±1.3	-0.1±1.1	-0.9±1.0	-0.4±1.3	-0.4±1.3	-1.0±1.4	-1.0±1.7	-0.8±1.6	-0.6±1.8	-0.6±1.3
	IRF	-1.2±1.0	-1.3±1.2	-1.3±1.2	-0.3±1.2	-1.3±1.0	-0.7±1.2	-0.7±1.0	-0.8±1.2	-1.2±1.3	-1.0±1.4	-1.0±1.3	-1.0±1.0
	NoIR	-0.5±1.3	-0.6±1.3	-0.6±1.1	-0.1±1.4	-1.1±1.0	-0.4±1.3	-0.8±1.3	-1.1±1.0	-0.9±1.4	-0.9±1.4	-0.5±1.4	-0.7±1.1
8	IRV	-0.4±1.3	-0.4±1.3	-0.4±1.4	0.1±1.2	-0.8±1.0	0.1±1.0	-0.3±1.2	-0.8±1.5	-1.0±1.5	-0.5±1.4	-0.5±1.4	-0.4±1.2
	IRF	-0.7±0.8	-1.0±1.1	-1.2±1.0	-0.3±1.2	-0.8±0.8	-0.3±1.5	-0.5±1.0	-0.5±1.2	-0.8±1.0	-0.7±1.0	-0.7±1.2	-0.7±0.9
	NoIR	0.0±1.4	0.0±1.4	-0.1±1.2	0.0±1.4	-1.0±1.1	0.0±1.2	-0.3±1.3	-1.3±0.9	-0.9±1.1	-0.9±1.4	-0.5±1.3	-0.4±1.0
10	IRV	0.1±1.4	0.0±1.2	0.0±1.4	0.1±1.2	-0.5±1.3	0.3±1.2	-0.1±1.1	-0.6±1.4	-0.8±1.5	-0.5±1.5	-0.1±1.5	-0.2±1.2
	IRF	-0.5±0.5	-0.7±0.5	-0.8±0.8	-0.2±1.0	-0.7±0.5	0.0±1.1	-0.2±1.0	0.2±1.0	-0.5±0.8	-0.3±0.8	-0.5±1.0	-0.4±0.6
	NoIR	0.1±1.5	0.3±1.3	0.0±1.3	0.1±1.5	-1.0±1.1	0.0±1.4	0.0±1.3	-1.0±0.9	-0.9±1.2	-0.9±1.4	-0.4±1.2	-0.3±1.1
12	IRV	0.3±1.3	0.1±1.5	0.1±1.5	0.5±1.1	-0.1±1.1	0.6±0.9	0.1±1.1	-0.6±1.4	-0.8±1.3	-0.5±1.5	0.0±1.5	0.0±1.2
	IRF	-0.2±0.8	-0.2±0.4	-0.5±0.5	0.3±1.0	-0.5±0.5	0.3±0.8	0.3±0.5	0.3±1.2	-0.2±1.0	-0.3±1.2	-0.2±0.8	-0.1±0.5
	NoIR	0.0±1.4	0.1±1.2	0.0±1.4	0.0±1.4	-0.8±0.9	0.0±1.4	-0.3±1.4	-0.9±1.1	-1.0±1.2	-0.9±1.4	-0.4±1.5	-0.4±1.1
14	IRV	0.4±1.2	0.3±1.4	0.3±1.4	0.6±1.2	0.0±1.3	0.6±0.9	0.5±1.2	-0.5±1.4	-0.8±1.3	-0.4±1.4	0.3±1.3	0.1±1.1
	IRF	0.2±0.8	0.2±0.8	-0.3±0.5	0.5±1.0	-0.2±0.8	0.5±0.8	0.7±0.5	0.7±0.8	-0.2±1.0	0.0±1.1	0.3±0.8	0.2±0.6
	NoIR	0.8±1.0	0.5±1.2	0.4±1.4	0.4±1.4	-0.8±0.7	0.3±1.3	0.3±1.2	-0.6±1.3	-0.8±1.8	-0.5±1.8	-0.1±1.6	0.0±1.1
16	IRV	0.8±1.0	0.6±1.2	0.4±1.2	0.6±1.2	0.1±1.4	0.9±1.0	0.4±1.2	-0.3±1.3	-0.5±1.2	-0.3±1.4	0.5±1.3	0.3±1.1
	IRF	0.3±0.5	0.2±0.8	-0.2±0.8	0.7±1.0	-0.2±0.8	0.7±0.8	0.7±0.5	0.8±1.0	0.2±1.3	0.0±1.5	0.5±0.8	0.3±0.7

Time (min)	Trial	Head	Face	Nose	Chest & Arms	Hands	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
	NoIR	0.8±1.0	0.8±1.0	0.5±1.3	0.5±1.3	-0.5±0.9	0.4±1.2	0.3±1.3	-0.5±1.3	-0.4±1.2	-0.3±1.3	0.4±1.4	0.2±1.0
18	IRV	0.9±1.0	0.9±1.0	0.4±1.2	0.9±1.1	0.3±1.2	1.0±0.9	0.5±1.2	-0.1±1.0	-0.3±1.3	-0.1±1.2	0.6±1.2	0.4±1.0
	IRF	0.7±0.5	0.7±0.5	0.0±0.6	1.0±1.1	-0.2±0.8	0.8±1.0	0.8±0.8	0.8±1.0	0.3±1.2	0.2±1.3	0.7±1.0	0.5±0.7
	NoIR	0.9±1.0	0.9±1.0	0.6±1.3	0.8±1.0	-0.3±1.0	0.8±1.3	0.3±1.3	-0.4±1.4	-0.3±1.2	-0.1±1.2	0.5±1.4	0.3±1.0
20	IRV	1.0±0.9	1.0±0.9	0.6±1.1	0.9±1.0	0.4±1.2	1.0±0.9	0.8±1.0	0.1±1.1	-0.1±1.2	0.0±1.1	0.9±1.0	0.6±0.9
	IRF	1.2±0.8	1.0±0.6	0.5±1.0	1.2±1.2	0.2±1.2	1.0±1.1	1.2±0.8	1.0±1.3	0.5±1.5	0.7±1.6	0.8±1.2	0.8±1.0
	NoIR	1.4±0.9	1.3±1.2	1.0±1.2	1.1±1.1	0.3±0.9	0.8±1.5	0.5±1.5	0.0±1.5	0.0±1.5	0.3±1.5	0.6±1.5	0.7±1.1
22	IRV	1.0±0.9	1.0±0.9	0.6±1.1	1.3±0.7	0.8±1.0	1.1±0.8	1.0±0.8	0.1±1.1	0.0±1.1	0.0±1.1	0.9±1.1	0.7±0.8
	IRF	1.2±0.8	1.0±0.6	0.8±1.0	1.2±1.2	0.3±1.2	1.3±1.2	1.3±0.8	1.0±1.3	0.7±1.6	0.8±1.7	1.0±1.7	1.0±1.0
	NoIR	1.5±0.9	1.4±1.2	1.0±1.2	1.4±1.2	0.5±0.9	0.9±1.1	0.9±1.4	0.4±1.6	0.4±1.6	0.4±1.6	0.9±1.6	0.9±1.0
24	IRV	1.1±1.0	1.3±0.9	0.6±1.1	1.4±0.7	0.9±1.0	1.5±0.8	1.1±0.8	0.3±1.3	0.3±1.2	0.1±1.2	1.0±1.1	0.9±0.8
	IRF	1.2±0.8	1.0±0.6	0.8±1.0	1.2±1.2	0.3±1.2	1.3±1.2	1.2±0.8	1.0±1.3	0.7±1.6	0.8±1.7	1.0±1.1	1.0±1.0
	NoIR	1.4±0.9	1.5±1.1	1.0±1.3	1.5±1.3	0.6±1.1	1.4±1.3	1.0±1.5	0.8±1.7	0.4±1.6	0.4±1.6	1.1±1.4	1.0±1.1
26	IRV	1.4±0.7	1.4±0.7	0.9±1.1	1.4±0.9	0.8±0.9	1.4±0.5	1.1±0.8	0.4±1.2	0.3±1.3	0.4±1.1	1.1±1.0	0.9±0.7
	IRF	1.3±0.8	1.3±0.8	0.8±1.0	1.3±1.2	0.3±1.2	1.3±1.2	1.3±0.8	1.2±1.2	0.7±1.6	0.8±1.7	1.0±1.1	1.1±1.0
	NoIR	1.5±0.9	1.6±1.1	1.1±1.4	1.6±1.2	0.8±1.0	1.4±1.3	1.0±1.5	1.0±1.3	0.5±1.5	0.5±1.5	1.1±1.4	1.1±1.0
28	IRV	1.6±0.7	1.4±0.7	0.9±1.1	1.6±0.5	1.3±0.9	1.6±0.5	1.3±0.7	0.6±0.9	0.4±1.1	0.6±1.1	1.3±1.0	1.1±0.7
	IRF	1.5±0.8	1.3±0.8	1.0±1.1	1.3±1.2	0.3±1.2	1.5±1.2	1.7±0.8	1.3±1.0	0.7±1.6	0.8±1.7	1.2±1.2	1.2±1.0

Time (min)	Trial	Head	Face	Nose	Chest & Arms	Hands	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
	NoIR	1.3±1.2	1.3±1.4	1.1±1.1	1.5±1.1	1.0±1.5	1.3±1.3	0.9±1.5	1.0±1.4	0.4±1.9	0.6±1.9	1.1±1.4	1.0±1.2
30	IRV	1.8±0.5	1.6±0.5	1.3±0.9	1.9±0.6	1.4±0.7	1.6±0.5	1.1±0.8	0.9±1.0	0.3±1.2	0.6±1.1	1.5±0.5	1.2±0.6
	IRF	1.7±0.5	1.7±0.5	1.5±0.8	1.7±0.8	0.7±1.2	1.5±1.2	1.5±0.8	1.7±0.5	0.7±1.5	0.7±1.5	1.5±1.2	1.3±0.8
	NoIR	1.1±1.5	1.1±1.5	0.9±1.2	1.6±0.7	1.3±1.3	1.1±1.1	0.8±1.3	0.4±1.5	0.1±1.7	0.8±1.8	0.9±1.6	0.9±1.1
32	IRV	1.4±0.7	1.5±0.5	1.4±0.7	1.6±0.5	1.4±0.5	1.6±0.5	1.1±0.8	0.8±0.9	0.6±1.1	0.8±1.0	1.5±0.5	1.2±0.6
	IRF	1.5±0.5	1.5±0.5	1.5±0.5	1.7±0.5	1.2±0.8	1.3±1.2	1.3±0.8	1.2±1.2	0.5±1.4	0.7±1.6	1.3±1.2	1.2±0.7
	NoIR	1.3±1.4	1.3±1.4	0.9±1.1	1.1±1.1	1.5±0.9	1.1±1.1	1.0±1.5	0.5±1.5	0.4±1.6	0.9±1.7	1.0±1.6	1.0±1.1
34	IRV	1.5±0.8	1.4±0.7	1.1±0.8	1.6±0.5	1.6±0.5	1.8±0.5	1.3±0.5	0.6±1.1	0.6±1.2	0.6±1.2	1.5±0.8	1.2±0.7
	IRF	1.8±0.4	1.8±0.4	1.8±0.4	2.0±0.6	1.3±0.8	1.5±1.4	1.7±0.5	1.2±1.2	0.7±1.4	0.7±1.6	1.3±1.2	1.5±0.6
	NoIR	1.3±1.4	1.3±1.4	0.6±1.4	1.4±1.1	1.4±0.9	1.3±1.0	0.9±1.6	0.4±1.6	0.3±1.6	0.5±1.8	0.9±1.6	0.9±1.0
36	IRV	1.3±1.4	1.4±1.1	1.1±1.1	1.8±0.7	1.5±0.5	1.4±1.1	1.3±0.7	0.5±1.1	0.5±1.2	0.8±1.2	1.5±0.8	1.1±0.8
	IRF	1.8±0.4	1.8±0.4	1.8±0.4	2.0±0.6	1.5±0.5	1.3±1.2	1.5±0.8	1.0±1.5	0.8±1.6	0.7±1.6	1.3±1.2	1.4±0.7
	NoIR	0.9±1.6	1.0±1.3	0.8±1.0	1.0±1.3	1.4±0.7	1.1±1.0	0.8±1.5	0.3±1.4	0.1±1.5	0.4±1.6	0.6±1.8	0.8±1.0
38	IRV	1.4±1.1	1.4±1.1	1.0±1.1	1.6±0.9	1.8±0.5	1.8±0.5	1.3±0.5	0.6±1.1	0.6±1.2	0.9±1.2	1.6±0.7	1.2±0.5
	IRF	1.8±0.4	1.8±0.4	1.8±0.4	2.0±0.6	1.8±0.8	1.5±1.4	1.7±1.0	1.2±1.6	0.8±1.6	0.7±1.6	1.3±1.8	1.5±0.7
	NoIR	1.1±1.7	1.3±1.8	0.6±1.6	1.0±1.7	1.3±1.0	1.0±1.1	0.9±1.5	0.1±1.5	0.3±1.7	0.6±1.5	0.9±1.1	0.8±1.1
40	IRV	1.4±1.1	1.4±1.1	1.3±1.2	1.5±0.8	1.6±0.5	1.5±1.2	1.3±1.0	0.9±1.1	0.6±1.1	0.9±1.1	1.4±0.9	1.2±0.9
	IRF	1.8±0.4	1.8±0.4	1.8±0.4	1.8±0.4	1.5±0.5	1.3±1.2	1.3±0.8	1.2±1.6	0.7±1.4	0.8±1.6	1.2±1.6	1.4±0.6

Table B4: Thermal sensation (arbitrary units, mean ± SD) responses during preconditioning. P relates to the 3 min standing period prior to sitting (ANOVA main effect $^{\#}P<0.05$, $^{*}P<0.01$, $^{**}P<0.001$; superscript^{1} indicates P is equal to $^{\#}$, *, **).

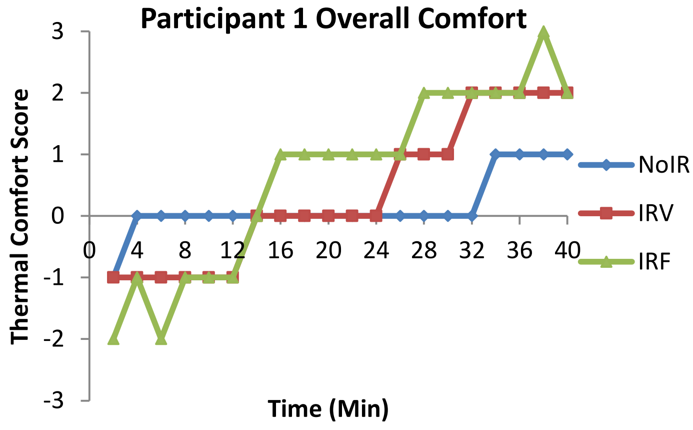
Time (min)	Trial	Head	Face	Nose	Chest & Arms#	Hands**	Seat Back Contact**	Seat Cushion Contact**	Lower Leg**	Feet**	Toes**1	Overall**	Average**
	NoIR												
P1	IRV												
	IRF												
	NoIR												
P2	IRV												
	IRF												
	NoIR												
P3	IRV												
	IRF												
	NoIR	-1.5±1.6	-1.4±1.6	-1.6±1.5	-0.9±1.5	-2.1±1.5	-1.3±1.7	-1.3±1.7	-1.8±1.5	-1.8±1.7	-1.5±1.7	-1.5±1.6	-1.5±1.4
2	IRV	-0.6±1.7	-0.6±1.7	-0.6±1.4	0.0±1.5	-1.4±1.2	-0.6±1.6	-1.0±1.5	-1.1±1.6	-1.3±1.7	-1.0±1.6	-1.1±2.0	-0.8±1.3
	IRF	-1.5±1.6	-1.3±1.8	-1.5±1.6	-0.5±1.5	-1.7±1.5	-1.2±1.6	-1.0±1.4	-1.2±1.2	-1.2±1.6	-1.2±1.6	-1.2±1.2	-1.2±1.4
	NoIR	-1.6±1.7	-1.3±1.7	-1.3±1.4	-1.0±1.7	-2.4±1.4	-1.3±1.8	-1.3±1.5	-1.6±1.2	-1.9±1.7	-1.8±1.8	-1.5±1.6	-1.5±1.4
4	IRV	-1.0±1.5	-1.0±1.3	-1.3±1.2	-0.5±1.3	-1.4±1.3	-0.9±1.7	-1.1±1.6	-1.5±1.8	-1.6±1.8	-1.1±1.7	-1.3±1.9	-1.1±1.4
	IRF	-1.3±1.2	-1.5±1.5	-1.7±1.5	-0.7±1.6	-1.8±1.2	-0.8±1.5	-1.0±1.3	-1.2±1.2	-1.3±1.6	-1.3±1.6	-1.3±1.0	-1.3±1.3

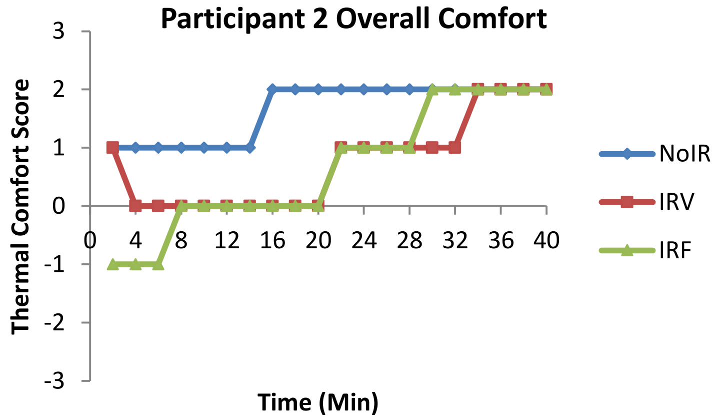
Time (min)	Trial	Head	Face	Nose	Chest & Arms	Hands	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
	NoIR	-1.1±1.7	-1.1±1.6	-1.4±1.4	-0.5±1.4	-2.0±1.2	-1.3±1.5	-1.5±1.5	-1.9±1.2	-1.8±1.5	-1.5±1.7	-1.5±1.4	-1.4±1.3
6	IRV	-0.8±1.7	-0.8±1.7	-0.9±1.7	-0.1±1.6	-1.0±1.2	-0.6±1.7	-0.8±1.7	-1.4±1.7	-1.6±1.8	-1.3±1.7	-1.1±1.8	-0.9±1.5
	IRF	-0.8±1.5	-1.3±1.5	-1.5±1.5	-0.5±1.5	-1.7±1.4	-1.0±1.4	-0.8±1.3	-1.0±1.4	-1.3±1.6	-1.5±1.6	-0.8±1.5	-1.2±1.4
	NoIR	-0.5±1.7	-0.5±1.7	-0.6±1.6	-0.4±1.8	-1.5±1.4	-0.5±1.8	-0.9±1.7	-1.8±1.2	-1.5±1.8	-1.3±1.8	-1.0±1.5	-0.9±1.4
8	IRV	-0.5±1.8	-0.3±1.7	-0.8±1.5	-0.1±1.5	-0.9±1.1	-0.5±1.3	-0.9±1.5	-1.3±1.7	-1.3±1.7	-1.0±1.8	-0.8±1.6	-0.7±1.4
	IRF	-0.8±1.2	-1.3±1.2	-1.3±1.4	-0.5±1.4	-1.2±1.2	-0.5±1.4	-0.5±1.0	-0.5±1.0	-0.8±1.0	-1.0±1.3	-0.8±1.2	-0.9±1.1
	NoIR	-0.3±1.8	-0.3±1.7	-0.6±1.6	-0.3±1.8	-1.3±1.3	-0.3±1.5	-0.8±1.4	-1.5±1.4	-1.4±1.7	-1.3±1.8	-0.9±1.6	-0.8±1.4
10	IRV	-0.4±1.7	-0.4±1.5	-0.5±1.6	0.0±1.3	-0.6±1.3	0.1±1.2	-0.1±1.4	-1.0±1.5	-1.4±1.6	-0.9±1.6	-0.5±1.5	-0.5±1.3
	IRF	-0.8±1.0	-0.8±1.0	-1.2±1.2	-0.2±1.0	-1.0±0.6	-0.2±1.3	-0.2±1.0	-0.2±1.0	-0.7±1.0	-0.7±1.2	-0.7±1.0	-0.6±0.8
	NoIR	-0.3±1.8	-0.1±1.6	-0.6±1.6	0.0±2.1	-1.1±1.5	-0.3±1.8	-0.5±1.7	-1.3±1.4	-1.4±1.7	-1.4±1.8	-0.8±1.7	-0.7±1.5
12	IRV	0.3±1.0	0.0±1.3	-0.5±1.4	0.5±1.1	-0.4±1.3	0.3±1.0	-0.3±1.2	-0.9±1.2	-1.3±1.6	-0.9±1.7	-0.3±1.4	-0.3±1.1
	IRF	-0.2±0.8	-0.3±0.5	-0.7±0.8	0.3±1.2	-0.8±0.8	0.0±1.3	0.2±0.8	0.3±1.0	-0.3±1.2	-0.7±1.5	-0.2±1.0	-0.2±0.7
	NoIR	0.0±1.8	0.0±1.8	-0.4±1.8	0.0±2.1	-1.1±1.6	-0.3±1.8	-0.4±1.8	-1.1±1.5	-1.6±1.9	-1.4±1.9	-0.8±1.7	-0.6±1.5
14	IRV	0.5±1.3	0.1±1.2	-0.1±1.2	0.5±1.1	-0.1±1.1	0.8±0.9	0.4±1.2	-0.8±1.3	-1.0±1.4	-0.8±1.7	0.0±1.2	-0.1±1.0
	IRF	0.2±0.8	0.0±0.0	-0.5±0.8	0.5±1.0	-0.3±0.8	0.7±0.8	0.5±0.5	0.5±1.0	0.0±1.1	-0.2±1.3	0.2±0.8	0.1±0.6
	NoIR	0.6±1.4	0.5±1.7	0.1±1.8	0.3±1.9	-1.1±1.2	0.1±1.5	0.0±1.5	-0.9±1.6	-1.3±1.9	-1.1±2.0	-0.5±1.7	-0.3±1.3
16	IRV	0.6±1.3	0.5±1.5	-0.1±1.2	0.6±1.2	-0.1±1.1	0.9±0.6	0.4±1.3	-0.8±1.3	-0.9±1.4	-0.6±1.5	0.4±1.4	0.1±1.0
	IRF	0.3±0.8	0.2±0.8	-0.2±1.0	0.7±1.0	-0.2±0.8	0.8±1.0	0.7±0.5	0.8±1.0	0.2±1.3	0.0±1.5	0.5±0.8	0.3±0.7

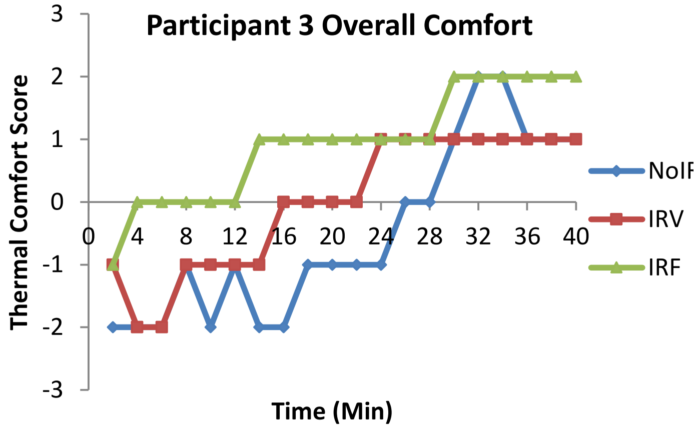
Time (min)	Trial	Head	Face	Nose	Chest & Arms	Hands	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
	NoIR	0.8±1.4	0.6±1.4	0.3±1.7	0.5±1.7	-0.5±0.8	0.4±1.2	0.4±1.4	-0.6±1.5	-0.9±1.6	-0.8±2.3	0.1±1.2	0.0±1.1
18	IRV	1.0±1.1	0.8±1.4	0.1±1.4	0.9±1.1	0.0±1.1	0.9±0.8	0.5±1.3	-0.5±1.2	-0.6±1.4	-0.5±1.4	0.4±1.2	0.3±0.9
	IRF	0.7±0.8	0.5±0.5	0.0±0.6	1.0±1.1	0.0±0.9	0.8±1.0	1.0±0.6	0.8±1.0	0.3±1.2	0.0±1.5	0.3±1.2	0.5±0.7
	NoIR	1.0±1.1	1.0±1.1	0.5±1.4	0.8±1.4	-0.5±1.1	0.6±1.3	0.4±1.3	-0.3±1.5	-0.6±1.5	-0.3±1.5	0.4±1.4	0.3±1.0
20	IRV	1.1±1.0	1.0±1.1	0.6±1.2	1.0±0.9	0.1±1.0	1.1±0.6	0.5±1.3	0.0±1.1	-0.5±1.3	-0.4±1.2	0.8±1.2	0.5±0.8
	IRF	1.0±0.9	0.8±0.8	0.3±1.0	1.2±1.2	0.2±1.2	1.0±1.1	0.8±1.2	0.8±1.0	0.5±1.4	0.5±1.4	0.8±1.2	0.7±0.9
	NoIR	1.4±1.2	1.1±1.1	0.6±1.5	1.1±1.5	0.3±1.2	0.9±1.4	0.6±1.5	0.0±1.5	-0.4±1.7	-0.1±1.7	0.6±1.5	0.6±1.2
22	IRV	1.1±1.0	1.3±0.9	0.9±1.1	1.4±0.7	0.8±0.9	1.4±0.5	0.6±1.2	-0.1±1.1	-0.3±1.2	-0.1±1.0	0.9±1.0	0.7±0.7
	IRF	1.0±0.9	0.8±0.8	0.7±1.0	1.2±1.2	0.2±1.2	1.3±1.2	1.2±0.8	1.0±0.9	0.5±1.4	0.5±1.4	1.0±1.1	0.8±0.9
	NoIR	1.4±1.2	1.5±0.9	0.9±1.4	1.4±1.2	0.4±1.1	1.0±1.4	0.6±1.5	0.1±1.5	0.0±1.6	0.1±1.8	0.9±1.6	0.7±1.1
24	IRV	1.4±0.9	1.4±0.7	0.8±1.0	1.5±0.5	1.0±0.9	1.5±0.8	0.9±1.1	0.1±1.2	0.0±1.1	0.0±1.2	1.1±1.1	0.9±0.7
	IRF	1.2±0.8	1.3±0.8	0.8±1.0	1.3±1.2	0.2±1.2	1.2±1.2	1.2±0.8	1.0±0.9	0.5±1.4	0.5±1.4	1.0±1.1	0.9±0.9
	NoIR	1.5±0.9	1.5±0.9	1.0±1.2	1.4±1.2	0.6±0.9	1.3±1.2	0.9±1.4	0.6±1.5	0.1±1.5	0.1±1.7	0.9±1.5	0.9±1.0
26	IRV	1.5±1.1	1.6±0.5	1.0±1.2	1.6±0.7	1.0±0.9	1.5±0.8	1.1±0.8	0.3±1.2	-0.1±1.4	0.0±1.1	1.4±0.7	1.0±0.7
	IRF	1.3±0.8	1.2±1.0	0.8±1.0	1.2±1.2	0.3±1.2	1.3±1.2	1.0±1.1	1.0±0.9	0.7±1.5	0.7±1.5	1.0±1.1	1.0±0.9
	NoIR	1.5±0.9	1.5±0.9	1.0±1.2	1.4±1.2	1.1±1.0	1.3±1.2	0.9±1.4	0.6±1.6	0.0±1.5	0.1±1.7	1.1±1.2	0.9±1.0
28	IRV	1.8±0.9	1.9±0.6	1.1±1.4	1.6±0.7	1.0±1.1	1.6±0.5	1.1±0.8	0.6±0.9	0.4±1.2	0.3±1.2	1.4±0.7	1.1±0.7
	IRF	1.5±0.5	1.5±0.5	1.2±0.8	1.5±0.8	0.7±1.0	1.3±1.2	1.3±0.8	1.3±0.8	0.7±1.5	0.7±1.5	1.0±1.1	1.2±0.7

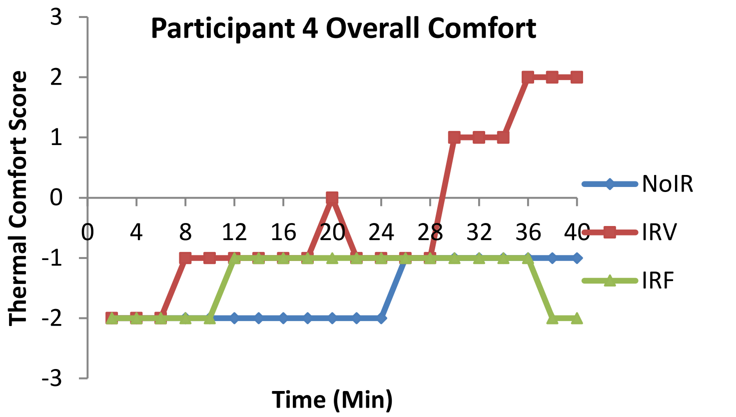
Time (min)	Trial	Head	Face	Nose	Chest & Arms	Hands	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
	NoIR	1.8±0.9	1.9±0.6	1.1±1.0	1.5±0.9	0.9±1.4	1.3±1.2	0.9±1.4	0.4±1.4	-0.1±2.0	0.4±1.8	1.3±1.4	1.0±0.9
30	IRV	1.8±0.9	1.8±0.9	1.3±1.2	1.9±0.4	1.4±0.7	1.6±0.5	1.0±0.9	0.9±1.0	0.5±1.1	0.5±1.1	1.4±0.7	1.3±0.6
	IRF	1.5±0.5	1.7±0.5	1.2±0.8	1.7±0.8	0.7±1.2	1.5±1.2	1.7±0.8	1.7±0.8	0.7±1.6	0.8±1.7	1.5±1.2	1.3±0.8
	NoIR	2.1±0.8	2.1±0.8	1.4±1.2	1.8±1.0	1.0±1.2	1.3±1.3	1.1±1.4	0.6±1.7	-0.1±2.0	0.1±2.0	1.1±1.4	1.1±1.0
32	IRV	1.9±1.0	2.1±0.6	1.4±1.1	1.9±0.4	1.4±0.7	1.5±0.8	1.0±0.9	0.6±0.9	0.4±1.2	0.4±1.1	1.8±0.5	1.3±0.6
	IRF	1.8±0.4	1.8±0.4	1.5±0.5	1.7±0.8	1.3±0.8	1.5±1.2	1.8±1.0	2.0±0.6	0.8±1.7	0.8±1.7	1.8±1.0	1.5±0.7
	NoIR	2.1±0.8	2.1±0.8	1.5±1.1	2.1±1.2	1.1±1.0	1.4±1.3	1.0±1.5	0.5±1.6	0.0±1.8	0.3±2.1	1.8±1.0	1.2±0.9
34	IRV	2.3±0.9	1.9±0.6	1.3±0.9	1.9±0.4	1.6±0.5	1.9±0.4	1.3±0.7	0.6±0.9	0.4±1.2	0.6±1.1	1.8±0.7	1.4±0.5
	IRF	2.0±0.0	2.0±0.0	1.8±0.4	1.8±0.4	1.7±0.5	1.5±1.2	1.8±1.0	2.0±0.6	1.0±1.7	1.0±1.9	1.8±1.0	1.7±0.6
	NoIR	2.3±1.0	2.3±0.9	1.4±1.2	2.1±1.0	1.5±0.9	1.5±1.2	1.0±1.5	0.4±1.7	0.1±2.0	0.8±1.8	1.8±1.5	1.3±1.0
36	IRV	2.3±0.9	2.3±0.9	1.4±1.1	2.1±0.4	1.9±0.4	2.0±0.0	1.4±0.7	0.5±1.1	0.3±1.3	0.4±1.2	1.6±0.7	1.4±0.4
	IRF	2.0±0.0	2.0±0.0	2.0±0.0	2.0±0.6	1.7±0.5	1.7±1.4	1.7±1.0	2.0±0.6	1.0±1.7	1.0±1.9	1.8±1.0	1.7±0.6
	NoIR	2.4±1.1	2.3±0.9	1.3±1.2	2.1±1.0	1.8±0.9	1.5±1.2	1.3±1.4	0.4±1.8	0.1±2.1	0.6±2.0	1.9±1.5	1.4±0.9
38	IRV	2.4±0.7	2.3±0.9	1.9±1.1	2.1±0.6	1.9±0.4	2.0±0.0	1.4±0.7	0.4±1.2	0.3±1.3	0.4±1.2	1.6±0.9	1.5±0.4
	IRF	2.2±0.4	2.0±0.0	2.0±0.0	2.2±0.4	1.8±0.4	1.8±1.5	2.0±1.1	2.0±0.6	1.0±1.7	0.8±1.7	1.8±1.0	1.8±0.5
	NoIR	2.4±0.9	2.4±1.1	1.8±1.4	2.4±0.9	1.9±0.8	1.6±1.2	1.4±1.3	0.3±1.8	0.3±2.1	0.5±2.2	1.8±1.5	1.5±0.8
40	IRV	2.4±0.7	2.4±0.9	1.9±1.2	2.1±0.4	1.9±0.4	2.0±0.5	1.4±0.5	0.6±1.1	0.4±1.3	0.5±1.2	2.0±0.5	1.6±0.3
	IRF	2.2±0.4	2.0±0.0	2.0±0.0	2.3±0.5	1.8±0.4	1.8±1.5	2.0±1.1	2.2±0.4	1.2±1.8	1.2±1.8	1.8±1.0	1.9±0.6

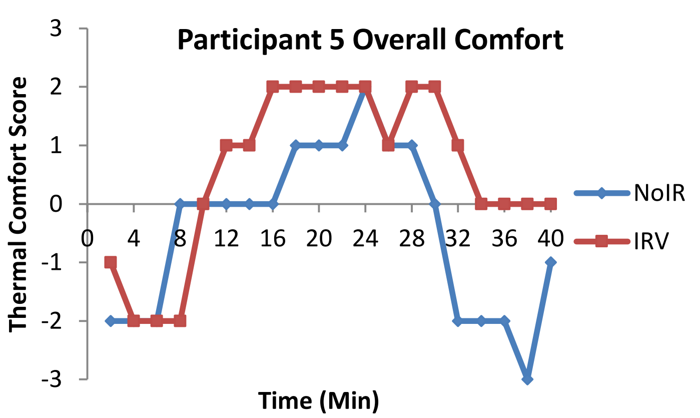
Figure B5 – Individual Overall Thermal Comfort Responses

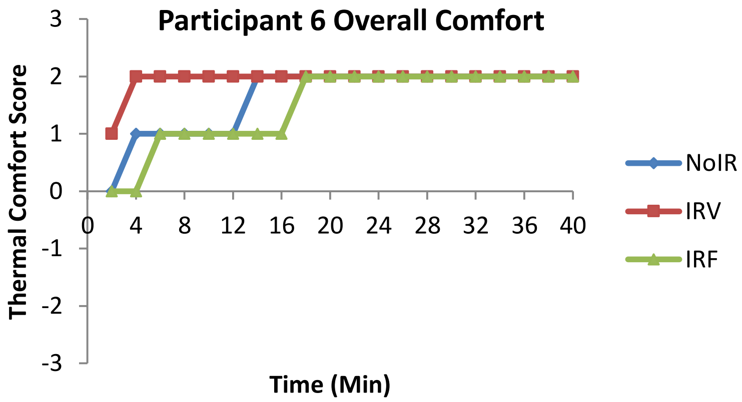


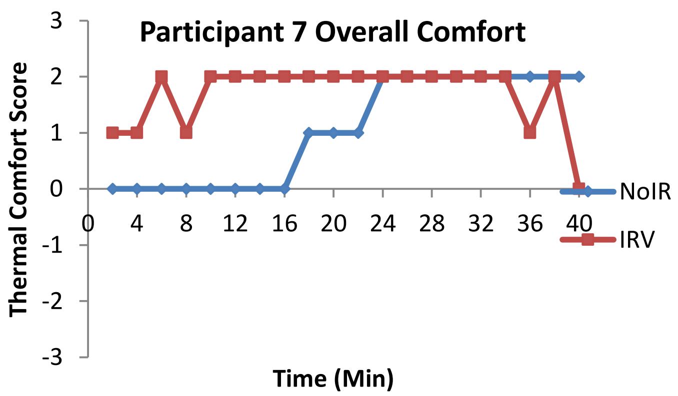


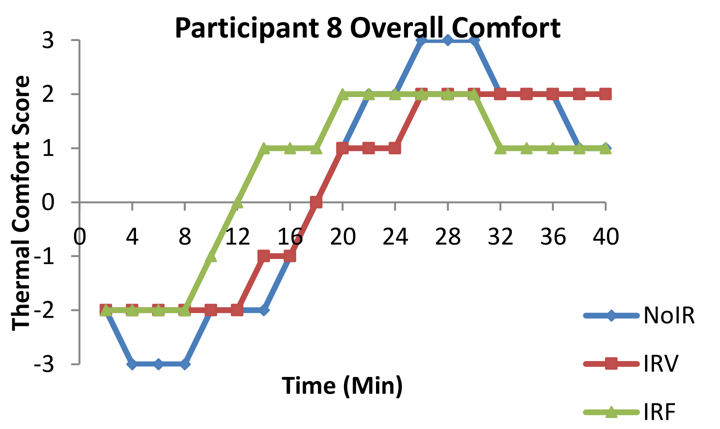




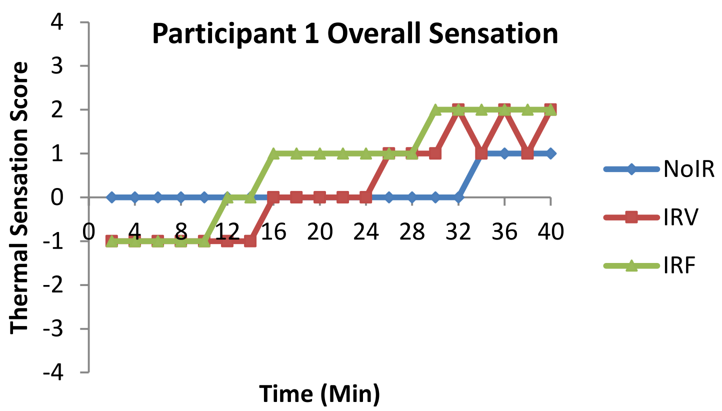


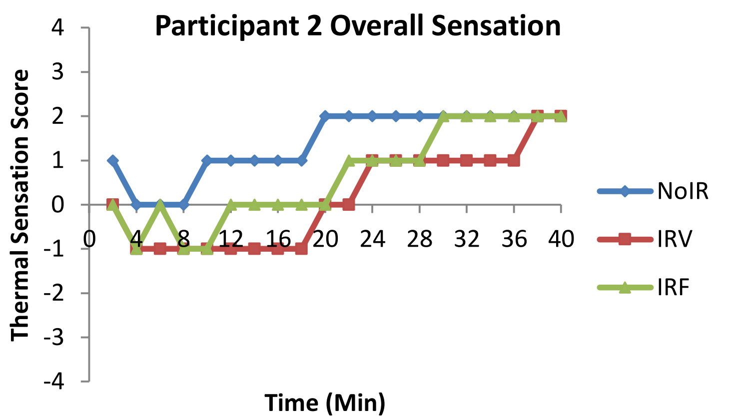


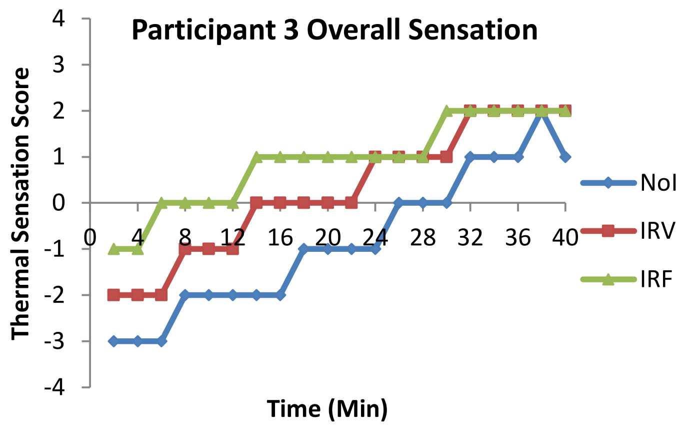


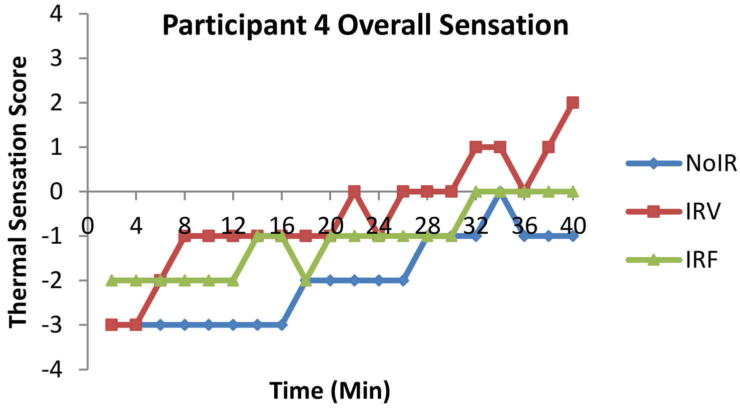


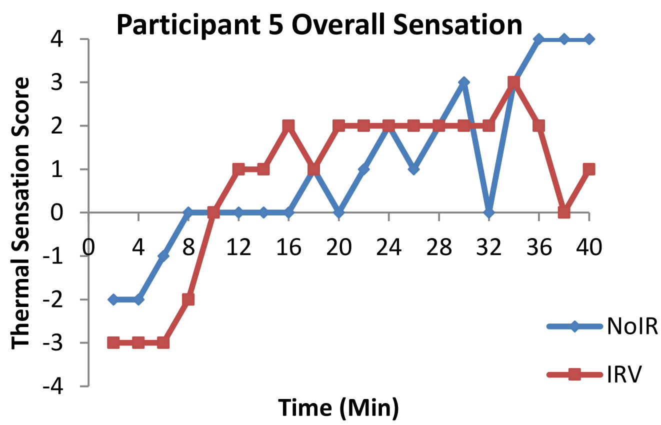
Appendix – Individual Overall Thermal Sensation Responses

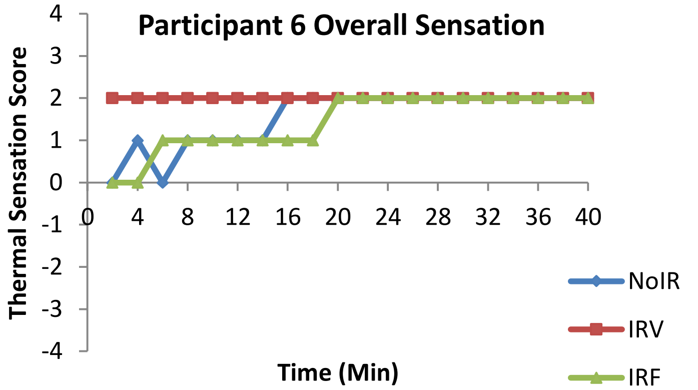


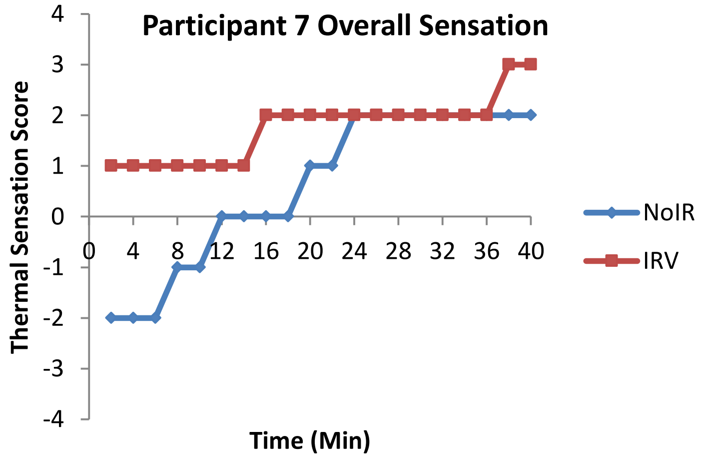












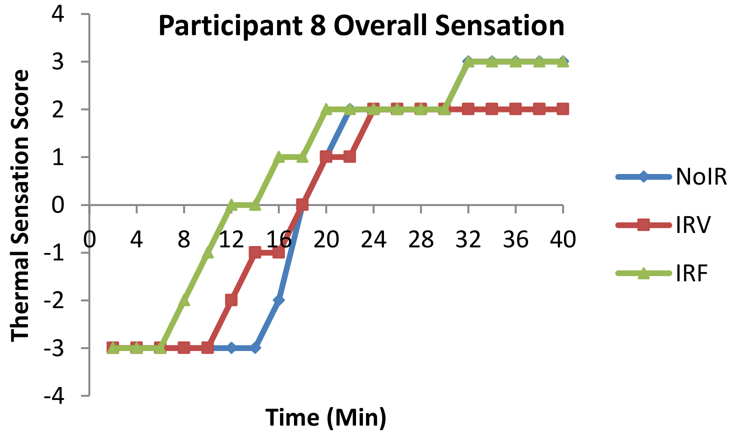


Table B5: Desirability (arbitrary units, mean ± SD) of the thermal environment responses during preconditioning. P relates to the 3 min standing period prior to sitting (ANOVA main effect $^{\#}P<0.05$, $^{*}P<0.01$, $^{**}P<0.001$; superscript^{1} indicates P is equal to $^{\#, *, **}$).

Time (min)	Trial	Seat*	Lower leg**	Face	Air**	Acceptability**
	NoIR					
P1	IRV					
	IRF					
	NoIR					
P2	IRV					
	IRF					
	NoIR					
P3	IRV					
	IRF					
	NoIR	-1.9±0.6	-2.4±0.5	-1.6±0.7	-2.3±0.5	-31.0±28.1
2	IRV	-1.8±1.0	-2.1±0.8	-1.1±1.1	-1.9±0.8	-17.1±42.5
	IRF	-2.3±0.8	-2.0±0.9	-2.2±0.8	-2.3±0.8	-36.0±31.5
	NoIR	-1.9±1.2	-2.5±0.8	-1.6±0.7	-2.1±0.8	-30.5±29.4
4	IRV	-1.6±1.2	-1.9±1.0	-1.4±1.1	-1.9±1.1	-15.3±44.3
	IRF	-1.8±1.0	-1.8±1.0	-1.8±1.0	-1.8±1.0	-30.2±34.3

Time (min)	Trial	Seat	Lower leg	Face	Air	Acceptability
	NoIR	-1.6±1.2	-2.3±0.9	-1.3±1.0	-1.9±1.0	-22.4±30.0
6	IRV	-1.5±1.2	-1.9±1.0	-1.1±0.8	-1.6±0.9	-11.9±44.7
	IRF	-1.5±1.0	-1.5±1.0	-1.3±1.0	-1.7±1.0	-26.2±38.1
	NoIR	-1.4±1.2	-2.0±0.9	-1.1±1.1	-1.9±1.0	-20.1±29.7
8	IRV	-1.4±1.1	-1.9±1.0	-0.9±0.6	-1.6±0.9	-7.8±43.2
	IRF	-1.3±0.8	-1.3±1.2	-1.5±1.0	-1.5±0.8	-18.0±34.7
	NoIR	-1.5±1.1	-2.1±0.8	-1.3±1.3	-1.9±1.0	-12.0±29.0
10	IRV	-0.9±0.8	-1.9±1.0	-0.8±0.7	-1.0±0.8	0.1±40.2
	IRF	-1.2±0.8	-0.8±1.0	-1.0±0.6	-1.2±0.8	-4.5±26.6
	NoIR	-1.4±1.2	-2.0±0.9	-1.3±1.3	-1.8±1.2	-9.5±30.2
12	IRV	-1.1±1.0	-1.8±1.0	-0.8±0.7	-1.3±0.9	4.6±37.2
	IRF	-0.8±0.8	-0.7±0.8	-0.7±0.5	-0.8±0.8	1.8±28.1
	NoIR	-1.3±1.0	-1.8±1.0	-0.9±1.0	-1.3±1.2	-5.4±27.0
14	IRV	-0.9±0.8	-1.8±1.0	-0.8±0.7	-0.9±0.6	9.8±34.7
	IRF	-0.7±0.8	-0.7±0.8	-0.7±0.5	-0.7±0.5	8.0±26.6
	NoIR	-1.0±1.1	-1.5±0.9	-0.6±0.7	-1.1±1.1	3.1±24.3
16	IRV	-0.8±0.9	-1.5±0.9	-0.5±0.8	-1.0±0.8	13.0±34.8
	IRF	-0.7±0.8	-0.5±0.5	-0.5±0.5	-0.7±0.5	17.8±30.5

Time (min)	Trial	Seat	Lower leg	Face	Air	Acceptability
	NoIR	-1.0±1.1	-1.5±0.9	-0.6±0.7	-1.3±1.0	9.0±23.6
18	IRV	-0.8±0.9	-1.4±1.1	-0.3±0.5	-0.8±0.5	18.9±33.5
	IRF	-0.7±0.8	-0.5±0.5	-0.2±0.4	-0.5±0.5	26.3±27.4
	NoIR	-0.9±1.1	-1.3±1.0	-0.4±0.5	-1.0±0.8	14.5±24.4
20	IRV	-0.6±0.7	-1.0±0.8	-0.1±0.4	-0.3±0.7	25.3±30.2
	IRF	-0.5±0.8	-0.2±0.4	-0.2±0.4	-0.3±0.5	32.8±31.1
	NoIR	-0.9±1.1	-1.1±1.1	-0.3±0.5	-0.6±0.7	23.0±27.4
22	IRV	-0.4±0.5	-1.0±0.8	-0.1±0.4	-0.1±0.6	27.8±30.1
	IRF	-0.3±0.8	-0.2±0.4	0.0±0.0	-0.2±0.4	38.7±28.1
	NoIR	-0.6±0.9	-1.0±1.1	-0.3±0.5	-0.5±0.5	26.9±28.6
24	IRV	-0.4±0.5	-1.0±0.8	-0.1±0.4	0.0±0.5	35.3±25.8
	IRF	-0.3±0.8	-0.2±0.4	0.0±0.0	-0.2±0.4	42.3±25.6
	NoIR	-0.6±0.9	-1.1±1.1	-0.3±0.5	-0.3±0.5	37.6±26.0
26	IRV	-0.3±0.5	-0.9±0.6	0.0±0.0	0.1±0.6	42.8±27.9
	IRF	-0.3±0.8	-0.2±0.4	0.2±0.4	-0.2±0.4	47.5±22.4
	NoIR	-0.6±0.9	-1.1±1.1	0.1±0.4	-0.1±0.4	41.3±23.0
28	IRV	-0.4±0.5	-0.8±0.7	0.0±0.0	0.3±0.5	44.5±30.0
	IRF	-0.2±0.4	-0.2±0.4	0.2±0.4	0.0±0.0	49.5±21.6

Time (min)	Trial	Seat	Lower leg	Face	Air	Acceptability
	NoIR	-0.6±0.9	-1.0±1.2	0.1±0.4	0.3±0.7	42.8±28.6
30	IRV	-0.4±0.5	-0.8±0.7	0.3±0.5	0.3±0.5	46.0±28.2
	IRF	-0.2±0.4	0.2±0.4	0.2±0.4	0.2±0.4	46.3±13.5
	NoIR	-0.6±1.2	-0.8±1.3	0.4±0.5	0.5±0.8	33.9±46.5
32	IRV	-0.3±0.5	-0.9±0.6	0.4±0.5	0.1±0.4	45.1±27.1
	IRF	0.0±0.6	0.3±0.5	0.5±0.5	0.7±0.8	43.0±17.1
	NoIR	-0.5±1.1	-0.8±1.2	0.6±0.7	0.5±0.8	32.8±45.1
34	IRV	-0.3±0.5	-0.8±0.5	0.5±0.8	0.5±0.5	50.6±25.1
	IRF	0.0±0.6	0.5±0.8	0.8±0.8	0.7±0.8	44.2±18.2
	NoIR	-0.5±1.3	-0.9±1.4	0.9±1.0	0.8±1.0	31.3±45.2
36	IRV	-0.3±0.5	-0.8±0.7	0.6±0.7	0.9±0.8	43.8±30.7
	IRF	0.0±0.6	0.7±0.8	0.8±0.8	0.8±0.8	44.5±18.8
	NoIR	-0.3±1.4	-0.5±1.6	1.0±1.1	0.9±1.1	27.8±44.8
38	IRV	-0.1±0.4	-0.8±0.7	0.9±1.0	0.9±1.0	42.5±36.3
	IRF	0.3±0.8	0.7±0.8	0.8±0.8	0.8±0.8	42.2±20.9
	NoIR	-0.3±1.4	-0.6±1.4	1.1±1.1	1.0±1.2	42.3±19.6
40	IRV	-0.1±0.4	-0.8±0.7	1.0±1.2	1.1±1.0	51.4±17.7
	IRF	0.3±0.8	0.7±0.8	0.8±0.8	0.8±0.8	42.5±20.9

Table B6: Core temperature, mean skin temperature and heat storage (mean ± SD). P relates to the 3 min standing period prior to sitting (ANOVA main effect $^{\#}P<0.05$, $^{*}P<0.01$, $^{**}P<0.001$; superscript^{1} indicates P is equal to $^{\#, *, **}$).

Time (min)	Trial	Rectal$^{\#}$ (°C)	Aural** (°C)	Mean skin temp^{1**} (°C)	Mean skin temp^{2**} (°C)	Heat storage^{1**} ($J \cdot g^{-1}$)	Heat storage^{2**} ($J \cdot g^{-1}$)	Heat storage^{3**} ($J \cdot g^{-1}$)	Heat storage^{4**} ($J \cdot g^{-1}$)
	NoIR	37.2±0.2	35.9±0.5	31.6±0.7	31.4±0.3	-0.3±0.3	-0.3±0.3	-0.2±0.2	-0.2±0.2
P1	IRV	37.2±0.3	36.0±0.5	31.6±0.5	31.2±0.3	0.0±0.8	0.0±0.8	0.0±0.6	0.0±0.6
	IRF	37.1±0.2	35.7±0.6	31.8±0.7	31.6±0.6	-0.1±0.1	-0.1±0.1	-0.2±0.1	-0.2±0.1
	NoIR	37.2±0.2	35.9±0.5	31.1±1.0	30.9±0.5	-0.6±0.5	-0.6±0.5	-0.6±0.3	-0.6±0.3
P2	IRV	37.2±0.3	35.9±0.5	31.0±0.7	30.8±0.4	0.8±2.7	0.7±2.6	0.4±1.7	0.3±1.5
	IRF	37.1±0.2	35.7±0.6	31.3±0.7	31.3±0.7	-0.4±0.2	-0.4±0.2	-0.5±0.2	-0.5±0.2
	NoIR	37.2±0.2	35.8±0.6	30.9±0.8	30.7±0.5	-0.8±0.4	-0.9±0.5	-0.8±0.3	-0.9±0.4
P3	IRV	37.2±0.3	35.8±0.7	30.8±0.7	30.5±0.4	0.6±2.8	0.4±2.4	0.2±1.7	0.0±1.3
	IRF	37.1±0.2	35.7±0.6	30.9±0.6	30.8±0.8	-0.6±0.2	-0.7±0.2	-0.7±0.3	-0.8±0.3
	NoIR	37.2±0.2	35.8±0.6	30.7±0.7	30.0±0.4	-0.9±1.4	-1.0±1.4	-1.2±1.0	-1.2±1.0
2	IRV	37.2±0.2	35.8±0.7	30.5±0.8	29.9±0.4	0.3±3.0	-1.0±0.3	-0.4±1.7	-1.2±0.3
	IRF	37.1±0.2	35.6±0.7	30.7±0.9	30.4±0.8	-1.5±0.9	-1.6±0.9	-1.5±0.6	-1.6±0.6
	NoIR	37.2±0.2	35.7±0.7	30.4±0.7	29.9±0.3	-0.8±1.1	-0.9±1.1	-1.1±0.9	-1.2±0.8
4	IRV	37.2±0.2	35.7±0.7	30.3±0.9	29.7±0.5	0.1±2.8	0.1±2.9	-0.5±1.7	-0.6±1.7
	IRF	37.1±0.2	35.5±0.7	30.4±0.6	30.1±0.6	-1.2±0.6	-1.3±0.6	-1.4±0.3	-1.5±0.3

Time (min)	Trial	Rectal	Aural	Mean skin temp[1]	Mean skin temp[2]	Heat storage[1]	Heat storage[2]	Heat storage[3]	Heat storage[4]
	NoIR	37.2±0.2	35.6±0.8	30.5±0.6	29.9±0.3	-0.8±1.1	-1.0±1.1	-1.2±0.9	-1.3±0.9
6	IRV	37.2±0.2	35.7±0.7	30.3±0.8	29.8±0.5	0.3±2.5	0.1±2.4	-0.3±1.5	-0.6±1.4
	IRF	37.1±0.2	35.4±0.7	30.3±0.6	29.9±0.6	-1.3±0.5	-1.5±0.6	-1.5±0.2	-1.7±0.3
	NoIR	37.2±0.2	35.6±0.8	30.5±0.5	30.0±0.3	-0.8±1.1	-1.0±1.2	-1.1±0.9	-1.3±0.9
8	IRV	37.2±0.2	35.6±0.8	30.4±0.8	29.9±0.5	0.3±2.5	0.2±2.5	-0.3±1.4	-0.5±1.4
	IRF	37.1±0.2	35.4±0.7	30.3±0.7	29.9±0.6	-1.6±0.8	-1.8±0.8	-1.6±0.4	-1.8±0.4
	NoIR	37.2±0.2	35.5±0.8	30.7±0.7	30.1±0.3	-0.8±1.3	-1.0±1.4	-1.1±0.9	-1.3±1.0
10	IRV	37.2±0.2	35.6±0.7	30.6±0.9	30.1±0.5	0.5±2.6	0.2±2.6	-0.2±1.5	-0.4±1.5
	IRF	37.1±0.2	35.4±0.8	30.5±0.6	30.0±0.5	-2.2±2.7	-2.4±2.6	-1.9±1.3	-2.1±1.3
	NoIR	37.2±0.2	35.5±0.8	30.7±0.7	30.2±0.2	-0.7±1.3	-0.9±1.3	-1.0±0.9	-1.2±1.0
12	IRV	37.2±0.2	35.6±0.7	30.5±0.9	30.1±0.5	0.4±2.5	-0.7±1.0	-0.2±1.4	-0.9±0.8
	IRF	37.1±0.2	35.4±0.8	30.6±0.6	30.1±0.5	-2.0±2.4	-2.2±2.3	-1.7±1.1	-1.9±1.1
	NoIR	37.2±0.2	35.5±0.8	30.8±0.7	30.3±0.2	-0.6±1.3	-0.9±1.3	-0.9±0.9	-1.2±1.0
14	IRV	37.2±0.2	35.7±0.7	30.7±0.9	30.2±0.5	0.5±2.6	0.3±2.6	-0.1±1.4	-0.3±1.5
	IRF	37.1±0.2	35.4±0.8	30.6±0.6	30.1±0.5	-1.3±0.8	-1.5±0.8	-1.4±0.5	-1.6±0.5
	NoIR	37.1±0.3	35.5±0.9	30.9±0.6	30.4±0.2	-0.6±1.3	-0.8±1.3	-0.9±1.0	-1.1±1.0
16	IRV	37.2±0.2	35.7±0.8	30.8±0.9	30.3±0.5	0.5±2.6	0.5±2.8	-0.1±1.4	-0.2±1.5
	IRF	37.1±0.2	35.4±0.8	30.7±0.6	30.2±0.5	-1.2±0.8	-1.4±0.8	-1.3±0.5	-1.5±0.5

Time (min)	Trial	Rectal	Aural	Mean skin temp[1]	Mean skin temp[2]	Heat storage[1]	Heat storage[2]	Heat storage[3]	Heat storage[4]
	NoIR	37.1±0.3	35.5±0.9	31.2±0.8	30.6±0.2	-0.5±1.2	-0.7±1.2	-0.7±0.9	-0.9±0.9
18	IRV	37.1±0.2	35.6±0.7	31.0±0.9	30.5±0.5	0.7±2.7	0.5±2.8	0.1±1.5	-0.2±1.6
	IRF	37.1±0.2	35.4±0.8	30.8±0.6	30.3±0.5	-1.2±0.8	-1.4±0.8	-1.3±0.5	-1.5±0.5
	NoIR	37.1±0.3	35.5±0.8	31.1±0.6	30.7±0.2	-0.5±1.3	-0.7±1.3	-0.7±1.0	-0.9±1.0
20	IRV	37.1±0.2	35.7±0.7	31.1±0.9	30.6±0.5	0.1±3.7	0.0±4.0	-0.2±2.1	-0.3±2.3
	IRF	37.1±0.2	35.4±0.8	30.8±0.6	30.4±0.5	-1.0±0.6	-1.2±0.5	-1.1±0.4	-1.3±0.4
	NoIR	37.1±0.3	35.6±0.8	31.3±0.6	30.8±0.1	-0.3±1.3	-0.4±1.3	-0.5±1.0	-0.6±1.0
22	IRV	37.1±0.2	35.7±0.6	31.3±0.8	30.7±0.5	0.5±3.2	0.5±3.4	0.1±1.8	0.0±2.0
	IRF	37.1±0.3	35.5±0.8	30.9±0.5	30.7±0.5	-0.7±0.2	-0.8±0.3	-0.9±0.1	-1.0±0.2
	NoIR	37.1±0.3	35.6±0.8	31.5±0.6	31.0±0.1	-0.3±1.3	-0.4±1.4	-0.5±1.0	-0.6±1.0
24	IRV	37.1±0.2	35.8±0.6	31.4±0.8	30.9±0.5	0.9±2.8	1.0±3.0	0.3±1.6	0.3±1.7
	IRF	37.1±0.3	35.5±0.8	31.1±0.5	31.0±0.5	-0.6±0.2	-0.7±0.3	-0.7±0.1	-0.9±0.2
	NoIR	37.0±0.3	35.7±0.8	31.7±0.7	31.2±0.1	0.0±1.4	0.0±1.3	-0.3±1.1	-0.4±1.0
26	IRV	37.1±0.2	35.8±0.6	31.6±0.9	31.1±0.5	0.6±3.4	0.7±3.6	0.2±1.9	0.2±2.1
	IRF	37.1±0.2	35.6±0.8	31.2±0.5	31.1±0.5	-0.5±0.2	-0.6±0.2	-0.6±0.2	-0.7±0.2
	NoIR	37.0±0.4	35.7±0.7	31.9±0.6	31.4±0.1	0.1±1.4	0.2±1.3	-0.2±1.1	-0.2±1.0
28	IRV	37.1±0.2	35.9±0.5	31.6±0.8	31.3±0.6	0.2±3.5	0.2±3.8	0.0±1.9	0.1±2.1
	IRF	37.1±0.3	35.6±0.7	31.2±0.6	31.1±0.6	-0.4±0.2	-0.4±0.2	-0.6±0.2	-0.6±0.2

Time (min)	Trial	Rectal	Aural	Mean skin temp[1]	Mean skin temp[2]	Heat storage[1]	Heat storage[2]	Heat storage[3]	Heat storage[4]
	NoIR	37.0±0.4	35.8±0.7	32.1±0.6	31.7±0.1	0.2±1.4	0.4±1.3	0.0±1.0	0.1±0.9
30	IRV	37.1±0.2	35.8±0.5	31.9±0.7	31.5±0.5	1.3±2.7	1.5±2.9	0.7±1.5	0.9±1.6
	IRF	37.0±0.2	35.7±0.7	31.4±0.6	31.3±0.7	-0.3±0.2	-0.3±0.1	-0.4±0.2	-0.4±0.2
	NoIR	37.0±0.3	35.8±0.7	32.4±0.6	32.0±0.1	0.4±1.4	0.6±1.2	0.2±1.0	0.4±0.9
32	IRV	37.0±0.2	35.9±0.5	32.1±0.7	31.7±0.5	1.4±2.7	1.7±2.8	0.9±1.5	1.1±1.5
	IRF	37.0±0.2	35.7±0.7	31.8±0.5	31.7±0.6	-0.1±0.2	0.0±0.1	-0.3±0.3	-0.2±0.3
	NoIR	37.0±0.4	35.9±0.7	32.6±0.6	32.3±0.2	0.6±1.3	0.8±1.2	0.4±0.9	0.6±0.8
34	IRV	37.0±0.2	36.0±0.4	32.3±0.7	32.0±0.6	1.6±2.6	1.7±2.6	1.1±1.5	1.2±1.4
	IRF	37.0±0.3	35.8±0.7	32.0±0.5	32.0±0.6	0.0±0.2	0.1±0.1	-0.1±0.3	0.0±0.2
	NoIR	36.9±0.4	36.0±0.6	32.7±0.6	32.4±0.2	0.6±1.3	0.9±1.2	0.5±0.9	0.8±0.8
36	IRV	37.0±0.2	36.0±0.5	32.5±0.7	32.2±0.6	1.7±2.6	2.0±2.7	1.2±1.5	1.5±1.5
	IRF	37.0±0.3	35.8±0.7	32.1±0.6	32.2±0.7	0.1±0.2	0.2±0.2	0.0±0.3	0.2±0.3
	NoIR	36.9±0.4	36.0±0.6	32.9±0.6	32.6±0.3	0.7±1.4	1.1±1.2	0.6±1.0	0.9±0.8
38	IRV	37.0±0.2	36.0±0.4	32.6±0.8	32.4±0.6	1.7±2.6	2.1±2.7	1.3±1.5	1.6±1.5
	IRF	36.9±0.3	35.9±0.6	32.2±0.6	32.4±0.7	0.1±0.2	0.4±0.1	0.1±0.3	0.3±0.2
	NoIR	36.9±0.4	36.1±0.6	32.9±0.6	32.7±0.3	0.8±1.4	1.2±1.2	0.6±1.0	1.0±0.8
40	IRV	36.9±0.2	36.1±0.4	32.7±0.8	32.5±0.6	1.8±2.6	2.0±2.5	1.4±1.5	1.6±1.4
	IRF	36.9±0.3	35.9±0.6	32.4±0.5	32.5±0.6	0.2±0.2	0.5±0.2	0.2±0.2	0.5±0.2

Mean skin temp[1] Ramanathan, [2] Oi et al.; Heat storage[1,2] Ramanathan using rectal and aural temp, Oi et al.[3,4] using rectal and aural respectively.

Mean skin temp[1] Ramanathan, [2] Oi et al.; Heat storage[1,2] Ramanathan using rectal and aural temp, Oi et al.[3,4] using rectal and aural respectively.

Table B7: Upper body skin temperatures (°C; mean ± SD) throughout each trial. P relates to the 3 min standing period prior to sitting (ANOVA main effect $^{\#}$P<0.05, *P<0.01, **P<0.001; superscript^{1} indicates P is equal to $^{\#,\ *,\ **}$).

Time (min)	Trial	Left lower back**	Right lower back**	Left upper back**	Right upper back**	Upper arm**	Forearm **	Chest**	Hand	Finger**	Nose**	Forehead**
	NoIR	32.9±1.2	32.1±1.7	33.4±1.1	33.1±1.3	31.5±1.1	32.2±1.1	32.1±1.6	29.4±2.3	28.1±3.6	29.4±1.6	31.2±0.5
P1	IRV	32.4±0.6	32.3±1.1	33.3±1.2	33.1±1.3	31.2±1.1	31.8±1.4	32.9±0.6	29.2±1.5	27.4±1.4	29.0±1.8	30.8±1.1
	IRF	33.8±0.8	33.9±0.5	33.4±1.1	33.3±1.3	31.1±1.1	31.6±1.7	33.3±1.5	29.2±2.4	26.8±2.9	29.7±1.1	31.5±1.0
	NoIR	32.6±1.3	31.8±1.7	33.0±1.3	32.7±1.4	31.1±1.0	32.0±1.3	32.3±2.2	28.8±2.2	26.7±4.1	27.8±1.7	30.6±0.6
P2	IRV	32.2±0.6	32.0±1.1	33.0±1.3	32.7±1.5	30.7±1.2	31.6±1.4	32.6±1.0	28.7±1.5	25.6±1.7	27.8±1.5	30.3±1.0
	IRF	33.4±1.1	33.6±0.5	33.1±1.3	33.0±1.5	31.1±1.0	31.9±1.4	33.3±0.9	28.8±2.7	24.7±3.6	28.1±1.3	30.6±1.1
	NoIR	32.4±1.3	31.6±1.7	32.7±1.3	32.4±1.4	30.9±1.0	31.8±1.3	32.2±1.8	28.3±2.2	25.8±4.4	26.5±2.1	30.1±0.7
P3	IRV	32.0±0.7	31.7±1.1	32.8±1.3	32.4±1.6	30.6±1.2	31.4±1.6	32.6±1.1	28.1±1.2	25.2±0.9	27.1±1.6	30.1±1.1
	IRF	33.1±1.3	33.3±0.6	32.8±1.4	32.8±1.7	30.6±1.0	31.9±1.5	33.2±0.8	28.5±2.9	23.9±3.6	26.8±1.6	30.0±1.1
	NoIR	31.1±1.3	30.2±1.6	32.6±1.4	32.3±1.2	30.7±1.0	31.6±1.0	32.3±0.7	27.7±2.0	23.3±4.3	23.9±3.7	29.6±0.8
2	IRV	30.6±0.4	30.0±0.9	32.7±1.4	32.3±1.6	30.3±1.0	31.1±1.4	32.1±1.0	27.3±1.0	24.4±0.8	25.4±2.1	29.7±1.1
	IRF	31.9±1.1	31.4±0.9	32.5±1.4	32.5±1.7	30.1±1.0	32.0±1.6	33.2±1.1	27.7±2.6	21.7±3.7	24.8±1.8	29.4±1.2
	NoIR	30.8±1.0	30.2±1.3	32.5±1.2	32.3±1.0	30.2±1.0	31.4±1.0	32.1±1.1	27.4±2.0	23.4±3.5	23.6±2.3	29.3±0.9
4	IRV	30.6±0.6	30.2±1.0	32.6±1.5	32.3±1.6	29.9±1.1	31.1±1.3	31.8±1.5	27.2±1.0	23.7±1.6	24.4±2.2	29.5±1.2
	IRF	31.2±0.8	31.0±0.6	32.4±1.5	32.4±1.6	29.6±1.1	31.4±1.3	32.9±1.3	27.6±2.4	21.7±3.1	23.7±1.8	29.3±1.2

Time (min)	Trial	Left lower back	Right lower back	Left upper back	Right upper back	Upper arm	Forearm	Chest	Hand	Finger	Nose	Forehead
	NoIR	31.1±0.9	30.5±1.2	32.6±1.1	32.3±1.0	30.0±1.0	31.4±0.9	32.3±1.1	27.1±1.8	22.3±3.2	23.3±2.7	29.4±1.0
6	IRV	30.9±0.6	30.5±1.0	32.6±1.5	32.4±1.5	29.7±1.1	31.1±1.3	31.8±1.4	27.1±1.0	23.1±1.3	24.4±2.4	29.8±1.2
	IRF	31.5±0.6	31.3±0.7	32.5±1.4	32.3±1.7	29.3±1.2	31.0±1.4	32.7±1.5	26.8±2.2	21.3±2.7	23.4±2.0	29.3±1.4
	NoIR	31.3±0.9	30.9±1.2	32.7±1.1	32.4±0.9	30.1±1.0	31.4±1.0	32.4±1.0	27.0±1.7	22.6±2.6	23.5±2.9	29.7±1.0
8	IRV	31.2±0.6	30.9±1.1	32.7±1.5	32.5±1.4	29.8±1.1	31.1±1.3	31.8±1.5	27.1±1.1	22.6±1.5	24.8±2.4	30.0±1.2
	IRF	31.8±0.5	31.6±0.7	32.6±1.3	32.3±1.6	29.2±1.6	31.2±1.3	33.1±1.4	26.7±2.1	20.8±3.0	23.3±2.3	29.6±1.6
	NoIR	31.6±0.8	31.2±1.1	32.8±1.1	32.5±0.9	30.2±1.1	31.4±1.1	32.7±1.1	26.9±1.7	22.2±2.6	24.0±3.1	30.0±1.0
10	IRV	31.5±0.6	31.2±1.1	32.7±1.4	32.6±1.4	29.9±1.2	31.2±1.3	32.0±1.5	27.1±1.0	22.5±1.7	25.2±2.4	30.3±1.2
	IRF	32.1±0.5	31.9±0.7	32.7±1.4	32.3±1.6	30.0±1.3	31.3±1.1	33.2±1.2	26.6±2.1	20.3±2.8	23.4±2.5	29.9±1.8
	NoIR	31.9±0.8	31.5±1.1	33.0±1.1	32.6±0.9	30.3±1.1	31.4±1.1	32.8±1.1	26.7±1.7	21.9±2.6	24.6±3.0	30.3±1.0
12	IRV	31.8±0.6	31.5±1.1	32.8±1.5	32.7±1.4	30.0±1.3	31.1±1.4	31.9±1.5	27.0±1.0	22.6±1.9	25.7±2.4	30.5±1.2
	IRF	32.3±0.5	32.2±0.8	32.8±1.4	32.4±1.7	30.0±1.2	31.4±1.2	33.2±1.2	26.4±2.0	20.0±2.6	23.8±2.6	30.1±1.7
	NoIR	32.2±0.8	31.8±1.1	33.0±1.0	32.6±0.9	30.3±1.1	31.4±1.1	32.9±1.1	26.7±1.7	21.8±2.7	25.1±3.1	30.6±1.0
14	IRV	32.0±0.6	31.8±1.1	32.8±1.5	32.8±1.4	30.0±1.3	31.1±1.4	32.0±1.4	27.0±1.1	22.7±2.2	26.2±2.3	30.8±1.2
	IRF	32.5±0.5	32.5±0.8	32.8±1.4	32.4±1.7	29.8±1.4	31.4±1.2	33.3±1.2	26.2±1.9	19.5±3.0	24.3±2.6	30.4±1.7
	NoIR	32.4±0.8	32.0±1.0	33.1±1.0	32.7±0.9	30.4±1.1	31.5±1.2	33.0±1.0	26.6±1.6	21.9±2.6	25.8±3.1	31.0±1.0
16	IRV	32.2±0.6	32.0±1.1	33.0±1.5	33.0±1.4	30.1±1.4	31.2±1.4	32.1±1.3	27.0±1.1	23.0±2.8	27.0±2.4	31.2±1.2
	IRF	32.7±0.5	32.7±0.8	32.9±1.4	32.5±1.6	29.8±1.5	31.5±1.2	33.3±1.1	26.2±1.9	20.6±2.3	25.1±2.7	30.8±1.6

Time (min)	Trial	Left lower back	Right lower back	Left upper back	Right upper back	Upper arm	Forearm	Chest	Hand	Finger	Nose	Forehead
	NoIR	32.6±0.7	32.2±1.0	33.2±1.1	32.8±0.9	30.5±1.1	31.5±1.2	33.2±0.9	26.7±1.6	22.3±2.8	26.7±3.1	31.4±1.0
18	IRV	32.5±0.6	32.3±1.1	33.1±1.5	33.1±1.4	30.2±1.4	31.3±1.4	32.4±1.2	27.0±1.1	23.4±3.1	27.7±2.4	31.5±1.2
	IRF	32.9±0.5	32.9±0.8	33.0±1.4	32.6±1.6	29.9±1.5	31.6±1.2	33.3±1.2	26.3±1.9	20.7±2.2	25.8±2.6	31.2±1.5
	NoIR	32.8±0.7	32.4±0.9	33.3±1.0	32.8±0.8	30.6±1.0	31.5±1.1	33.3±0.8	26.9±1.6	22.8±3.0	27.5±3.0	31.8±0.9
20	IRV	32.6±0.6	32.5±1.1	33.2±1.4	33.2±1.3	30.3±1.4	31.4±1.3	32.5±1.1	27.1±1.1	23.7±3.2	28.3±2.4	31.9±1.2
	IRF	33.0±0.5	33.1±0.8	33.1±1.4	32.7±1.6	30.0±1.3	31.6±1.2	33.3±1.1	26.3±1.3	20.9±2.1	26.5±2.5	31.6±1.5
	NoIR	33.0±0.7	32.6±0.9	33.4±1.0	33.0±0.8	30.7±1.1	31.6±1.1	33.5±0.8	27.0±1.5	22.9±4.2	28.3±2.8	32.2±0.9
22	IRV	32.8±0.6	32.7±1.0	33.3±1.4	33.3±1.3	30.4±1.4	31.5±1.3	32.7±1.1	27.2±1.2	24.3±3.4	29.2±2.4	32.3±1.1
	IRF	33.2±0.6	33.3±0.8	33.2±1.3	32.9±1.6	30.0±1.3	31.5±1.4	33.1±0.9	26.6±1.2	21.2±2.2	27.4±2.3	32.0±1.5
	NoIR	33.2±0.7	32.8±0.9	33.5±1.0	33.1±0.8	30.9±1.1	31.6±1.0	33.6±0.7	27.2±1.6	24.0±4.7	29.4±2.7	32.6±0.9
24	IRV	33.0±0.6	32.8±1.0	33.4±1.4	33.4±1.4	30.6±1.3	31.6±1.2	32.9±1.1	27.4±1.4	25.1±3.7	30.1±2.4	32.6±1.1
	IRF	33.3±0.6	33.4±0.7	33.4±1.3	33.1±1.5	30.3±1.3	32.1±1.1	33.2±0.9	26.8±1.6	21.6±2.1	28.2±2.1	32.4±1.4
	NoIR	33.3±0.7	32.9±0.8	33.7±1.0	33.3±0.8	31.1±1.1	31.7±1.0	33.8±0.7	27.4±1.8	25.3±5.4	30.3±2.5	33.0±0.8
26	IRV	33.1±0.6	33.0±1.0	33.5±1.4	33.5±1.3	30.7±1.3	31.8±1.2	33.2±1.1	27.7±1.6	26.0±3.7	30.8±2.3	33.0±1.0
	IRF	33.4±0.6	33.6±0.7	33.5±1.3	33.2±1.4	30.4±1.3	32.1±1.2	33.3±0.9	27.0±1.9	21.9±2.2	28.9±2.0	32.8±1.3
	NoIR	33.4±0.7	33.1±0.8	33.8±1.0	33.4±0.8	31.3±1.1	31.8±1.0	33.9±0.7	27.8±2.0	26.3±5.7	31.1±2.2	33.3±0.7
28	IRV	33.2±0.6	33.1±1.0	33.6±1.3	33.7±1.2	30.9±1.3	31.9±1.3	33.1±1.0	28.2±2.0	27.3±3.9	31.6±2.2	33.3±0.9
	IRF	33.6±0.6	33.7±0.7	33.6±1.2	33.2±1.3	30.3±1.4	31.6±1.7	33.3±0.8	27.1±2.1	22.7±2.3	29.8±1.9	33.2±1.2

Time (min)	Trial	Left lower back	Right lower back	Left upper back	Right upper back	Upper arm	Forearm	Chest	Hand	Finger	Nose	Forehead
	NoIR	33.5±0.7	33.2±0.8	34.0±1.0	33.6±0.8	31.6±1.1	31.9±0.9	34.2±0.6	28.6±2.2	27.5±5.7	31.9±1.9	33.7±0.7
30	IRV	33.4±0.6	33.3±0.9	33.8±1.2	33.8±1.2	31.1±1.3	32.0±1.3	33.4±0.8	28.6±2.0	28.6±3.5	32.3±2.1	33.7±0.8
	IRF	33.7±0.6	33.8±0.7	33.7±1.1	33.4±1.3	30.6±1.3	31.7±1.5	33.4±0.8	27.4±2.2	24.6±3.6	30.8±1.7	33.5±1.1
	NoIR	33.7±0.7	33.3±0.8	34.1±0.9	33.7±0.8	31.8±1.1	32.1±0.9	34.4±0.6	29.5±2.5	28.8±5.6	32.7±1.6	34.1±0.6
32	IRV	33.5±0.6	33.4±0.9	33.9±1.2	33.9±1.1	31.4±1.2	32.0±1.3	33.6±0.7	29.3±2.1	30.1±3.2	32.9±1.9	34.0±0.7
	IRF	33.8±0.6	33.9±0.7	33.9±1.1	33.5±1.2	31.1±1.2	32.5±1.1	33.7±0.8	28.2±2.6	27.4±4.4	31.8±1.5	33.9±1.0
	NoIR	33.8±0.7	33.4±0.8	34.2±0.9	33.9±0.8	32.0±1.1	32.2±0.9	34.5±0.5	30.3±2.8	29.7±5.7	33.3±1.5	34.3±0.6
34	IRV	33.6±0.6	33.5±0.9	34.0±1.1	34.0±1.1	31.6±1.2	32.2±1.2	33.8±0.6	29.9±2.0	31.2±2.8	33.3±1.7	34.3±0.6
	IRF	33.9±0.6	34.0±0.6	34.0±1.1	33.7±1.2	31.4±1.2	32.6±1.0	33.8±0.9	29.2±2.6	27.0±5.3	32.8±1.1	34.2±0.9
	NoIR	33.9±0.7	33.5±0.8	34.3±0.9	34.0±0.8	32.2±1.1	32.3±1.0	34.6±0.5	30.7±3.0	30.0±5.4	33.5±1.2	34.4±0.5
36	IRV	33.7±0.6	33.6±0.9	34.1±1.1	34.2±1.1	31.8±1.1	32.3±1.1	34.0±0.7	30.6±1.9	32.1±2.4	33.6±1.6	34.4±0.6
	IRF	34.0±0.6	34.1±0.6	34.1±1.0	33.8±1.1	31.5±1.2	32.8±1.0	33.9±0.9	30.0±2.4	27.9±4.4	33.3±0.9	34.3±0.9
	NoIR	34.0±0.7	33.6±0.7	34.5±0.9	34.1±0.8	32.3±1.1	32.4±1.0	34.7±0.5	31.1±3.0	30.5±5.1	33.6±1.1	34.5±0.5
38	IRV	33.8±0.7	33.7±0.9	34.2±1.0	34.3±1.1	31.9±1.1	32.5±1.1	34.2±0.7	31.2±1.8	32.8±2.0	33.6±1.4	34.5±0.5
	IRF	34.1±0.6	34.2±0.6	34.2±1.0	33.9±1.1	31.7±1.2	32.9±0.9	34.0±0.9	30.7±2.0	29.0±4.1	33.4±0.9	34.4±0.8
	NoIR	34.1±0.7	33.7±0.7	34.6±0.9	34.2±0.8	32.4±1.1	32.5±1.1	34.8±0.5	31.3±2.9	30.6±4.6	33.7±0.9	34.6±0.5
40	IRV	33.9±0.7	33.8±0.8	34.3±1.1	34.4±1.0	32.0±1.1	32.6±1.1	34.3±0.7	31.6±1.8	33.0±1.9	33.7±1.3	34.5±0.5
	IRF	34.2±0.7	34.3±0.6	34.3±1.1	34.0±1.1	31.7±1.1	33.0±0.9	34.1±0.8	31.4±1.7	29.8±3.8	33.4±0.8	34.4±0.8

Table B8: Lower body skin temperatures (°C; mean ± SD) throughout each trial. P relates to the 3 min standing period prior to sitting (ANOVA main effect $^{\#}P<0.05$, $^{*}P<0.01$, $^{**}P<0.001$; superscript^{1} indicates P is equal to $^{\#,*,**}$).

Time (min)	Trial	Toe**	Foot#	Inner lower leg**	Outer lower leg**	Anterior thigh**	Posterior thigh left**	Posterior thigh right**	Left buttock**	Right buttock**
	NoIR	24.7±2.8	29.7±2.4	29.6±0.9	29.3±4.2	31.9±1.3	32.5±2.1	32.3±1.9	31.6±1.7	31.6±1.8
P1	IRV	24.6±3.1	30.0±1.5	29.5±0.6	29.6±1.0	31.7±1.5	32.2±1.4	31.6±0.8	31.1±1.8	30.8±1.9
	IRF	24.9±3.7	29.7±3.1	30.5±0.9	30.1±1.1	31.0±0.8	33.7±0.9	32.8±1.3	31.6±2.3	30.9±2.2
	NoIR	24.4±2.8	29.7±2.4	28.9±1.1	30.2±1.0	31.4±1.5	32.1±2.2	32.0±1.9	31.2±1.6	31.1±1.7
P2	IRV	24.2±3.1	29.9±1.5	29.0±0.5	29.0±1.4	31.2±1.6	31.9±1.4	31.2±0.9	30.8±1.8	30.5±1.8
	IRF	24.6±3.7	29.5±3.2	29.8±1.0	29.2±1.4	30.7±1.0	33.2±1.2	32.2±1.4	31.1±2.3	30.3±2.2
	NoIR	24.0±2.8	29.6±2.4	28.5±1.2	29.7±1.0	31.1±1.6	31.9±2.2	31.8±1.8	30.9±1.5	30.8±1.7
P3	IRV	23.9±3.0	29.7±1.6	28.7±0.6	28.5±1.7	30.7±1.8	31.7±1.4	31.0±0.9	30.5±1.8	30.2±1.8
	IRF	24.3±3.7	29.4±3.2	29.4±1.0	28.6±1.5	30.4±1.1	32.8±1.3	31.8±1.4	30.7±2.3	29.9±2.2
	NoIR	23.4±2.8	29.2±2.3	28.1±0.9	29.4±1.1	30.4±1.4	30.6±1.9	30.0±1.4	29.0±1.3	28.6±1.3
2	IRV	23.5±3.0	29.4±1.5	28.0±1.2	28.5±1.7	30.3±1.7	30.2±1.5	29.5±1.0	28.9±1.5	28.8±1.4
	IRF	23.6±3.8	29.1±3.2	28.8±0.8	28.4±1.2	29.5±1.2	31.1±1.7	29.3±1.0	29.1±2.1	28.1±1.5
	NoIR	22.7±2.8	29.0±2.2	27.9±0.8	29.2±1.2	30.4±1.4	30.1±1.8	29.9±1.3	28.7±1.2	28.5±1.2
4	IRV	22.9±2.8	29.1±1.5	27.8±1.5	28.5±1.6	30.7±1.8	30.0±1.2	29.4±0.8	28.7±1.3	28.6±1.3
	IRF	23.0±3.7	28.9±3.2	28.7±0.8	28.6±1.1	29.4±1.8	30.5±1.4	29.6±1.1	28.7±1.8	28.0±1.2

Time (min)	Trial	Toe	Foot	Inner lower leg	Outer lower leg	Anterior thigh	Posterior thigh left	Posterior thigh right	Left buttock	Right buttock
	NoIR	22.3±2.8	28.7±2.2	28.0±0.8	29.3±1.1	30.7±1.1	30.2±1.8	30.1±1.5	28.9±1.2	28.7±1.3
6	IRV	22.5±2.8	28.9±1.4	27.8±1.5	28.7±1.4	30.7±1.6	30.2±1.0	29.6±0.9	28.8±1.2	28.7±1.3
	IRF	22.7±3.7	28.7±3.2	28.8±0.8	28.7±1.0	29.1±1.9	30.9±1.1	30.0±1.2	28.7±1.8	28.2±1.2
	NoIR	22.0±2.9	28.6±2.2	28.1±0.8	29.4±1.1	30.9±1.3	30.4±1.8	30.3±1.6	29.1±1.3	28.9±1.3
8	IRV	22.5±2.8	28.7±1.4	28.0±1.4	28.9±1.3	31.0±1.3	30.4±0.9	29.8±1.1	28.9±1.3	28.8±1.3
	IRF	22.5±3.6	28.6±3.2	29.0±0.8	28.9±0.8	29.1±0.8	31.2±0.9	30.5±1.3	28.8±1.9	28.5±1.2
	NoIR	22.0±2.7	28.5±2.2	28.2±0.7	29.5±1.1	30.9±1.5	30.6±1.9	30.5±1.7	29.3±1.5	29.1±1.4
10	IRV	22.4±2.7	28.7±1.4	28.1±1.4	29.0±1.3	31.1±1.4	30.6±1.8	30.0±1.2	29.1±1.3	28.9±1.3
	IRF	22.5±3.5	28.5±3.2	29.1±3.2	29.0±1.8	29.5±0.8	31.6±0.9	30.8±1.3	28.9±2.0	28.7±1.3
	NoIR	21.9±2.7	28.4±2.2	28.3±0.7	29.6±1.1	30.8±1.3	30.9±1.8	30.7±1.7	29.5±1.6	29.3±1.5
12	IRV	22.3±2.7	28.6±1.4	28.1±1.4	28.9±1.7	31.3±1.5	30.7±0.7	30.1±1.4	29.3±1.4	29.1±1.4
	IRF	22.3±3.5	28.4±3.3	29.1±0.8	29.1±1.8	29.7±1.6	31.8±0.8	31.1±1.2	29.0±2.0	28.9±1.4
	NoIR	21.8±2.7	28.4±2.2	28.4±0.6	29.7±1.1	30.8±1.2	31.0±1.9	30.9±1.7	29.7±1.7	29.4±1.6
14	IRV	22.3±2.6	28.5±1.4	28.2±1.3	29.1±1.2	31.4±1.5	30.9±0.7	30.3±1.4	29.5±1.5	29.2±1.4
	IRF	22.3±3.5	28.3±3.3	29.3±0.8	29.2±0.8	29.4±1.6	32.1±0.8	31.3±1.2	29.2±2.1	29.1±1.4
	NoIR	21.8±2.6	28.4±2.3	28.5±0.6	29.8±1.1	31.1±1.4	31.2±1.8	31.1±1.7	29.9±1.8	29.6±1.6
16	IRV	22.2±2.6	28.4±1.4	28.4±1.1	29.2±1.2	31.6±1.5	31.0±0.7	30.4±1.5	29.7±1.5	29.4±1.5
	IRF	22.2±3.4	28.3±3.3	29.4±0.8	29.3±0.8	29.6±1.5	32.3±0.8	31.6±1.2	29.3±2.2	29.3±1.4

Time (min)	Trial	Toe	Foot	Inner lower leg	Outer lower leg	Anterior thigh	Posterior thigh left	Posterior thigh right	Left buttock	Right buttock
	NoIR	21.9±2.6	28.4±2.4	28.7±0.5	29.9±1.0	31.2±1.5	31.4±1.8	31.2±1.7	30.0±1.9	29.7±1.7
18	IRV	22.3±2.7	28.4±1.4	28.5±1.1	29.3±1.2	31.7±1.5	31.1±0.7	30.5±1.5	29.8±1.6	29.5±1.5
	IRF	22.2±3.4	28.2±3.3	29.5±0.8	29.4±0.8	29.7±1.4	32.4±0.8	31.7±1.2	29.4±2.3	29.5±1.5
	NoIR	22.0±2.5	28.5±2.4	28.9±0.5	30.0±1.0	31.1±1.2	31.6±1.8	31.4±1.7	30.2±1.9	29.9±1.7
20	IRV	22.3±2.7	28.4±1.4	28.7±1.0	29.4±1.1	31.8±1.5	31.3±0.7	30.6±1.6	30.0±1.6	29.7±1.5
	IRF	22.2±3.4	28.2±3.3	29.7±0.8	29.5±0.9	29.8±1.3	32.6±0.8	31.9±1.2	29.6±2.3	29.7±1.6
	NoIR	22.1±2.5	28.4±2.4	29.0±0.5	30.2±0.9	31.2±1.2	31.7±1.8	31.5±1.7	30.4±2.0	30.0±1.8
22	IRV	22.4±2.6	28.4±1.3	28.9±0.9	29.4±0.9	32.0±1.5	31.4±0.8	30.7±1.6	30.2±1.6	29.8±1.5
	IRF	22.2±3.4	28.2±3.3	29.9±0.8	29.6±0.9	30.1±1.5	32.7±0.8	32.0±1.3	29.7±2.4	29.8±1.7
	NoIR	22.2±2.5	28.4±2.4	29.2±0.5	30.4±0.8	31.4±1.3	31.8±1.7	31.7±1.6	30.5±2.0	30.1±1.8
24	IRV	22.6±2.7	28.5±1.3	29.1±0.8	29.6±0.9	32.0±1.5	31.5±0.8	30.9±1.6	30.3±1.7	29.9±1.6
	IRF	22.3±3.4	28.2±3.3	30.0±0.8	29.8±0.8	30.3±1.5	32.8±0.8	32.1±1.3	29.9±2.4	30.0±1.7
	NoIR	22.4±2.5	28.5±2.4	29.4±0.5	30.5±0.8	31.6±1.4	32.1±1.6	31.9±1.6	30.7±2.1	30.3±1.8
26	IRV	22.7±2.8	28.5±1.3	29.4±0.7	29.8±0.9	32.2±1.5	31.6±0.8	31.0±1.5	30.5±1.7	30.0±1.6
	IRF	22.4±3.4	28.2±3.3	30.2±0.8	30.0±0.7	30.5±1.2	32.9±0.8	32.3±1.2	30.0±2.4	30.1±1.7
	NoIR	22.7±2.5	28.5±2.4	29.7±0.5	30.7±0.8	31.7±1.2	32.2±1.6	32.1±1.6	30.8±2.1	30.4±1.8
28	IRV	22.9±2.9	28.5±1.3	29.6±0.6	29.9±0.9	32.4±1.5	31.7±0.8	31.2±1.5	30.7±1.7	30.1±1.6
	IRF	22.5±3.4	28.2±3.3	30.4±0.9	30.1±0.6	30.7±1.1	33.0±0.9	32.5±1.0	30.1±2.4	30.2±1.7

Time (min)	Trial	Toe	Foot	Inner lower leg	Outer lower leg	Anterior thigh	Posterior thigh left	Posterior thigh right	Left buttock	Right buttock
	NoIR	23.0±2.6	28.6±2.4	29.9±0.6	30.9±0.8	32.0±1.1	32.3±1.5	32.2±1.5	31.0±2.1	30.6±1.9
30	IRV	23.1±2.9	28.6±1.2	29.9±0.6	30.0±0.9	32.6±1.4	31.8±0.8	31.3±1.5	30.8±1.7	30.3±1.6
	IRF	22.7±3.4	28.2±3.3	30.6±0.9	30.3±0.6	30.9±0.9	33.0±0.9	32.6±1.0	30.2±2.4	30.3±1.8
	NoIR	23.3±2.6	28.6±2.4	30.2±0.6	31.1±0.7	32.5±1.2	32.5±1.5	32.4±1.5	31.1±2.1	30.6±1.9
32	IRV	23.5±3.2	28.7±1.2	30.2±0.6	30.3±0.9	32.7±1.5	32.0±0.8	31.5±1.4	31.0±1.7	30.5±1.8
	IRF	23.3±3.9	28.2±3.2	30.9±0.9	30.5±0.5	31.2±0.9	33.1±0.9	32.7±0.9	30.4±2.4	30.5±1.8
	NoIR	23.6±2.6	28.7±2.4	30.4±0.6	31.3±0.7	32.7±1.1	32.6±1.4	32.6±1.5	31.2±2.1	30.7±1.9
34	IRV	23.9±3.6	28.8±1.2	30.4±0.5	30.5±0.9	33.0±1.4	32.2±0.7	31.7±1.2	31.1±1.7	30.7±1.8
	IRF	24.0±4.7	28.3±3.2	31.1±0.9	30.7±0.5	31.5±0.9	33.1±0.9	32.8±0.9	30.5±2.4	30.6±1.8
	NoIR	23.8±2.8	28.7±2.5	30.6±0.5	31.4±0.8	33.0±1.1	32.8±1.3	32.7±1.5	31.4±2.1	30.9±2.0
36	IRV	24.2±3.8	28.9±1.2	30.5±0.5	30.6±1.0	33.2±1.4	32.2±0.8	31.9±1.1	31.3±1.8	30.8±1.8
	IRF	24.3±5.0	28.4±3.3	31.3±0.9	30.8±0.5	31.7±0.9	33.2±0.9	32.9±1.0	30.7±2.4	30.7±1.8
	NoIR	24.0±2.9	28.7±2.5	30.7±0.6	31.5±0.8	33.2±1.1	32.9±1.2	32.8±1.5	31.5±2.1	30.9±2.0
38	IRV	24.4±3.9	29.0±1.2	30.5±0.6	30.6±1.2	33.2±1.2	32.3±0.8	32.0±1.0	31.4±1.8	30.9±1.8
	IRF	24.5±5.1	28.5±3.3	31.4±0.9	30.9±0.5	31.8±1.0	33.3±0.9	33.0±1.0	30.8±2.3	30.8±1.8
	NoIR	24.8±2.7	28.8±2.5	30.7±0.6	31.6±0.8	33.2±0.9	33.0±1.1	33.0±1.3	31.6±2.1	31.0±2.0
40	IRV	24.5±3.9	28.9±1.3	30.6±0.6	30.8±1.1	33.3±1.1	32.5±0.7	32.2±1.0	31.6±1.8	31.0±1.8
	IRF	24.8±5.3	28.7±3.4	31.4±0.9	31.0±0.5	31.9±1.0	33.4±0.9	33.1±0.9	30.9±2.3	30.9±1.8

Table B9: Heat flux (W·m^2; mean ± SD). P relates to the 3 min standing period prior to sitting. (ANOVA main effect $^{\#}P<0.05$, $^{*}P<0.01$, $^{**}P<0.001$; superscript[1] indicates P is equal to $^{\#, *, **}$).

Time (min)	Trial	Inner lower leg**	Outer lower leg**	Nose*	Forehead**
	NoIR	171.7±147.3	270.7±165.9	618.4±181.5	484.6±137.7
P1	IRV	143.9±120.0	332.5±207.0	580.7±201.1	370.7±35.7
	IRF	144.4±103.6	713.4±540.8	647.5±253.8	327.3±134.8
	NoIR	178.8±146.2	245.5±149.9	534.3±157.3	460.4±100.8
P2	IRV	146.2±116.3	435.6±351.5	520.8±188.2	372.0±49.8
	IRF	141.9±107.5	607.9±531.7	616.7±234.5	320.8±109.8
	NoIR	172.9±139.6	239.5±132.9	533.1±129.8	460.7±125.5
P3	IRV	147.8±113.5	432.7±317.2	507.4±236.9	418.5±110.0
	IRF	142.5±109.2	497.4±415.1	557.5±217.3	312.3±120.3
	NoIR	207.0±131.3	288.1±172.6	501.8±115.8	445.4±119.3
2	IRV	136.7±81.8	341.3±356.2	468.1±244.3	385.1±56.1
	IRF	175.4±75.9	467.3±362.9	475.8±214.0	305.5±119.2
	NoIR	203.5±115.5	202.5±122.6	433.3±110.2	452.1±123.3
4	IRV	132.3±84.4	314.3±371.3	357.5±213.7	350.1±45.7
	IRF	146.9±46.2	493.4±427.1	406.8±204.4	304.2±121.6

Time (min)	Trial	Inner lower leg	Outer lower leg	Nose	Forehead
	NoIR	169.9±80.8	175.5±83.8	304.7±106.6	383.0±86.2
6	IRV	110.2±72.2	315.2±425.9	272.3±202.2	311.5±44.8
	IRF	119.4±38.2	497.5±473.3	347.2±251.0	285.9±105.4
	NoIR	149.3±76.1	160.3±80.9	261.2±126.4	353.7±93.2
8	IRV	99.3±60.4	294.8±397.2	235.6±198.8	288.9±49.2
	IRF	108.2±34.9	493.8±483.5	275.7±188.2	241.8±91.6
	NoIR	140.4±72.6	312.4±401.4	249.1±128.5	336.5±82.0
10	IRV	94.2±55.4	296.0±407.0	214.3±183.3	279.3±50.1
	IRF	106.6±35.8	471.6±457.0	230.9±196.5	227.1±83.6
	NoIR	133.9±72.4	308.0±408.2	236.8±147.8	322.0±81.0
12	IRV	93.4±54.5	269.0±348.4	213.6±192.3	266.1±51.6
	IRF	96.0±34.8	484.7±484.5	225.4±176.0	225.2±87.4
	NoIR	116.3±53.3	289.7±377.8	234.1±152.3	292.5±71.3
14	IRV	83.6±48.9	253.4±326.0	208.8±212.2	249.3±43.7
	IRF	80.7±29.2	422.4±417.2	210.1±174.9	224.3±87.3
	NoIR	108.2±46.1	298.5±375.9	217.8±157.5	268.5±67.6
16	IRV	76.0±44.3	249.3±332.9	186.0±212.2	221.2±33.7
	IRF	73.6±27.0	359.3±365.7	199.2±177.1	200.3±69.3

Time (min)	Trial	Inner lower leg	Outer lower leg	Nose	Forehead
	NoIR	97.7±40.8	270.6±356.9	210.7±155.7	256.8±73.2
18	IRV	77.2±51.7	254.2±374.4	168.8±199.7	204.4±34.6
	IRF	62.4±27.5	333.8±359.2	200.0±178.7	181.9±60.4
	NoIR	89.3±39.2	266.2±361.2	202.5±159.7	236.8±67.5
20	IRV	65.7±41.3	231.0±340.6	151.8±185.1	189.6±30.1
	IRF	54.5±25.0	417.5±446.3	190.1±170.4	165.6±51.6
	NoIR	74.5±23.7	258.1±367.5	195.2±165.2	215.1±62.7
22	IRV	61.1±42.0	227.8±358.8	155.6±197.3	173.6±24.2
	IRF	47.6±21.1	435.5±485.3	161.8±150.1	147.3±42.5
	NoIR	66.7±23.7	243.1±343.5	200.2±177.3	197.5±57.8
24	IRV	55.2±39.9	218.4±363.6	163.9±160.1	160.7±19.3
	IRF	41.3±23.3	344.5±385.7	151.1±134.3	132.6±43.7
	NoIR	62.5±26.7	235.6±351.3	204.0±179.3	178.9±48.8
26	IRV	49.7±39.9	205.3±345.8	175.0±157.0	148.9±25.3
	IRF	32.0±24.4	515.6±669.8	142.9±144.3	121.5±36.6
	NoIR	50.1±22.2	228.7±360.7	194.3±152.3	163.9±44.6
28	IRV	34.7±20.9	193.1±329.1	167.5±147.0	128.6±20.2
	IRF	22.3±25.2	383.8±456.3	135.2±130.2	115.0±32.8

Time (min)	Trial	Inner lower leg	Outer lower leg	Nose	Forehead
	No IR	41.6±17.1	221.4±369.8	184.0±122.2	143.6±46.3
30	IRV	20.7±11.6	182.2±314.3	152.4±125.3	109.9±16.7
	IRF	13.2±17.8	392.7±486.8	124.2±112.4	96.2±26.9
	No IR	30.8±12.4	204.5±358.5	162.1±97.2	123.6±39.1
32	IRV	15.0±8.1	184.9±347.7	148.5±125.8	100.3±16.7
	IRF	-2.3±33.2	395.6±519.9	122.4±84.6	84.0±25.8
	No IR	30.0±9.8	204.2±364.0	188.7±76.6	119.6±34.1
34	IRV	14.6±7.2	172.8±335.1	152.0±110.2	93.6±13.1
	IRF	-0.2±26.0	402.8±541.4	154.9±84.6	78.3±24.6
	No IR	35.5±19.5	209.5±371.6	193.4±70.4	121.3±30.7
36	IRV	14.4±7.7	157.7±293.1	155.3±92.6	100.0±16.5
	IRF	-5.1±37.6	372.2±484.8	172.9±67.7	78.5±23.2
	No IR	34.1±17.6	209.8±371.9	190.5±58.5	120.5±31.4
38	IRV	19.7±14.1	156.4±284.5	163.5±88.3	101.0±11.7
	IRF	2.6±25.1	369.4±479.6	177.0±53.8	84.2±25.6
	No IR	32.4±13.6	187.9±329.2	185.4±58.3	120.2±35.4
40	IRV	19.2±14.2	165.7±318.1	149.7±77.2	95.3±15.8
	IRF	4.7±19.3	250.6±355.2	168.5±43.2	79.6±27.5

APPENDIX C

Table C1: Thermal comfort post hoc tests to examine significant main effect for condition.

Post hoc comparisons	Head	Face	Nose	Chest & Arms	Hands	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
IRF vs. IRV	-	-	-	NS	NS(P=0.055)	NS	NS	P<0.001	NS	NS	NS	NS
NoIR vs. IRV	-	-	-	P=0.01	P<0.001	P<0.001	P<0.001	P<0.05	NS	NS	P=0.001	P<0.01
NoIR vs. IRF	-	-	-	NS(P=0.076)	NS	P<0.01	P<0.001	P<0.001	P<0.05	NS(P=0.051)	P<0.05	P<0.05

Table C2: Thermal sensation post hoc tests to examine significant main effect for condition.

Post hoc comparisons	Head	Face	Nose	Chest & Arms	Hands	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
IRF vs. IRV	-	-	-	NS	NS	NS	NS(P=0.082)	P<0.001	P<0.05	NS(P=0.052)	NS	NS
NoIR vs. IRV	-	-	-	P<0.05	P<0.001	P<0.001	NS(P=0.05)	NS(P=0.145)	NS(P=0.128)	NS	P<0.01	P<0.05
NoIR vs. IRF	-	-	-	NS(P=0.076)	P=0.001	P<0.01	P<0.001	P<0.001	P<0.01	P=0.001	P<0.001	P=0.001

Table C3: Regression values between thermal comfort and thermal sensation scores for all body areas.

Trial	Head	Face	Nose	Chest & Arms	Hand	Seat Back Contact	Seat Cushion Contact	Lower Leg	Feet	Toes	Overall	Average
NoIR	0.92	0.93	0.90	0.89	0.98	0.98	0.96	0.96	0.98	0.96	0.94	0.97
IRV	0.95	0.97	0.95	0.97	0.99	0.97	0.98	0.99	0.97	0.97	0.99	0.99
IRF	0.98	0.99	1.00	0.99	0.99	0.98	0.97	0.93	0.98	0.97	0.97	0.99
All trials	0.94	0.95	0.95	0.94	0.98	0.98	0.96	0.96	0.96	0.96	0.96	0.98

Table C4: Desirability post hoc tests to examine significant main effect for condition.

Post hoc Comparisons	Seat	Lower leg	Face	Air	Acceptability
IRF vs. IRV	NS	$P<0.001$	NS	NS	NS
NoIR vs. IRV	$P<0.01$	NS	NS($P=0.137$)	$P<0.01$	$P<0.001$
NoIR vs. IRF	$P<0.05$	$P<0.001$	NS($P=0.092$)	$P<0.001$	$P<0.05$

Table C5: Core temperature, mean skin temperature and heat storage post hoc tests to examine significant main effect for condition.

Post hoc comparisons	Rectal	Aural	Mean skin temp[1]	Mean skin temp[2]	Heat storage[1]	Heat storage[2]	Heat storage[3]	Heat storage[4]
IRF vs. IRV	$P<0.05$	NS	$P<0.001$	NS($P=0.069$)	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$
NoIR vs. IRV	NS	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$
NoIR vs. IRF	NS	NS($P=0.1$)	$P<0.001$	$P<0.001$	NS	NS	NS	NS

Table C6: Upper body skin temperatures post hoc tests to examine significant main effect for condition.

Post hoc comparisons	Left lower back	Right lower back	Left upper back	Right upper back	Upper arm	Forearm	Chest	Hand	Finger	Nose	Forehead
IRF vs. IRV	$P<0.001$	$P<0.001$	NS	$P<0.001$	$P<0.01$	$P<0.001$	$P<0.001$	NS	$P<0.001$	$P<0.001$	$P<0.001$
NoIR vs. IRV	$P<0.001$	NS	$P<0.01$	$P<0.001$	$P<0.001$	$P<0.01$	$P<0.001$	NS	$P<0.001$	$P<0.001$	NS
NoIR vs. IRF	$P<0.01$	$P<0.001$	$P<0.05$	NS	$P<0.001$	$P<0.001$	NS	NS	$P<0.001$	$P<0.001$	$P<0.01$

Table C7: Lower body skin temperatures post hoc tests to examine significant main effect for condition.

Post hoc comparisons	Toe	Foot	Inner lower leg	Outer lower leg	Anterior thigh	Posterior thigh left	Posterior thigh right	Left buttock	Right buttock
IRF vs. IRV	P<0.05	P<0.05	P<0.001	NS	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001
NoIR vs. IRV	NS	NS	NS(P=0.75)	P<0.001	P<0.001	P<0.001	P<0.001	P<0.05	P<0.05
NoIR vs. IRF	P<0.05	NS	P<0.001	P<0.001	P<0.001	P<0.001	P<0.05	P<0.001	P<0.001

Table C8: Heat flux post hoc tests to examine significant main effect for condition.

Post hoc comparisons	Inner lower leg	Outer lower leg	Nose	Forehead
IRF vs. IRV	P<0.05	P<0.001	NS	P<0.001
NoIR vs. IRV	P<0.001	NS	P<0.01	P<0.001
NoIR vs. IRF	P<0.001	P<0.001	NS	P<0.001

APPENDIX D

Figure D1: ASHRAE thermal comfort scale

+3	VERY COMFORTABLE
+2	COMFORTABLE
+1	SLIGHTLY COMFORTABLE
0	NEUTRAL
-1	SLIGHTLY UNCOMFORTABLE
-2	UNCOMFORTABLE
-3	VERY UNCOMFORTABLE

Figure D2: ASHRAE thermal sensation scale

+4	VERY HOT
+3	HOT
+2	WARM
+1	SLIGHTLY WARM
0	NEUTRAL
-1	SLIGHTLY COOL
-2	COOL
-3	COLD
-4	VERY COLD

Figure D3: 7 point thermal desirability scale

+3	A significantly lower temperature would be better
+2	A lower temperature would be better
+1	A slightly lower temperature would be better
0	The current temperature is fine
-1	A slightly higher temperature would be better
-2	A higher temperature would be better
-3	A significantly higher temperature would be better

Figure D4: Acceptability of environment scale outlined by Zhang et al (2007)

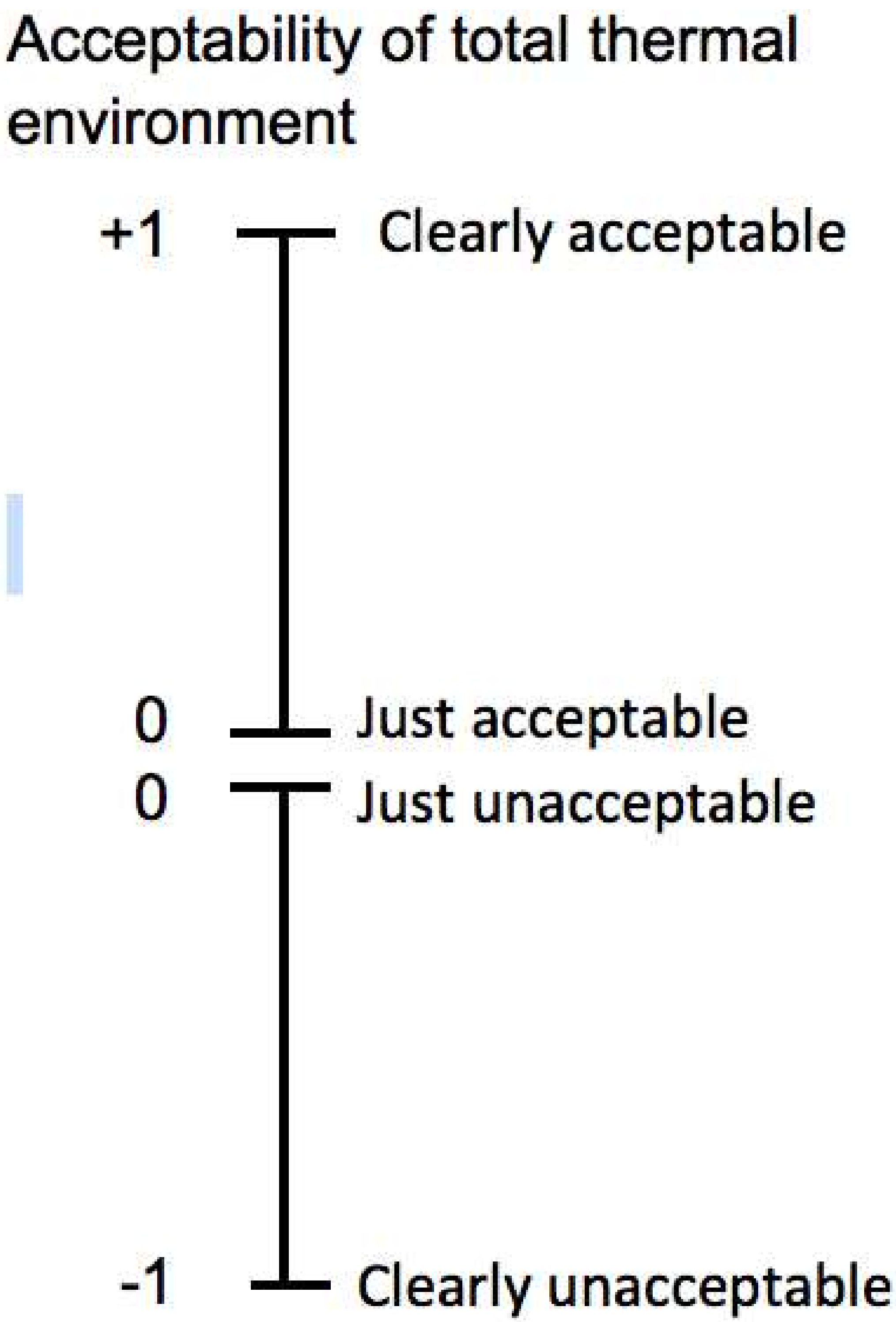


Figure D5: Certificate of ethical approval

Certificate of Ethical Approval

Student:

David Collins

Project Title:

Evaluation of Infra red heating as an adjunct to achieve car seat occupant thermal comfort

This is to certify that the above named student has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

09 January 2015

Project Reference Number:

P28084