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Patterns of verbal and nonverbal memory and executive function predict language and literacy ability

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Patterns of verbal and nonverbal memory and executive function predict language and literacy ability

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Abstract

This thesis examines the profiles of difficulty seen in three groups of impaired children (10 – 15 years), those with language only impairment (DLD), literacy only impairment (dyslexia) and comorbid literacy and language impairment (D-DLD). The aim of the project is to establish whether or not distinct profiles of difficulty can differentiate between groups.

Performance of the impaired groups was compared to both a chronological age-matched group (CAs) and younger literacy and language ability level groups. Performance was assessed for literacy, language, phonology, processing, short-term memory, working memory, executive function, attention and central executive measures over two time points.

The three groups showed qualitatively different profiles of impairment. They did however share an overlap in certain difficulties which may explain their high rates of comorbidity. The DLD group showed mild difficulty in spelling, phonological awareness and severe difficulty in language but were unimpaired in executive function, processing speed and short-term memory. The dyslexic group showed difficulty in word level literacy, phonology and verbal short-term memory. The D-DLD group showed difficulty in word level and text level literacy, phonology, language, executive function and verbal short-term memory.

This is the first project to include DLD, dyslexic, D-DLD, age-matched and ability matched groups simultaneously. It is also the first project to compare these different groups simultaneously over an extensive battery of working memory measures. It reveals distinct patterns of difficulty, in each of the impaired groups, that has implications for models previously conceptualising the overlap between the disorders. It also has implication for intervention in the classroom based on the strengths and weaknesses revealed for each group.

Objectives: To establish the patterns of impairment in each of my groups, and to suggest implications for current conceptualisations of overlap, and methods of classroom intervention.

List of common abbreviations

Short term memory (STM)

Working memory (WM)

Long-term memory (LTM)

Executive function (EF)

Central executive (CE)

Developmental language disorder - oral language difficulties only (DLD)

Comorbid literacy and language difficulty (D-DLD)

Chronological age-matched (CA)

Reading ability level group (RA)

Language ability level group – matched to DLD group (LA/DLD)

Language ability level group – matched to D-DLD group (LA/D-DLD)

Poor Comprehenders (PCs)

Time point one (T1)

Time point two (T2)

Attention deficit hyperactivity disorder (ADHD)

Speech sound disorder (SSD)

Autism spectrum disorder (ASD)

Nonverbal IQ (NVIQ)

Family Risk (FR)

Rapid automised naming (RAN)

Phonological awareness (PA)

Nonword repetition (NWR)

Sight word efficiency (SWE)

Phonetic decoding efficiency (PDE)

Reaction time (RT)

d prime (*d'*)

Standard deviation (SD)

Walk don't Walk task (WDW)

Continuous performance task (CPT)

Special educational needs coordinator (SENCO)

General Introduction

This thesis examines the underlying cognitive skills of children aged 10 – 15 years with either literacy difficulty (dyslexia), developmental language disorder (DLD) or comorbid (D-DLD) literacy and language difficulty. Dyslexia is a specific deficit characterised by difficulty in spelling and the fluent decoding of words (Lyon, Shaywitz, & Shaywitz, 2003). Developmental language disorder (formerly specific language impairment - SLI) occurs both with (D-DLD) and without (DLD) literacy difficulty. It is non-specific and characterised primarily by difficulty in receptive and expressive oral language. Controversially the DSM-5 (American Psychiatric Association, 2013) defines both dyslexia and DLD (which it terms language disorder) as specific disorders. To this extent the existing DSM-5 (American Psychiatric Association, 2013) definition of 'language disorder' is more akin to the formerly used 'SLI'. This is at odds with the current consensus that DLD can co-occur with difficulty in other areas in addition to language and that terminology should reflect this (Bishop, Snowling, Thompson, Greenhalgh, & CATALISE-2, 2017). Dyslexia is defined under the category of specific learning difficulty and DLD under communication disorders. According to the DSM-5 (American Psychiatric Association, 2013), for both disorders, difficulties must have persisted for more than six months despite the provision of extra help. The skills affected must measure significantly below that expected for age on standardised tests and have an adverse effect on everyday functioning. Difficulty must onset during school years and cannot be explained by other disorders (e.g. visual problems, neurologial disorders) or adverse conditions (e.g. inadequate instruction).

Both literacy and language disorders have similar prevalence rates, 3 – 10% of children (Snowling, 2000; Tomblin et al., 1997). A high proportion of children with language difficulty also show additional literacy difficulty (Arosio, Pagliarini, Perugini, Barbieri, & Guasti, 2016; Botting, Faragher, Simkin, Knox, & Conti-Ramsden, 2001; Marshall & Messaoud-Galusi, 2010;

Stark & Tallal, 1988; Tallal, Allard, Miller, & Curtiss, 1997; Snowling & Melby-Lervåg, 2016). McArthur, Hogben, Edwards, Heath and Mengler (2000) found that 53% of children classed as having a specific reading difficulty could also be classed as having a specific oral language difficulty. This was also true vice versa of children with a specific oral language difficulty. This has led researchers to question whether or not the disorders share a common aetiology. Several models have thus been developed which conceptualise the overlap between literacy and language impairment (Bishop & Snowling, 2004; Catts, Adlof, Hogan, & Weismer, 2005; Ramus, Marshall, Rosen, & van der Lely, 2013). However, these models concentrate largely on an overlap in phonological and language processes between the disorders. No models have attempted to profile the groups in terms of their underlying memory and attentional skills despite an overlap in observed patterns of difficulty (Schuchardt, Bockmann, Bornemann, & Maehler, 2013). This thesis rectifies this comparing the disorders in terms of short-term memory (STM), attention and executive function (EF).

This thesis is based around Baddeley's (2000) working memory (WM) model and steps through the model, administering tasks tapping each level. It includes measures assessing verbal and nonverbal STM, WM and EF. It also examines attentional processes and the overall supervisory system – the central executive (CE). At each level I compare performance of impaired (dyslexic, DLD, D-DLD) groups to a chronological age-matched group of typically developing children (CA) and younger ability level groups. Ability level groups are typically developing children matched for literacy (RA) or language ability (LA/DLD, LA/D-DLD).

I begin by defining dyslexia and DLD/ D-DLD in chapter one, how each disorder is characterised and how the overlap between disorders has previously been conceptualised. I then define the WM system, its key components and the way in which these interrelate. Lastly I look at some of the key studies that have assessed multiple areas of the WM system in my impaired groups. In chapter two, I introduce my experimental groups and explain how they are grouped and matched to younger ability level groups. I administer a battery of background measures assessing literacy, language, phonology and processing skills. I report this data and summarise the key differences between my groups. In chapter three, I move on to the first of my experimental studies. I give an overview of the literature surrounding verbal and nonverbal memory, including studies which have looked at measures in isolation and measures from different modalities. I also discuss the few studies which have included multiple impaired groups. I then report the findings of my own verbal and nonverbal STM and WM measures. In chapter four, I address measures of verbal and nonverbal EF, specifically, inhibition and updating. Again I discuss the literature examining each EF in my groups before reporting the results of my own measures. In chapter five, I look at standardised measures of both sustained and selective attention. I discuss papers that have used similar measures in my groups and then report the results of three measures assessing these types attention. In the penultimate chapter I turn my attention to the supervisory body responsible for orchestrating all of the aforementioned processes; the CE. I administer a novel measure designed to assess this domain general construct. In chapter seven I present my general discussion. This brings together results from background measures and also experimental measures throughout the thesis. I compare patterns of impairment between my groups and discuss the implications for a model defining patterns of cognitive impairment in my groups. I then define this model.

Chapter 1 - Literature Review

1. General introduction

This chapter introduces the disorders of dyslexia and developmental language disorder (D-DLD). It explains the key defining characteristics of each disorder and the proposed relationship between the two. For some time, researchers have questioned to what extent the two disorders are related due an overlap in aetiology (Bishop & Snowling, 2004; Catts et al., 2005; Ramus et al., 2013). This chapter begins by stepping through and describing each disorder before describing the potential overlap. It must be noted that when referring to developmental language disorder I abbreviate it to D-DLD. This is because the majority of children with early oral language difficulty develop additional literacy difficulties and also experience a difficulty in phonology (Bishop & Snowling, 2004). I assume therefore that literature discussing children with developmental language disorder are in fact talking about the group I define experimentally as D-DLD. A small proportion of children show oral language difficulty only without literacy difficulty. I refer to these children as DLD. Only when studies have expressly screened and not found additional literacy difficulty will I use the term DLD. I have chosen to do this to avoid confusion and for ease of comparison between the literature and my experimental groups. Literature describing groups with language difficulty have referred to participants as having DLD, language delay, language disorder and specific langue impairment / disorder which can become confusing (Bishop, 2014, 2017).

Several studies have assessed multiple processes (STM, WM, EF) for my groups (Jeffries & Everatt, 2004; Henry, Messer, & Nash, 2012; Reiter, Tucha, & Lange, 2005). Fewer studies have done this across different groups simultaneously (Cowan et al., 2017; Schuchardt et al., 2013). The latter section of this chapter introduces the WM model before presenting key studies which have looked at WM in groups with literacy and language difficulty.

I end by introducing my own model which outlines the overlap between groups for verbal and nonverbal, STM, WM, EF and CE impairment.

2. Dyslexia

Dyslexia is a specific word reading disorder characterised by persistent difficulty in spelling and the accurate and fluent decoding of text (Lyon et al., 2003). Children who meet the criteria for dyslexia perform typically in nonverbal IQ (NVIQ) tasks. They do not experience hearing loss or a handicap from any other neurological disorder (American Psychiatric Association, 2013) and have experienced adequate reading instruction (Bishop & Snowling, 2004; Catts, McIlraith, Bridges, & Nielsen, 2017).

2.1 Underlying causes – phonology, cause or effect?

Research focusing on the underlying deficits in dyslexia broadly occupies two areas (Ramus, 2003). The first, and now most widely accepted theory is the 'phonological deficit theory' (Snowling, 2000). Three factors, although not synonymous, contribute to this phonological deficit in dyslexia: poor phonological awareness (PA), poor phonological / verbal STM and poor lexical retrieval evidenced by rapid automised naming tasks (RAN; Wagner, Torgesen, & Rashotte, 1994; Wagner et al., 1997).

All three factors implicate phonological representations and this observation led to the formulation of a more detailed theory, the 'degraded phonological representations hypothesis'. This suggests that phonological representations in impaired readers are poorly defined, fuzzy or underspecified (see Elbro, 1996, 1998; Elbro & Jensen, 2005; Serniclaes, Van Heghe, Mousty, Carre´, & Sprenger-Charolles, 2004; Snowling, 2000). When phonological representations are encoded they are degraded, with the process leading to the loss of phonetic features. These features are then missing when dyslexic readers need to make comparisons or repeat words.

This theory is distinct to the later ‘access theory’ (Ramus, 2014; Ramus & Szenkovits, 2008). The access theory suggests that phonological representations are intact and that all phonetic features are correctly encoded. Instead participants with literacy impairment experience a difficulty in accessing these phonological representations. Ramus and Szenkovits (2008) summarise difficulties in STM, conscious awareness (requiring WM) and speeded access to long-term memory (LTM) representations, as synonymous with ‘access’ problems. PA for example requires ‘conscious awareness’, the online maintenance of representations, whereas RAN tasks require ‘speeded access’ to representations. Ramus and Szenkovits, (2008) argue that PA, verbal STM and RAN all require access mechanisms (both lexical and sublexical) to allow passage to phonological representations. Through several studies they demonstrated intact phonological representations for dyslexic individuals. They argue that difficulties only arise when verbal STM or WM demands are increased, placing greater strain on mechanisms that allow access to phonological representations.

Other theories have concentrated on ‘access to’ rather than ‘quality of’ phonological representations. The ‘anchoring deficit hypothesis’ (Ahissar, 2007) suggests that typical readers are able to make temporary but solid associations between pictures and phonological representations in RAN tasks. They then retrieve information from a temporary store. Dyslexic participants are unable to do this as automatically as CA participants. Without this facilitation, dyslexic participants are forced to constantly make online pairings of pictures and phonological representations which require fluid access. According to this theory then, dyslexic individuals should perform similarly to typical readers on RAN tasks with large stimulus sets that do not repeat. However, this is not the case (Di Filippo, Zoccolotti, & Ziegler, 2008). A softer interpretation of the anchoring deficit hypothesis therefore may be more accurate; typical readers are better able to make use of verbal STM and WM processes in tasks with RAN demands.

A second area of major focus in dyslexia research is general auditory and sensorimotor deficits and several different theories fall in to this area. In general, these theories propose distal causes for dyslexia, causing dyslexia by causing impaired phonological skills. The 'cerebellar theory' (Nicolson, Fawcett, & Dean, 2001) suggests that deficits in dyslexia arise from a dysfunction of the cerebellum. This dysfunction impacts motor control, speech articulation and automatisation. These factors significantly impact on the ability to encode phonological representations and map phoneme-grapheme correspondences. To this extent it might be that phonological difficulties are caused by other underlying problems in dyslexia such as sensorimotor difficulties. Phonological difficulties would be a by-product of the broader deficits underpinning the disorder rather than the specific cause of literacy difficulty.

Another theory, the 'visual theory' (Stein & Walsh, 1997) uses visual crowding, visual stress and unstable visual fixations as evidence of visual deficits in dyslexia. In particular it suggests that dyslexic individuals have a difficulty with processing written text. The 'rapid auditory processing theory' (Tallal, 1980) suggests phonological deficits in dyslexia stem from auditory difficulties. Dyslexic individuals find it hard to process sounds that are short or change rapidly and experience difficulty in distinguishing between frequencies or the temporal order of sounds. A theory which subsumes all of the aforementioned theories is the 'magnocellular theory' (Stein, 2001, 2018). It suggests dysfunctional cells in sensory pathways are responsible for a host of visual, auditory and motor difficulties in dyslexia.

2.2 Family risk, the overlap between literacy and language disorders

Studies of children at family risk of dyslexia (FR) further highlight the role that phonology plays in reading difficulty. Pennington and Lefly (2001) found that FR children who went on to develop dyslexia had poor PA at 5 years. However both FR children who did develop dyslexia and those who did not showed poorer phonological skills than children not at risk of dyslexia. Phonological difficulties it seems are present in FR children regardless of whether or not they go on to develop dyslexia (Snowling, Gallagher, & Frith 2003)

FR studies also highlight the early overlap between literary and language disorders (see Nash, Hulme, Gooch, & Snowling, 2013). There is high risk that children with pre-school language difficulties will develop reading difficulties (Carroll, Mundy, & Cunningham, 2014; Isoaho et al., 2016; Snowling, Bishop, & Stothard, 2000). Language skills such as expressive and receptive vocabulary predict reading ability via their link with reading predictors (letter naming, PA and RAN; Torppa, Lyytinen, Erskine, Eklund, & Lyytinen, 2010). Scarborough (1990) found that FR children (3 years) who later became dyslexic showed poorer vocabulary knowledge than FR children who did not go on to become dyslexic. Similarly, Snowling et al. (2003) found that FR children who later developed dyslexia had poorer language skills at age three including non-word repetition, expressive language and receptive vocabulary. Gerrits and de Bree (2009) found similar expressive and receptive language difficulties in children at FR of dyslexia. Hulme, Nash, Gooch, Lervåg and Snowling (2015) found that pre-school language ability predicted performance on tasks assessing PA and phoneme-grapheme knowledge, which later predicted reading. This was true for both FR children who did and did not go on to develop dyslexia. In a review of 95 studies of children at FR of dyslexia, Snowling and Melby-Lervåg (2016) found preschool measures of oral language predicted later reading outcomes. Children who went on to develop reading difficulties had poorer vocabulary development than those who didn't develop difficulties. It is clear then that early oral language difficulties present a risk for later literacy development.

The impact that reading difficulty or limited access to written text has on future language development is less well established (Bishop & Snowling, 2004). Share and Silva (1987) found that standard vocabulary scores declined in children between the ages of three and 11 diagnosed with dyslexia, presumably from reduced access to written text. However, oral language difficulties may have already been present in the sample when they were pre-literate. Snowling, Duff, Nash and Hulme (2016) found that children at FR of dyslexia formed a substantial group of those with late emerging language difficulties in middle school. Phonological difficulties seen in children at FR of dyslexia (Snowling & Levag, 2016) may cause difficulties in language later on.

Literacy difficulty seems to be prevalent in children with unresolved language difficulty (Bishop & Adams, 1990). However even children with resolved language difficulties seem to experience lower literacy levels than CA groups over time (Stothard, Snowling, Bishop, Chipcase, & Kaplan, 1998). Stothard et al. (1998) looked at the literacy and language performance of a group of adolescents (15-16 years) with a history of pre-school language impairment compared to CAs. At age four, they were divided in to those with typical NVIQ and those with below average NVIQ. Children with typical NVIQ were further subdivided at age five and a half in to two groups, those with persistent, and those with resolved, language difficulties. Those with typical NVIQ, but resolved language difficulties, performed worse than CAs on tasks assessing PA and composite literacy (single word reading, spelling and reading comprehension). Composite literacy scores however were within a normal range for NVIQ / age for those with resolved difficulties. These children it seems, although not dyslexic, do exhibit a lower level of literacy than peers with similar language scores. Lower levels of literacy are likely related to early language difficulty. Those with both typical and non-typical NVIQ and persistent language difficulties at five and a half showed deficits in all areas of literacy and language tested. This suggests that literacy difficulty is prevalent in children with early language difficulties both resolved and persistent. It should be noted that Bishop and Adams (1990), failed to find literacy difficulty at age eight and a half in the same group with typical NVIQ and resolved language difficulty. However Stothard et al.'s (1998) study suggests that as time goes on, those with early language difficulty do still fall behind. Children with unresolved language difficulties in Bishop and Adam's (1990) study also showed difficulty in all areas of literacy assessed at eight and a half.

2.3 Intervention

A key question that arises from FR studies is whether or not children who show early risk signs of dyslexia, such as language difficulty, can benefit from early intervention (see Snowling, 2013). Bowyer-Crane et al. (2008) tested two interventions designed to target children entering school with poor language skills. One targeted the development of decoding skills, the other, improving oral language skills. Children exposed to the decoding intervention made greater improvements in PA, letter-sound knowledge and reading than those who received the oral language intervention, while the children in the oral language intervention improved in narrative tasks. Improvements in these skills persisted after the intervention had stopped. More children remained within the 'at risk' category for reading difficulty in the language intervention group (68.1%) than the decoding intervention group (50%). This highlights the importance of phonology in both oral language and literacy difficulty.

Many interventions concentrate on phonology when trying to improve word level reading skills (see Duff & Clarke, 2011; Snowling & Hulme, 2011). Interventions largely concentrate on PA training and phonics instruction. Meta-analyses suggest that both are effective separately (see Bus & Van IJzendoorn, 1999; National Reading Panel [NRP], 2000). However, the most effective interventions are those which include both PA and phonics instruction (Torgesen, 2005). PA training significantly improves when paired with letter knowledge training (NRP, 2000). Phonics programs involve letter knowledge (i.e. teaching phoneme-grapheme correspondences) but rely on children having a basic level of PA.

2.4 Individual risk

Whilst phonology plays a key role, several factors place children at risk of developing dyslexia. No one factor alone is likely sufficient to cause reading difficulties. For instance, many studies have found auditory (Amitay, Ahissar, & Nelken, 2002; Chiappe, Stringer, Siegel, & Stanovich, 2002; Share, Jorm, Maclean, & Matthews, 2002), visual (Amitay, Ben-Yehudah, Banai, & Ahissar, 2002) and motor (Ramus, Pidgeon, & Frith, 2003) difficulties in dyslexia but not all dyslexics experience each difficulty. At the same time a phonological deficit alone is not enough to cause reading difficulties. Some FR children do not go on to develop dyslexia despite having experienced phonological difficulties (Carroll & Breadmore, 2018; Snowling & Melby-Lervåg, 2016).

Several studies have tried to determine which factors might pose the largest risk for children developing dyslexia. Ramus et al. (2003) administered phonological, auditory, visual and cerebellar tasks to dyslexic individuals. Despite different combinations of difficulties in participants, all participants showed a phonological deficit with five participants showing purely phonological deficits. Similarly, White et al. (2006) administered phonological, motor, visual, speech and auditory tasks to participants and found that half of their participants were impaired in phonological processing, with four possessing a purely phonological deficit. Both studies concluded phonological processing as the strongest predictor of reading ability. In their recent review of 95 publications, Snowling and Melby-Lervåg (2016) confirmed a phonological deficit as the primary risk factor for children at FR risk of dyslexia with phonological STM ability predicting deficits in preschool years, and PA later on. Letter knowledge and RAN are also strong predictors of reading difficulty. In another recent study, Saksida et al. (2016) looked at three potential risk factors in dyslexic children; a phonological deficit, visual stress and reduced visual attention span. Most participants showed a phonological difficulty in terms of accuracy (92.1%), speed (84.8%) or both (79.3%). Only 28.1% of the participants showed deficits in visual attention span and all of these participants also experienced a phonological deficit. Dyslexic participants did not show more visual stress than the control group. Children with both visual and phonological difficulties had similar reading impairments to those with purely phonological deficits, suggesting the importance of the latter.

Of all the risk factors that exist for dyslexia, phonological difficulty may pose the greatest single threat then. However it is widely acknowledged that in most cases of dyslexia, several risk factors present cumulatively to cause disorder. Thompson et al. (2015) investigated the individual risk factors responsible for dyslexia and how these factors accumulate to predict dyslexia. The authors found that it was possible to predict the likelihood of developing dyslexia when different combinations of risk factors were present. They followed preschool children at FR of dyslexia and those with speech and language difficulties until the age of eight. For those who did develop dyslexia, FR was a greater predictor at preschool than language ability. FR remained a constant predictor at each time point as well as RAN, letter knowledge, PA and executive skills. Language difficulty at the individual level was not a good predictor of dyslexia until school age (5 years). Very early language difficulty then cannot be assumed to predict literacy difficulty later on.

Literacy difficulty is caused by a combination of difficulties in multiple areas (Pennington, 2006; Thompson et al., 2015) however phonological difficulty most likely poses the greatest risk.

3. D-DLD

Comorbidity refers to a greater than expected co-occurrence between disorders. Some researchers estimate that 50% of dyslexic individuals show comorbid oral language difficulty (Stark & Tallal, 1981). This may be due in part to the overlap of risk factors shared by the disorders (Pennington, 2006). In the case of dyslexia and D-DLD, many researchers have argued that both share an underlying risk factor, a deficit in phonological ability (Bishop & Snowling, 2004). Intervention studies that target phonological decoding in children with early language difficulties again highlight this shared risk factor (Bowyer-Crane et al., 2008). Naturally this begs the question, are dyslexia and D-DLD in some way causally related? This thesis looks at the relationship between the two disorders. It aims to assert whether the two are causally related or whether both present with unique but overlapping profiles of difficulty.

3.1 Defining D-DLD

Children with D-DLD experience a persistent difficulty in oral language, specifically in the production of spoken language (expressive difficulty) and / or the understanding of spoken language (receptive difficulty; Boyle, McCartney, O'Hare, & Law, 2010). In D-DLD, oral language ability lags behind that expected given a child's age, the reason for which is not obvious (Bishop & Snowling, 2004). Unlike speech sound disorder (SSD) which specifically affects the production of speech sounds, D-DLD affects expressive and receptive vocabulary in addition to syntactic language skills (Pennington, 2006). A general consensus is that, children must perform at least one standard deviation (SD) below the mean for their age on two or more tasks assessing language to be defined as D-DLD (Henry et al., 2014; McArthur, et al., 2000; Tomblin et al., 1997). They should also not experience hearing loss or any other genetic or neurological disorder (Bishop, 2014).

However, there is still disagreement over the diagnostic criteria and terminology used for D-DLD (Bishop, 2014; Conti-Ramsden & Durkin, 2017) and the question of 'how specific is D-DLD' is still a pertinent one. For some time, researchers have refrained from using the term 'specific language impairment' as it is misleading. The term suggests that children with language difficulties do not experience nonverbal difficulty. Some researchers have gone as far to suggest that the term 'language delay' be attributed to children who have both verbal and nonverbal difficulties whereas 'language disorder' should be used for children who have specific language difficulties (Bishop, 2017). However, this presents a difficulty for children who experience language difficulty and comorbid neurodevelopmental disorders such as autism spectrum disorder (ASD) or attention deficit disorder (Bishop, 2017). These disorders inherently embody a wide range or difficulties both verbal and nonverbal. In a recent paper, Bishop (2017) collected opinions regarding the terminology surrounding language difficulty. A panel agreed that children experiencing language difficulties primarily should be referred to as having developmental language disorder whereas those with other neurodevelopmental disorders primarily (such as ASD) should be referred to as having ASD with DLD.

The term specific language disorder also presents a problem for children who experience both verbal and nonverbal difficulties in cognition, which is common in language disorders (Botting, 2005). Whilst previously, IQ discrepancy definitions of language disorder were adopted (difficulty in language the presence of typical NVIQ), it is now understood that NVIQ should not be a constraining factor for diagnosing D-DLD in children (Bishop 2017; Bishop, Snowling, Thompson, & Greenhalgh, 2016). In the most recent DSM-V (American Psychiatric Association, 2013), NVIQ within a typical range was removed as diagnostic criteria for language disorder (Norbury et al., 2016). Instead of causing language difficulties, low NVIQ is a factor that often co-occurs with low language (Bishop et al., 2016; Botting 2005). To receive a diagnosis of D-DLD, children only need to attain a minimum level of nonverbal ability to allow for everyday independent functioning (Bishop, 2017). To this extent, the discrepancy between language ability and age is more important than that between language and nonverbal ability when establishing a diagnosis (Bishop, 2014,). Having said this, researchers have made it clear that any markers of D-DLD should not correlate with IQ and should themselves be uniquely predictive of language ability, rather than individual attainment (Bishop, North, & Donlan, 1996).

3.2 Markers of D-DLD

D-DLD is a heterogeneous disorder and because of this, there is less agreement in key theories underlying it. Different children can display different patterns of impairment which can lead to similar difficulties in language. Children with D-DLD can either experience a specific difficult leading to their impairment in language or a combination of several (non-specific) difficulties, leading to language problems (see Archibald & Joanisse, 2009). In turn, different combinations of language skills can be affected in D-DLD and often children will display different sets of difficulties or markers (Isoaho, Kauppila, & Launonen, 2016).

One marker of D-DLD is a difficulty in grammar (Bishop, Adams, & Norbury, 2006). Theorists argue that language learning is aided by innate structures in the brain. If these grammatical frameworks are damaged, then the acquisition of language rules will be problematic (Joanisse & Seidenberg, 1998). Several different grammatical difficulties have been seen in D-DLD including a difficulty in inflection and tense marking (Loeb & Leonard, 1991; Van der Lely & Ullman, 2001), in thematic role assignment (Bishop, 2003) and answering 'what, where, when or why' questions (Forteneau & van der Lely, 2008).

In terms of other linguistic markers, Conti-Ramsden, Botting and Faragher (2001) found several which did not correlate with IQ. One of these is nonword repetition (NWR) difficulties and many studies have found similar deficits (Bishop et al., 1996; Conti-Ramsden, 2003; Dollaghan & Campbell, 1998; Gathercole & Baddeley, 1990; Montgomery, 1995). NWR deficits are present also in children with a history of language difficulty but whose problems had resolved (Bishop et al., 1996). Many researchers attribute this difficulty to poor verbal STM (Baddeley, Gathercole, & Papagno, 1998; Bishop et al., 2006) or a difficulty in the access of phonological representations (Ebbels, Dockrell, & van der Lely, 2012). Gathercole and Baddeley (1990) suggest that items rapidly decay in verbal STM for D-DLD children or a limitation in verbal STM capacity causes difficulty for D-DLD children. A meta-analysis assessing

23 studies of NWR in D-DLD children found difficulties to be robust across a range of age spans. In some studies it was also found that D-DLD children had a severe impairment for even short nonwords which increased with severity for longer nonwords (Estes, Evans, & Else Quest, 2007). Having said this, Estes et al. (2007) note that not every test of NWR is the same, some providing larger effect sizes than others. Indeed several factors can affect whether NWR deficits are observed including task type and language tested. Some studies have failed to find NWR deficits (but still found sentence repetition deficits) for example in Cantonese orthographies (Stokes, Wong, Fletcher, & Leonard, 2006).

A second and potentially stronger marker of language difficulty is sentence repetition. Again this is a robust finding in children with D-DLD and has been witnessed several times (Bishop et al., 1996; Conti-Ramsden et al., 2001; Kamhi & Catts, 1986; Stokes et al., 2006). Sentence repetition requires the integration of information from verbal STM and additional language information (syntax, grammar) from LTM (see Alloway, Gathercole, Willis, & Adams, 2004; Gathercole & Baddeley 1993). NWR tasks can also draw on information stored in LTM. Nonwords that have a similar sound structure to existing words are said to have high 'wordlikeness'. For example, '*glistering*' sounds similar to '*glistening*' (Gathercole, Willis, Baddeley, & Emslie, 1994). Nonwords with greater 'wordlikeness' are more likely to be correctly repeated than unfamiliar nonwords (Gathercole, Willis, Emslie, & Baddeley, 1991). Where possible, children will use their existing vocabulary knowledge to succeed in NWR tasks, utilising information stored in LTM. The integration of information from long term stores in both NWR and sentence repetition tasks involve WM processes (Gathercole et al. 1994). Information held in the temporary stores must be compared online to existing information in LTM. The WM demands of sentence repetition tasks are more complex than those in NWR tasks (Conti-Ramsden, 2001; Riches, 2012). Tasks will often require a processing element such as a true / false judgment at the end of each sentence. Conti-Ramsden (2001) found sentence repetition to be the best predictor of language difficulty with an overall accuracy of 88% and this is likely due to the involvement of WM. It is therefore suggested that verbal WM difficulty is a strong indicator of D-DLD.

A difficulty in temporal processing has also been highlighted as a marker of D-DLD, in particular in relation to receptive vocabulary skills (Share et al., 2002). D-DLD participants find it hard to respond correctly to rapidly changing acoustic information. This suggests an acoustic perceptual difficulty in D-DLD could affect speech reception (McArthur & Bishop, 2004).

4. The relationship between literacy and language impairment

Dyslexia and DLD frequently co-occur. Many children with dyslexia experience some degree of oral language difficulty and vice versa (Arosio et al., 2016; Botting et al., 2001; Marshall & Messaoud-Galusi, 2010; Stark & Tallal, 1988; Tallal et al., 1997; McArthur et al., 2000; Snowling & Melby-Lervåg, 2016). Despite an awareness of this, a large number of children receive a diagnosis of dyslexia whilst experiencing additional undiagnosed language difficulties (Arosio et al., 2016).

4.1 An overlap in aetiology

The relationship between literacy and language difficulty is complex and may vary according to disorder type i.e. developmental phonological dyslexia vs. surface dyslexia, expressive vs. receptive language difficulty (Pennington & Bishop, 2009; Snowling & Bishop, 2004). Many causal factors exist for both dyslexia (Lyytinen et al., 2006; Pennington et al., 2012, Ramus et al., 2003) and D-DLD (Tomblin, 1991). One such factor, phonological processing difficulty, has been found in both dyslexic (Elbro & Jensen, 2005; Snowling, 1987; Tallal 1980) and D-DLD groups (Claessen, Kane, & Williams, 2013; Maillart, Schelstraete, & Hupet, 2004; Tallal, Stark, Kallman, & Mellits, 1980). Several studies have focused therefore on the ability to form and store phonological representations in these groups (Carroll & Snowling, 2004; Kamhi

& Catts, 1986; McArthur et al., 2000; Robertson, Joanisse, Desroches, & Terry, 2013; Snowling & Hulme, 2012; Wong, Kidd, Ho, & Au, 2010). Phonological processing difficulty may distinguish between DLD children who do and do not experience additional reading impairment (Loucas, Baird, Simonoff, & SIonims, 2016). Catts et al. (2017) found that pre-school children with (and without) language difficulty, that experienced a difficulty in PA, were more likely to develop reading difficulty.

4.2 Modelling the overlap

It is easy to see why early theories, such as the 'Severity Hypothesis', suggest that dyslexia and D-DLD form different manifestations of the same underlying deficit. Both disorders experience a difficulty in phonological and auditory processing, access and storage with D-DLD children being more 'severely' affected than dyslexic children (Kamhi & Catts, 1986; Snowling, 2000). However, later models have moved away from this and instead consider dyslexia and D-DLD to be distinct disorders which overlap. Most of these models are similar in that they profile the phonological and non-phonological language difficulties found in both D- DLD and dyslexia. I now go on to describe three different models that have tried to conceptualise the overlap between literacy and language disorders. It must be noted that these models were defined when language difficulty was still referred to as SLI. I have preserved this original term when discussing the models here. This is to make the distinction clear when I compare my DLD group to the previous conceptualisations of SLI in the models.

4.2.1 The additional deficit model

The additional deficit model (Bishop & Snowling, 2004), also known as the 2D model, predicts that children with literacy and language difficulty can be differentiated along two spectrums (phonological and non-phonological language skills), see Figure 1. Bishop and Snowling (2004) suggest that both dyslexic and language impaired children ('classic SLI') have a difficulty in phonology causing word reading problems. Children with 'classic SLI' have additional deficits in non-phonological aspects of language (syntax, discourse, semantics). They experience a double deficit in phonological and non-phonological aspects of language which contribute to word reading problems. According to Bishop and Snowling (2004), this is in contrast to dyslexic children who experience word reading problems only because of a difficulty in phonology. They also specify a third group of children who experience a different type of literacy difficulty (i.e. problems in reading comprehension but not decoding). These ‘poor comprehenders’ (PCs) do not experience phonological difficulty but experience difficulty in language skills such as syntax and semantics (Nation, Clarke, & Snowling, 2002). There has been disagreement as to whether purely language impaired groups should be considered PCs. Indeed Nation, Clarke, Marshall and Durand (2004) found children classified as PCs often met the criteria for language impairment on several language assessments. Both language only impaired groups (SLI Only) and PCs experience difficulty in comprehension and language. PCs do not experience difficulty in phonology however. This is outlined clearly on the additional deficit model as the PC group appear in the bottom right quadrant indicating poor language but proficient phonology, see Figure 1 . It is important to highlight that Bishop and Snowling’s (2004) language only impaired group (PCs) are not the same as my language only impaired group (DLD). It is true that my DLD group and Bishop and Snowling’s (2004) PCs both experience language difficulty. They also both share a difficulty in reading comprehension. My DLD group however have phonological difficulty (see section 4.3). My DLD group (with poor language, poor phonology but proficient decoding skills) would not fit within the 2D model. The PCs however do.

Figure 1: The additional deficit model, Bishop and Snowling (2004).

4.2.2 The component model

The major difficulty with the additional deficit model is that is predicts that children with ‘classic SLI’ always have dyslexia. Phonological difficulty is thought to be the underlying cause of reading difficulty in children with dyslexia (Snowling, 2000). If children with dyslexia and oral language difficulty both show phonological difficulty, then it follows that both will experience decoding difficulty. We know however that language difficulty can occur in the absence of dyslexia (Bishop, McDonald, Bird, & Hayiou-Thomas, 2009; Catts et al., 2005; Kelso, Fletcher, & Lee, 2007). It could be that not all children with SLI experience phonological difficulty, and the additional deficit model certainly predicts this in the form of PCs. Yet research has proven that SLI children with phonology difficulty (but no decoding difficulty) do exist (Catts et al., 2005; Ramus et al., 2013; Snowling et al., 2019). Alternatively the phonological difficulty in children with dyslexia and SLI only could be different (Pennington & Bishop, 2009). Indeed research does suggest that the phonological deficit is milder in children with language difficulty only (Bishop et al., 2009; Catts et al., 2005; Kelso et al., 2007). Catts et al. (2005) found evidence for children with dyslexia only, dyslexia plus SLI, and SLI only. The children with SLI only presented both with and without phonological difficulties. This gives support to the existence of PCs (no phonological difficulty) but also an SLI only group (phonological difficulty). Ramus et al. (2013) used the classifications of disorders outlined in Catts et al. (2005) and created the ‘component model’. They then used the two-dimensional framework (phonological and nonphonological language skills) of Snowling and Bishop (2004) to plot the relationship between the disorders, see

*Figure **2***. It must be noted however that the component model, considers literacy and language difficulties to be independent, but co-occurring, suggesting unique culminations of cognitive deficit. It is hard to plot such within a two-dimensional framework. For example the component model considers SLI to occur both with and without phonological difficulty. In

*Figure **2*** (taken from Ramus et al., 2013), the bottom left quadrant shows both PCs and a SLI only group occupying the same area. However the authors note that this is just for completeness. The reality is that group differences cannot be highlighted by two dimensions alone. In fact multiple strengths and weaknesses lead to the unique profiles of difficulty in each group.

Figure 2: The component model taken from Ramus et al. (2013).

4.2.3 Multiple-component models

Multiple-component models take in to account the combination of difficulties that lead to impairment in different groups. Although Ramus et al. (2013) found the component model to be a better fit than the additional deficit model, they did concede that the two dimensional framework was not sufficient to define the groups. Using a factor analytic approach they found that a third variable, phonological representations, accounted significantly for the difference between groups. They concluded that explicit phonological skills (i.e. RAN) which require verbal STM, WM and attention might be more important for literacy proficiency but an implicit ability to process phonological representations might be more important for oral language. Research supports this, as the presence of RAN difficulties alongside other phonological difficulties in SLI are most likely to result in additional dyslexia (Vandewalle, Boets, Ghesquière, & Zink, 2012).

In another paper, Pennington, (2006) describes a ‘multiple cognitive deficit model’ of developmental disorders. Pennington (2006) suggests that complex behavioural disorders such as dyslexia and language difficulty are multifactorial in their aetiology. Multiple risk (e.g. verbal STM, PA) and protective factors (e.g. proficient EF, WM) come together to determine the probability of developing a disorder. They affect the development of cognitive processes producing phenotypic profiles in each disorder. Pennington (2006) suggests that the cause of disorders cannot be reduced to one factor and that instead several are necessary. Therefore it is likely that comorbidity will occur between disorders that share common factors. They argue for a role of verbal WM and EF in dyslexia (McGrath et al., 2011). They note that verbal WM often occurs as a shared cognitive deficit in disorders.

5. Summary

All of the above models agree that literacy and language disorders share common factors likely responsible for their comorbidity. Whilst later models have begun to consider factors such as STM, WM and EF, existing models largely concentrate on language and literacy processes such as phonology, semantics etc.

A model is required that concentrates on the underlying cognitive processes responsible for the implicit processing of phonological representations and explicit use of phonological skills. This would involve an investigation into the strengths and weaknesses of D-DLD, DLD and dyslexia in terms of WM and EF. I now turn my attention to these processes, describing their relation to literacy and language.

6. WM architecture

Links between verbal WM and language and literacy development have been established for some time (Baddeley, 2003; Daneman & Carpenter, 1980; Daneman & Merikle, 1996; Gathercole & Baddeley, 2014). NWR utilises both verbal STM and WM processes. Many studies have looked at the relationship between NWR and vocabulary, finding that the former predicts the latter (Baddeley et al., 1998; Gathercole & Baddeley, 1989). This has inspired the theory that the phonological loop developed as a language learning device and that it is likely impaired in D-DLD (Gathercole, 2006). Baddeley et al. (1998) found that adult participants were unable to learn new foreign language word pairs when they had a verbal STM deficit. Similarly, articulatory suppression tasks which impair access to the verbal STM store reduce participants' ability to learn novel word pairs (see Baddeley, 2013). However, some researchers consider the link to be in the opposite direction; language and literacy levels account for NWR performance (Snowling, Chiat, & Hulme, 1991; Nation & Hulme, 2011).

Verbal STM is predictive of literacy ability (Melby-Lervåg, Lyster, & Hulme, 2012). In case studies of children, deficits in the phonological loop were found to be responsible for poor reading (Baddeley & Wilson, 1993). It has also been found to predict PA which is highly implicated in literacy ability (Mann & Liberman, 1984). The nonverbal STM store has also been linked to language proficiency to some degree. Poor visual spatial skills have been found to impact on grammatical comprehension in children with William's Syndrome. Children had poorer comprehension for sentences that involve spatial propositions like 'above' or 'below' (Phillips, Jarrold, Baddeley, Grant, & Karmiloff-Smith, 2004).

EFs are also strongly linked to scholastic achievement. Updating ability (refreshing of WM) has been found to predict fluency and reading ability more widely (Artuso & Palladino, 2016; Jerman, Reynolds, & Swanson, 2012). In St-Clair-Thompson and Gathercole (2007), updating was found to uniquely contribute to English and maths scores. Inhibition uniquely contributed to English, maths and science scores. Verbal WM was also found to be uniquely associated with English and nonverbal WM with maths, English and science. Jarvis and Gathercole, (2003) found that both verbal and nonverbal WM contributed to English, maths and science attainment.

Similarly, links exist between attention and language processing (Conner, Albert, Helm-Estabrooks, & Obler, 2000). Sustained attention correlates with several language skills including both simple and complex sentence comprehension (Montgomery, Evans, & Gillam, 2009), language production (Duinmeijer, de Jong, & Scheper, 2012) and narrative generation (Blom & Boerma, 2016).

Lastly, research suggests that the ability to form temporary cross-modal bindings is highly related to word recognition (Wang, Allen, Lee, & Hsieh, 2015). The episodic buffer is responsible for integrating information from the phonological loop and the visuospatial sketchpad and storing this temporarily. Wang and Allen (2018) found that children's word recognition was related to performance on tasks binding nonwords and abstract shapes. Cross-modal binding is highly implicated in forming phoneme-grapheme correspondences (see Jones, Branigan, Parra, & Logie, 2013). Accessing and binding information from LTM with information in WM is also critical to literacy. Binding in LTM is related to word recognition, PA, spelling and RAN (Hulme, Goetz, Gooch, Adams, & Snowling, 2007).

I now give an overview of the WM model and discuss briefly how literacy and language impairment may be affected in each area. Figure 3 gives an overview of the WM system and depicts how each subsystem relates to the others. I have also used this figure to create my thesis map at the end of each experimental chapter. This thesis examines the performance of impaired and control groups at each level of the WM model. Results build from the simple short term sores through to the complex CE. By using this figure to create a thesis map, I can show how my results build for each group for each stage of the model, to paint an overall picture of task performance.

Figure 3: The relationship between the components (verbal / nonverbal STM stores, CE, episodic buffer) and processes (EF, WM, attention) outlined in Baddeley's (2000) WM model.

6.1 The short-term stores and WM

The first component in the model, the verbal STM store, is responsible for the temporary storage of verbal information. It can be divided in to two sub-components. The first is a limited capacity phonological buffer. Word length effects show that recall falls dramatically for multi-syllabic versus monosyllabic word lists suggesting a limited storage capacity (Cowan, 2016). The phonological buffer stores temporary traces of verbal information which quickly decay if not maintained via sub-vocal rehearsal. The sub-vocal rehearsal of information takes place in the second sub-component of verbal STM, the phonological loop (Baddeley, 2002). This is not a store but rather an extension of verbal STM responsible for rehearsal. A sharp decline in recall for words lists is seen if sub-vocal rehearsal is prevented via articulatory suppression (i.e. say “the” repeatedly), during verbal STM tasks (Baddeley, Lewis, & Vallar, 1984).

If nonverbal items are presented that can be named, then the phonological loop takes on the role of registering the items by sub-vocalising them. Evidence for this comes from studies where phonologically similar letters are presented nonverbally for recall. Letters are harder to recall when they’re similar sounding (T, V) versus dissimilar (L, Y; Baddeley, 2003). Though not visually similar, the phonological similarity after sub-vocalisation impairs recall.

The second distinct store in the model, the nonverbal STM store or visuospatial sketchpad, is responsible for the storage of nonverbal, spatial and kinaesthetic information (Baddeley, 2003). Whilst verbal information is stored in a unitary manner, nonverbal information is further split in to static (visual) and dynamic (spatial) representations (Jeffries & Everatt, 2004). Static representations are stationary whereas dynamic representations are presented sequentially creating order. A static STM task then would be one in which the stimuli are presented at once, for example, a pattern in a 3 x 3 matrix grid. Participants would be shown the pattern and then asked to immediately recall which squares in the grid made up the pattern. A dynamic memory task on the other hand would present the stimuli / pattern sequentially. For example the pattern shown in the 3 x 3 matrix would be presented one block at a time. Participants would have to recall this pattern in order. Span tasks are dynamic and they require participants to recall information in order. A well-known dynamic STM task is the Corsi-blocks task in which participants recall the order of blocks highlighted on a screen or tapped on a board.

The independence of the two STM stores was established early on in studies assessing verbal and nonverbal memory. In one study, participants found it difficult to use nonverbal but not verbal memory aids when performing a concurrent nonverbal task (following a light with their eyes; see Baddeley, 2007). Verbal STM has a larger capacity for information storage than nonverbal STM (Crowder & Morton, 1969; Penney, 1989). The nonverbal STM store does not have its own rehearsal mechanisms (unlike the verbal store). It requires greater assistance from EFs and attentional processes to maintain focus and temporarily reserve information in the visuospatial sketchpad (Baddeley & Hitch, 1974; Miyake et al., 2000). Verbal STM and WM on the other hand are able to utilise the phonological loop.

The next step up from the simple storage of information is its active manipulation. WM describes an active state. It refers to simultaneous maintenance (storage in STM stores) and manipulation (processing) of information (Schuchardt et al., 2013). In their classic multicomponent model of WM, Baddeley and Hitch (1974) describe a hierarchical system in which the processing component of WM necessarily draws on two separate and distinct short-term stores. A short-term memory task is one that only requires the temporary storage of information, i.e. recall a list of digits in the same order they were presented. In WM tasks, executive and attentional processes work on the information in the temporary stores. An example would be the recall of digits in reverse order of their presentation. The digit information is stored in the temporary STM stores but active WM processes are required to manipulate the information online and reverse it. Whilst the verbal and nonverbal STM stores are domain specific, storing only verbal and nonverbal information respectively, the processing component of WM is domain general. It is a common component responsible for the processing of both types of information (Alloway, Gathercole, & Pickering, 2006; Kane et al., 2004).

6.1.1 Verbal STM and WM in dyslexia and D-DLD

The role that verbal STM plays in dyslexia and D-DLD individually is very well researched. Many studies have reported a difficulty in verbal STM and WM in both dyslexic (Booth, Boyle, & Kelly, 2010; Brosnan et al., 2002; Jefferies & Everatt, 2004; Smith-Spark, Fisk, Fawcett, & Nicolson, 2003; Varvara, Varuzza, Sorrentino, Vicari, & Menghini, 2014) and D-DLD groups (Archibald & Gathercole, 2006a ; Hick, Botting, & Conti-Ramsden, 2005a; Gillam, Cowan, & Day, 1995; Gillam, Cowan, & Marler, 1998; Vugs, Hendriks, Cuperus, &Verhoeven, 2014).

Verbal STM difficulties make up a third of the dyslexic triad, three core difficulties which contribute to literacy difficulty (Wagner et al., 1994). Its implication in reading difficulties is well documented and links have been found between verbal STM and children at FR of dyslexia regardless of literacy ability (Snowling, 2000; Snowling & Melby-Lervåg , 2016; Wagner & Torgesen, 1987).

Researchers have proposed theoretical accounts for D-DLD suggesting that it is a verbal STM disorder evidenced by persistent difficulties in nonword repetition. Theories include the ‘phonological storage deficit hypothesis’ (Vugs et al., 2014) which suggests that D-DLD children have difficulty with the temporary storage of novel verbal information.

There are differences in the type of STM deficit experienced by both groups. Dyslexic participants experience a difficulty in recalling the serial order of information predominantly in verbal domains (Hachmann et al., 2014). However, D-DLD groups experience difficulty in both item recall (static) and serial order recall (dynamic) of verbal and nonverbal information (Bavin, Wilson, Maruff, & Sleeman, 2005; Nithart et al., 2009). Difficulties in dyslexic groups seem to be appropriate for literacy level (Roodenrys & Stokes, 2001), whereas D-DLD groups show a robust deficit compared to both CA and language ability matched groups (Gathercole & Baddeley, 1990)

A deficit in verbal WM also links dyslexia and D-DLD. One theory, the ‘double jeopardy hypothesis’ (Archibald & Gathercole, 2006a) suggests that D-DLD individuals have deficits both in verbal STM and also the domain general CE which enables WM, EF and attention. This is in contrast to dyslexic individuals who only experience a difficulty in verbal domains. Pickering and Gathercole (2004) found that children with specific difficulties such as dyslexia or DLD, exhibited a specific difficulty in verbal domains, namely verbal STM. Children with nonspecific difficulty, D-DLD, had problems in domain general processes such as WM and the CE. However, the ‘double jeopardy hypothesis’ is difficult to establish in D-DLD groups, due to the hierarchical nature of WM (Briscoe & Rankin, 2009). WM, EF and CE necessarily draw on information in the short-term stores. Therefore a deficit in a slave storage system (verbal or nonverbal) could account for WM difficulty in the absence of a domain general difficulty in the CE. If D-DLD participants experience a difficulty in nonverbal WM in the absence of nonverbal STM difficulty, then this suggests they experience a domain general CE deficit. However, if they do experience a difficulty in nonverbal STM, then that difficulty could for any nonverbal WM and nonverbal EF difficulty seen in the group.

6.1.2 Nonverbal STM and WM in dyslexia and D-DLD

Research focusing on nonverbal processes in dyslexia and D-DLD is less dense than the body of research focussing on verbal processes. Research into nonverbal STM has also returned mixed results for both dyslexic and D-DLD groups, making it hard to resolutely confirm or deny a double jeopardy hypothesis for D-DLD. Often mixed results can be attributed to task impurity; that is, verbal demands being present in nonverbal tasks or several EF processes also being measured simultaneously (Miyake et al., 2000). For example, if tasks require the verbal recoding of stimuli presented visually, i.e. naming pictures to remember presentation order, then dyslexic and D-DLD groups will likely experience a difficulty (Gillam et al., 1998; Gould & Glencross, 1990). At the same time, there is a lack of adequate screening for comorbid disorders. Studies which have suggested that nonverbal STM deficits exist in dyslexia may be better evidence of comorbid difficulties or additional attentional problems in children (Savage, Cornish, Manly, & Hollis, 2006). In general, limited nonverbal STM and WM deficits have been found for dyslexic children unless tasks put particular demands on attentional resources (Smith-Spark et al., 2003; Vellutino, 1979). Children with dyslexia do experience difficulty in sustained attention tasks with high EF demands and therefore any tasks which implicate such may cause difficulty (Marzocchi, Ornaghi, & Barboglio, 2009). Difficulties in nonverbal STM / WM tasks do not stem from a deficit in the nonverbal STM, but instead from general difficulty in sustained attention or task impurity.

Greater evidence exists for nonverbal difficulty in D-DLD groups (Hick et al., 2005; Vugs et al., 2014). However, D-DLD participants do not always show a difficulty in nonverbal STM tasks (Archibald & Gathercole, 2006b; Briscoe & Rankin, 2009). When controlling for NVIQ, Marton (2008) only found difficulties for nonverbal WM tasks but not a nonverbal STM task. Tasks with greater EF demands (nonverbal WM tasks) revealed larger group differences. However we know that even nonverbal STM tasks implicate EF and this has likely led to mixed results in the literature. Nonverbal STM tasks implicate EF as additional attentional resources are required to maintain the stored visual representations. The nonverbal STM store itself does not have its own rehearsal mechanisms like the phonological loop. It could be that D-DLD participants do not experience a difficulty in simple storage of nonverbal information and therefore difficulty in nonverbal WM and EF tasks cannot be attributed to nonverbal STM difficulty. Instead D-DLD participants experience a domain general deficit in the CE.

6.2 Executive function

EF is the term used to describe several different, inter-related, sub-processes responsible for goal-directed behaviour (Shallice et al., 2002). They are utilised in particular for tasks which are novel, complex or include conflict. According to Baddeley and Hitch's (1974) model, EFs are stored within and controlled by the CE described in the following section. They act upon information in the STM stores and enable the operation of WM by facilitating cognitive control (Daneman & Carpenter, 1980). To this extent, WM is highly correlated with executive processes (Baddeley, 2003). They are described by Nee et al. (2012) as the operations that make WM work. Again, the relationship between WM and EF is not balanced across the different domains. Stronger links exist between EF and nonverbal WM than EF and verbal WM (Busch et al., 2005; Marton, 2008). Whilst both nonverbal STM and WM tasks both highly implicate EF, only verbal WM rather than verbal STM tasks implicate EF (Miyake et al., 2000). This highlights the importance of EF for WM but also for nonverbal tasks regardless of their complexity.

EFs are separable yet interrelated and factor analytic studies confirm the existence of at least three main EFs: inhibition (the ability to ignore irrelevant information), updating (the ability to continually renew information in WM), and shifting (the ability to switch between sources of information or between cognitive processes (see Miyake & Friedman, 2012; Miyake et al., 2000). Research suggests that EF is developmentally sensitive with different EFs coming online at different stages Processes such as inhibition develop early on (Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012; Usai, Viterbori, Traverso, & DeFranchis, 2014). Processes such as shifting and updating develop later (Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003). In this thesis I concentrate predominantly on inhibition and updating; shifting is discussed further in relation to attention in chapter 5 and the CE in chapter six. I have not included a chapter purely dedicated to shifting in this thesis. Shifting is a mental operation that is likely involved in all cognitive and executive tasks that require a focus of attention. Shifting, although an independent process is highly related to other EFs such as inhibition and updating (Miyake et al., 2000). Neuroimaging studies suggest that shifting encompasses several different operations but crucially that all of these activate similar brain regions (see Wager, Jonides, & Reading, 2004). For example participants might be required to shift between a decision rule in a task, i.e. add three or minus three to stimuli (see St Clair-Thompson & Gathercole, 2006) or shift perceptual focus between different sets of stimuli, i.e. bind verbal and nonverbal information. Because of the clear overlap between shifting and other processes I decided it would be better to focus on attention more broadly rather than shifting specifically.

6.2.1 EF in dyslexia and D-DLD

EFs are contained within and deployed by the CE. They are domain general acting on information in the verbal and nonverbal temporary stores. Therefore the double jeopardy hypothesis is also applicable when discussing EF in relation to dyslexia and D-DLD. If D-DLD participants have a double deficit in the domain general CE (and verbal STM), it is likely they experience difficulty in verbal and nonverbal EFs. Research suggests that this is true, with D-DLD participants experiencing difficulty in nonverbal updating and inhibition tasks (Im-Bolter, Johnson, & Pascual-Leone, 2006). D-DLD groups also experience more difficulty in tasks with higher EF demands, suggesting a deficit in the CE is driving their difficulty (Lukács, Ladányi, Fazekas, & Kemény, 2016).

Dyslexic groups therefore should show difficulties predominantly in verbal EF tasks and those with high demands. This is true for updating measures (Ackerman & Dykman, 1993; Lee Swanson, Howard, & Saez, 2006; Smith-Spark et al., 2003). However, the picture presented for inhibition is much less clear, with some studies suggesting a difficulty (Lee Swanson et al., 2006; Wang et al., 2012) and others not (Landerl, Fussenegger, Moll, & Willburger, 2009;

Rubinsten & Henik, 2006). Despite this, the most consistent difficulties tend to be observed in verbal inhibition tasks for dyslexic groups.

6.4 The central executive

The CE forms the most complex component of the WM system. It is often criticised as being a poorly defined and convoluted (Parkin, 1998). This is not surprising given the complex and overlapping nature of the processes housed within the CE itself (see Figure 3). Baddeley (2012) refers to the CE a control system responsible for performing all tasks outside the remit of the two slave systems. The sustained effort the CE exerts, achieving balance between the several components in the WM system, is called cognitive control (Tropper, 2009). The CE is limited in capacity and therefore exerts strict attentional processes to achieve cognitive control (Vugs et al., 2014). It is domain general, acting on both the verbal and nonverbal stores. Similar to WM, there is a greater overlap between the CE and nonverbal STM than the CE and verbal STM. Engle, Tuholski, Laughlin and Conway (1999) found that verbal STM and WM share less variance at the latent variable level than nonverbal STM and WM. Both nonverbal STM and WM rely on the CE to prevent memory decay. There is a mutual reliance on the CE in both nonverbal STM and WM.

The CE has two broad roles, one to control attention and two to bind information together (Baddeley, 2012). In terms of its attentional capacity, it is responsible for selectively focusing and maintaining attention, dividing attention and also switching attention between tasks and process. It uses these attentional processes to allocate attention between: the verbal and nonverbal STM stores, storage and processing capacities in WM, and different EFs (Baddeley & Hitch, 1974; Im-Bolter et al., 2006). The CE houses and employs various EFs to achieve a goal, mainly processes which enable updating, shifting and inhibition (Miyake et al., 2012). Other more complex EFs such as planning can be seen as a product of these more basic processes. It is also thought to house separate attentional processes to divide, focus and maintain attention. However, EFs such as inhibition and switching also facilitate the different types of attention, inhibition ignoring irrelevant information to preserve focus for example. This is where the processes within the CE become confusing. To what extent the processes are independent or in fact represent different facets of a unitary EF construct is debated.

In its second major capacity, the CE is responsible for integrating (binding) and storing information from different sources and modalities and interfacing with LTM. Whilst attentional resources in the CE allow mostly for the binding of information, the episodic buffer is responsible for storing these formed representations (Baddeley, 2012).

6.3.1 Attentional processes in the CE

The CE is responsible for attention (Finneran, Francis, & Leonard, 2009). Attention is a domain general processes acting on information in the temporary stores. Like the STM stores, attention is capacity limited due largely to the limited capacity of the CE (Baddeley, 2003). Researchers have postulated the existence of several 'types' of attention. Roughly these have been split in to processes responsible for dividing attention, sustaining attention and focusing or selective attention (Leclercq, 2000; Manly, Robertson, Anderson, & Nimmo-Smith, 1998; Posner & Peterson, 1990). Sustained attention is responsible for continuously attending or maintaining alertness to a stimulus in order to process it (Finneran et al., 2009). Selective attention is responsible for reducing focal attention to allow participants to attend certain stimuli over others (Cowan, 1988). Divided attention involves the management and allocation of resources to different sources of information depending upon their relevance (Savage et al., 2006). Tasks will often require several types of attention to be completed. Not only will a participant have to make the executive decision to attend one or more stimuli, they may also have to sustain this over time. To this extent it can be hard to extract identify which attentional processes each task taps.

If participants with D-DLD experience a difficulty in the domain general CE then it follows that attentional problems will also be evident. Some researchers have gone as far to suggest that the ability to process language online in D-DLD individuals is largely constrained by their ability to allocate attention (Campbell & Mcneil, 1985; Montgomery,2008). A number of studies have revealed robust deficits in both verbal and nonverbal sustained attention (Finneran et al., 2009), selective attention (Spaulding, Plante, & Vance, 2008) and divided attention (Hoffman & Gillam, 2004) in D-DLD.

Attentional difficulties are less substantial in dyslexia (Lukov et al., 2015). Where difficulties do arise they tend to be for divided and sustained, not selective, attention tasks, in particular those with verbal or additional EF demands (Lachmann, Schumacher, & van Leeuwen, 2009; Moores & Andrade, 2000; Moores, Nicolson, & Fawcett, 2003).

6.3.2 The episodic buffer in the CE

A later addition to the WM model is the episodic buffer (Baddeley, 2000; Baddeley, Allen, & Hitch, 2011). It is the later version of the WM model that is tested in this thesis. The episodic buffer is a fractionation of the CE. It was noted that the WM system needed a place in which representations containing bound elements e.g. verbal and nonverbal, semantic, phonological and sensory, could be stored. This gave rise to the inclusion of the episodic buffer. The episodic buffer is a storage unit which is able to hold a limited (about 4 chunks) of integrated information. It provides a link between the verbal and nonverbal stores. Whilst the episodic buffer is not primarily responsible for binding information (i.e. the CE carries out the majority of this role), it does play a part in further integrating information in to bound representations (Baddeley, 2012). It forms part of a memory system responsible for episodic memory (memory for events) as is responsible for storing memories made up from multiple sources. It also acts as the gateway between WM and LTM, allowing for old and new information to be integrated. It also stores information that overflows from the verbal and nonverbal temporary stores. Evidence for this overflow comes from work on recalling long prose passages (20+ ideas) with amnesic patients impaired in LTM. Participants performed as well as controls on these tasks even though the information was too large for STM stores. Previously LTM has been thought to facilitate passage recall however this evidence suggested another process was operating by which information could be chunked together (Miller, 1956).

Both dyslexic (Albano, Garcia, & Cornoldi, 2016; Jones et al., 2013; Toffalini, Tomasi, Albano, & Cornoldi, 2018) and D-DLD (Schuchardt et al., 2013) groups have been found to experience a difficulty in tasks which require the binding of verbal and nonverbal information. This is unsurprising given the link between verbal and nonverbal binding and literacy (Hulme et al., 2007; Snowling, 2000; Wang et al., 2012).

7. Assessing multiple WM and EF processes

Several studies have looked at multiple processes including, memory, EF, attention and the CE simultaneously for impaired groups. These studies suggest that children with D-DLD experience a difficulty in both verbal and nonverbal memory and EF tasks. Vugs et al. (2014) found verbal and nonverbal STM, WM and inhibition difficulty in D-DLD children. Im-Bolter et al. (2006) found children with D-DLD experience difficulty in nonverbal updating, inhibition and measures of verbal and nonverbal attention. Henry et al. (2012) found D-DLD groups experienced difficulty in verbal and nonverbal WM and nonverbal inhibition. Together these studies suggest that the difficulties in D-DLD extend to both verbal and nonverbal domains. This supports the notion that D-DLD groups experience a difficulty not only in verbal STM but also the domain general CE. This is further supported by studies that look at multiple groups. Schuchardt et al. (2013) found verbal WM difficulties in both dyslexic and D-DLD groups but only CE difficulties in D-DLD groups.

For dyslexia difficulties seem to be constrained much more to the verbal domain. Smith-Spark et al. (2003) found verbal STM, WM and updating deficits in dyslexia but not nonverbal difficulties unless tasks were particularly demanding. Similarly Jeffries and Everatt, (2004) found difficulties in verbal WM, inhibition and CE tasks but not nonverbal WM tasks. Lastly Reiter et al. (2005) found dyslexic participants scored lower on verbal but not nonverbal inhibition tasks. However, participants also scored lower on both verbal and nonverbal WM. Largely these studies support the theory that children with dyslexia experience constrained to the verbal domain. Difficulties in verbal STM likely cause difficulties in verbal EF and CE tasks.

These studies, although stronger evidence of the profile of difficulty in each group (due to the testing of multiple processes) still leave us with gaps in our understanding. Very few studies take in to account comorbid difficulties, with few studies choosing to examine multiple groups. At the same time studies often fail to adequately screen for additional impairments groups. Task impurity (Miyake et al., 2000) presents a large problem. Tasks often measure multiple EF processes simultaneously which include both verbal and nonverbal elements. Very few studies consciously separate tasks into verbal and nonverbal domains which may be critical to establishing a pattern of difficulty in different groups. Lastly, to the best of my knowledge, no study has ever chosen to administer tasks that expressly measure each level of Baddeley's (2000) WM model. I rectify this by administering carefully controlled, verbal and nonverbal tasks of STM, WM, attention, EF and CE, to carefully defined groups with literacy and language impairment.

8. Summary

Difficulties in dyslexia likely stem from a robust deficit in verbal STM. Due to the hierarchical nature of WM, any EF, attentional or CE processes that draw on the verbal STM will also be impaired. Participants with dyslexia also likely experience some difficulty in domain general sustained attention over long periods of time, but only for tasks with high EF demands. Tasks that require the binding of verbal and nonverbal information are also likely affected.

For D-DLD groups, a double deficit is experienced both in verbal STM and also the domain general CE. This leads to difficulty in verbal and nonverbal WM, EF, attentional and CE tasks. Deficits are likely more pronounced in D-DLD than dyslexic groups for verbal tasks.

Research using groups with DLD only is severely limited, although existent research does suggest that these groups, if they do experience difficulty, are only affected in verbal STM (Pickering & Gathercole, 2004). The attentional aspects of the CE seem to share greater links with language than literacy (Blom & Boerma, 2016; Conner et al., 2000; Duinmeijer et al., 2012; Montgomery et al., 2009). Therefore I might expect groups with language only difficulty to also show a deficit in certain CE and attention tasks. If this is not the case, then it is possible that they have developed compensatory CE mechanisms that have afforded alternative routes to literacy.

Chapter 2 – Methods and matching

1. Introduction

This thesis compares the cognitive abilities of children with dyslexia, developmental language disorder (DLD) and dyslexia plus developmental language disorder (D-DLD). I compare these groups to four control groups; one matched for chronological age (CA) and three younger groups matched for language (LA/DLD, LA/D-DLD) or reading level (RA). This chapter outlines the profile of each group in terms of task performance on literacy, language and processing measures. It also discusses the reasoning behind including younger ability level groups when comparing across disorders.

1.1 Inclusion of ability level groups

In literacy and language research, a comparison with reading level matches, in addition to CA matches, has become the norm, (Backman, Mamen, & Ferguson, 1984; Bradley & Bryant, 1978; Bryant & Goswami, 1986; Jackson & Butterfield, 1989; Jarrold & Brock, 2004; Snowling, 1980; Vellutino & Scanlon, 1989). The method allows for stronger conclusions in terms of the underlying cause of impairment. Experimental task performance for impaired groups can often be lower than that expected given their CA. But it can also be appropriate given their younger literacy / language level (ability level). Participants with dyslexia for example may perform similarly to seven year olds, with similar literacy levels, on verbal STM tasks. If dyslexic participants perform similarly to reading level matches, it is possible to conclude that performance in verbal STM is a consequence of literacy / language level (Cain, Oakhill, & Bryant, 2000). Although the ability is delayed it is as expected given participant ability level and improves in line with improvement in ability. If dyslexic performance is below both CA and ability level groups, it is likely that whatever is causing impairment in literacy is also causing impairment in verbal STM (Cain et al., 2000). The dyslexic group would have an underlying deficit in verbal STM. If they scored lower than CA groups but higher than ability level groups, then I would also conclude that they are delayed in verbal STM ability. By including a group of younger, typically developing children with the same reading / language level as older dyslexic / DLD participants, it is possible to make firmer conclusions about causation.

Comparing impaired children to only ability level groups (and not CA) is also problematic. Impaired groups are older than reading level matches and have greater familiarity with text and spoken language. This leads to more developed semantic, syntactic and meta-cognitive skills. Familiarity can have positive (word and pronunciation familiarity) and negative (bad decoding habits) effects (Van den Broeck, & Geudens, 2012). Whilst younger typical children rely more heavily on decoding, older impaired children use word familiarity to help recognise real words (Stanovich & Siegel, 1994; Van den Broeck et al., 2010). It is crucial therefore to include not only ability level groups but also a CA comparison group. By using CA groups I can identify whether or not a delay exists for impaired groups. Dyslexic groups may score higher than reading level groups for example but lower than a CA group. The performance of the dyslexic group therefore isn't typical or expected given literacy level. Instead it is delayed relative to that expected given their age.

1.2 Forming ability groups

While it is important to include ability level groups, it can be difficult to know which ability to match when comparing across disorders. For example, I could match for language, literacy (word or nonword reading ability) or NVIQ. All developmental disorders have factors that are specific and non-specific (see Jarrold & Brock, 2004). Non-specific factors are those which likely co-occur but are not in themselves responsible for the disorder, or crucial for a diagnosis of impairment. Using this rationale, a difficulty in phoneme awareness is a specific factor in dyslexia, but visual crowding would be non-specific. Difficulties in expressive and receptive vocabulary are specific to DLD, with NVIQ difficulties being a non-specific factor. As previously mentioned I include three impaired groups in this thesis; dyslexic, a group with language only difficulties (DLD) and a group with both literacy and language difficulties (D-DLD). Traditionally researchers consider those with developmental language disorder (usually termed DLD) to express both language and literacy difficulty. Snowling, Bishop and Stothard (2000) suggest that early language difficulty necessarily causes comorbid literacy difficulties later on. This suggests that few children with language problems will not develop later literacy problems (however see Catts et al., 2005). Whilst this has been my experience to an extent, I have been able to identify a small but well defined group with language difficulty only. I have chosen to label this group DLD to highlight their pure language deficit. I feel D-DLD is a better fit for groups with comorbid literacy and language difficulties.

I have chosen to match my groups to ability level groups based on specific factors. For dyslexia this is literacy difficulty measured by real word reading level and for DLD this is oral language measured by expressive and receptive vocabulary level. Subsequently, this thesis includes, one reading level group (RA) matched to the dyslexic group and two language level groups, the first (LA/DLD) matched to the DLD group.

Following Snowling et al's. (2000) logic, early language difficulty is responsible for later reading problems in groups with comorbid difficulties. D-DLD groups therefore are primarily affected in language. Again oral language is a specific factor affecting children with D-DLD. My second language level group (D-DLD) then is matched to the second language level group (LA/D-DLD) for oral language ability.

2. Method: Participants

Measures from 148 participants [1] (female = 91) were included in the thesis. Strict inclusion criteria were imposed for impaired, CA and ability level groups (summarised in this section). Participants were either assigned or excluded from groups based on their scores on standardised literacy and language measures and information provided in a screening questionnaire at timepoint one (T1). According to the parental questionnaires, all participants spoke English as a first language.

Participants were recruited from a number of different schools across central England (Warwickshire, Staffordshire, the West Midlands, Wiltshire, Leicestershire and Nottinghamshire). These included three mainstream state primary schools, eight mainstream state secondary schools and two specialist schools for children with special educational needs (24 participants in the impaired groups). A number of participants were also recruited via direct contact with parents who expressed an interest in the research (30 ability level matches, 1 D-DLD participant, 4 CA matches).

2.1 Impaired groups

Participants with a formal diagnosis of impairment but who did not meet the necessary cut off for inclusion were removed. Participants with a comorbid diagnosis of autism / Asperger's or NVIQ scores of 70 or below were also removed (see Bishop, 2017). The impaired and CA groups did not differ in age at T1, $F(3,86) = 1.26$, $p = .30$, r = 0.20. See Table 1.

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[1] Ten participants were removed at early screening: two participants with statements but typical literacy/language, one participant older than the target sample, and three participants scoring < 2SD below the mean for IQ. Two participants were also removed for comorbid diagnosis of Autism / Asperger's.

Table 1: Number, mean (SD) of age, NVIQ and min / max NVIQ, language and literacy age by group.

Group	N	Age	NVIQ		Reading Age	Language Age
		T1	*Mean*	*Min - Max*		
Dyslexic	29 (f 18)	13.25 (0.98)	97.38 (12.26)	70 - 123	9.41	12.34
DLD	10 (f 8)	13.84 (0.89)	91.6 (7.28)	74 - 100	13.13	9.76
D-DLD	28 (f 19)	13.70 (1.07)	90.68 (11.13)	71 - 109	9.49	9.33
CA	23 (f 16)	13.48 (1.15)	103.78 (8.16)	88 - 119	13.39	13.52
RA	29 (f 13)	9.17 (1.60)	108.24 (12.21)	86 - 143	9.53	9.84
LA/DLD	10 (f 4)	9.72 (0.86)	108.1 (13.04)	92 - 129	10.88	9.80
LA/D-DLD	28 (f 17)	9.22 (1.16)	104.64 (12.86)	85 - 127	11.03	9.25

2.1.1 Dyslexic

In total there were 29 participants (11;6 – 15;9 years, f = 18) in the dyslexic group with a mean age of 13.25(SD 0.98) years at T1. Participants were included in the dyslexic group if they had standard scores of 90 or less on the Sight Word Efficiency (SWE) task (T1) from the Test of Word Reading Efficiency (TOWRE – Torgesen, Wagner, & Rashotte, 1999). See Table 2.

According to the questionnaire, 21 dyslexic participants had a dyslexia statement and were receiving extra help in school. Four were receiving support for literacy difficulties and were referred by their school’s special educational needs coordinator (SENCO) as dyslexic without a formal diagnosis. The remaining four were referred by the SENCO but had no formal statement and were not receiving express help in literacy. They met the cut off criteria for literacy difficulty according to the TOWRE SWE task (Torgesen et al., 1999). All had normal or corrected to normal vision and hearing. Two dyslexic participants had a comorbid diagnosis of dyspraxia and received support for emotional difficulties.

Table 2: Mean (SD), min-max, for raw and standard sight word efficiency and listening comprehension scores by group.

	Raw Sight Word Efficiency	Standard Sight Word Efficiency		Raw Listening Comprehension	Standard Listening Comprehension	
Group	*Mean(SD)*	*Mean(SD)*	*Min-Max*	*Mean(SD)*	*Mean(SD)*	*Min-Max*
Dyslexic	58.72 (12.05)	82.41 (8.85)	62-90	30.41 (2.82)	99.66 (7.9)	91-117
DLD	80.6 (6.13)	98.9 (5.16)	91-109	26.5 (2.88)	82.3 (8.46)	60-90
D-DLD	59.61 (10.78)	81.39 (6.18)	65- 90	25.71 (2.51)	80.71 (7.63)	66-90
CA	81.57 (7.18)	101.83 (8.36)	91-120	31.83 (2.31)	102.35 (5.94)	93-114
RA	59.03 (14.57)	104.31 (8.04)	91-123	26.21 (4.16)	105.76 (10.44)	91-124
LA/DLD	69.50 (9)	108.1 (7.68)	96-126	26.6 (2.8)	101.3 (4.19)	94-107
LA/D-DLD	70.57 (7.73)	113.5 (8.88)	95-126	25.64 (2.42)	101.82 (7.79)	91-118

2.1.2 DLD

In total there were 10 participants (11;10 – 14;11 years, f = 8) in the DLD group with a mean age of 13.84(SD 0.89) years at T1. Participants were included in the DLD group if they had standard scores of 90 or less on the listening comprehension task (T1) from the Wechsler Individual Achievement Test - III (WIAT – III – Wechsler, 2005).

According to the questionnaire one DLD participant had a formal statement of impairment and was receiving additional language support. Seven were receiving support for language difficulties and were referred by their school's SENCO as having DLD. The remaining two participants were referred by the SENCO but did not have a formal statement and were not receiving help in school. They nonetheless met the cut off criteria for language difficulty according to the WIAT-III listening comprehension task (Wechsler, 2005). None of the DLD participants had additional neurological or motor impairments and all had normal or corrected to normal vision and hearing.

2.1.3 D-DLD

In total there were 28 participants (10;3 – 15;4 years, f = 19) in the D-DLD group with a mean age of 13.70 (SD 1.07) years at T1. Participants were included in the D-DLD group if they had standard scores of 90 or less on both the SWE and listening comprehension tasks (T1).

According to the questionnaire 22 D-DLD participants had formal statements of both dyslexia and DLD and were receiving additional support for literacy and language in school. Five were receiving support for literacy and language difficulties and were referred by their school's SENCO as having both dyslexia and DLD. The remaining participant was referred by the SECNO but did not have a formal statement and was not receiving help in school. They met the criteria for both literacy and language difficulty according to the TOWRE SWE task (Torgesen et al., 1999) and WIAT-III listening comprehension task (Wechsler, 2005) respectively. Of the D-DLD participants, one had a comorbid diagnosis of both dyspraxia and attention deficit disorder (ADD); one had a comorbid diagnosis of dyscalculia. Two participants in the D-DLD group were reported to have a hearing impairment, one with mild unilateral hearing loss, and one with mild temporary hearing loss. Neither of these participants wore hearing aids. The participant with mild temporary hearing loss was not experiencing hearing loss at time of assessment. Regardless, every time these participants completed an auditory task, extra care was taken to ensure that they could hear the stimuli and this was assessed informally prior to testing.

2.2 CA group

In total there were 23 participants (11;11 – 15;6 years, f = 16) in the CA group with a mean age of 13.48(1.15) years at T1. CA participants were group-wise matched to participants in the impaired groups for age. Participants were included in the CA group if they had standard scores between 91 and 126 on both the SWE and listening comprehension tasks (T1). Participants were removed if they had any additional neurological difficulties. All CA participants achieved a standard score of 85 or above for NVIQ at T1 (WASI – III, Psychological Corporation, 1999). No participants in the CA group had a formal diagnosis of literacy, language or other educational, neurological or motor impairment. All of the CA group had normal or corrected to normal vision.

2.3 Ability level groups

Impaired groups were individually pair-wise matched (within six months) to three younger ability level groups based on either reading (from SWE) or language ages (from listening comprehension) at T1, see

Table 1. I chose to use the same tasks for both grouping and matching participants as it avoids regression artefacts (Van den Broeck, & Geudens, 2012). Participants were considered for ability level groups if they had standard scores between 91 and 126 on both the SWE and listening comprehension tasks. They also required a standard score of 85 or above for NVIQ at T1 (WASI – III, Psychological Corporation, 1999). According to the questionnaire, no participants in the ability level groups had a formal diagnosis of literacy, language or other educational difficulty, neurological or motor impairment. One participant in the LA/ DLD group was reported as having a stammer in early childhood that had been resolved. All of the ability level participants had normal or corrected to normal vision.

Due to time constraints it was not possible to recruit all unique participants to form the LA/DLD group (N=10). Therefore this group (9/10 participants) was formed of existing RA matches who had language ages that pair-wise matched the DLD group[2]. No analysis contained both the RA and LA/DLD groups.

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[2] Variance attributed to reading is distinct from that attributed to language ability. Any variance unique to language ability was not utilised in comparisons of RA and dyslexic groups. DLD group

Independent samples t-tests confirmed that the ability level groups were all younger than their impaired groups, see Table 1. For the dyslexic group, equal variances were not assumed[3], (dyslexic group: $t(46.53) = 11.68$, $p < .01$, $d = 3.08$.; D-DLD group: $t(54) = 15.05$, $p < .01$, $d = 4.01$; DLD group: $t(18) = 10.54$, $p < .01$, $d = 4.71$). The two language matched groups (LA/D-DLD, LA/DLD) were a similar age, $t(36) = -1.24$, $p = .23$, $d = 0.49$.

2.3.1 RA group

The dyslexic group were pairwise matched to 29 (6 – 11;7 years, f=13) RA level matches, mean age 9.17 (SD 1.60) years. The RA level group had typical reading (and language) abilities. They were matched to the dyslexic group for reading age ascertained on the TOWRE SWE task at T1 (Torgesen et al., 1999). Raw scores were calculated and converted to reading age equivalents. Each dyslexic participant was then pairwise matched to an individual RA level match (within six months). A t-test confirmed the dyslexic and RA group were well matched, $t(56) = -0.09$, $p = .93$, $d = 0.02$.

Interestingly the D-DLD group also performed similarly to the RA level group on the TOWRE SWE task (Torgesen et al., 1999), $t(55) = 0.17$, $p = .87$, $d = 0.05$. It was not my intention to group-wise match the D-DLD group to an RA level group. The similarity between the two groups means it is possible to examine the effect of reading ability on D-DLD performance. Therefore I continued to compare the RA and D-DLD groups on measures throughout this thesis.

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performance is uniquely attributed to language ability and therefore it was reasoned that RA matches could also act as LA/DLD matches. Nine out of ten of the LA/DLD group were formed of RAs.

[3] From here onwards, where degrees of freedom contain decimals, equal variances were not assumed. This was highlighted by significant p values in the Levene's test. Corrected values were used.

2.3.2 LA/DLD group

The DLD group were matched to 10 (8;1 – 11;1 years, f=4) language level matches, mean age 9.72 (SD 0.86) years. The LA/DLD group had typical language (and literacy) abilities. They were matched to the DLD group for language age ascertained on the listening comprehension task at T1 (WIAT-III, Wechsler, 2005). Raw scores were calculated and converted to language age equivalents. Each DLD participant was then pairwise matched to an individual LA/DLD level match (within six months). A t-test confirmed the DLD and LA/DLD group were well matched, $t(18) = -0.08$, $p = .94$, $d = 0.04$.

2.3.3 LA/D-DLD group

The D-DLD group were matched to 28 (7;2 – 11;2 years, f=17) language level matches, mean age 9.22 (SD 1.16) years. The LA/D-DLD group had typical language (and literacy) abilities. They were matched to the D-DLD group for language age ascertained on the listening comprehension task at T1 (WIAT-III, Wechsler, 2005). Raw scores were calculated and converted to language age equivalents. Each D-DLD participant was then pairwise matched to an individual LA/D-DLD level match (within six months). A t-test confirmed the D-DLD and LA/-DLD group were well matched, $t(54) = 0.11$, $p = .91$, $d = 0.02$.

3. Method: matching / grouping tasks

The project complied with British Psychological Society ethical guidelines and was approved by both Warwick University and Coventry University ethics committees. Consent was obtained from parents and participants. After completing task batteries, children received a £5 amazon voucher. Participants in the impaired and CA groups completed two 45 minutes sessions at T1 and two 45 minute sessions at time two (T2), 12 months later (see

*Table **3***) for a summary of tasks undertaken at each time point. Due to time constraints, the ability level groups completed a condensed battery of tasks in three 45 minute sessions, at a single time point (T1). Initial testing sessions largely consisted of background and screening measures. The later sessions consisted of experimental measures. All participants, as far as possible, completed measures in the same order. Where possible all testing took place on an individual, one to one basis, either within a classroom at school or in quiet room at the participant's home. A small group of children were tested in a lab at Coventry University in the presence of others (i.e. parents, another experimenter). For speed, the Gray's Silent Reading task (GSRT, Wiederholt & Blalock, 2000) and the spelling task from the British Abilities Scale - III (BAS-III, Elliot & Smith, 2011) were administered in small groups. Group testing was permitted for these tasks by the manual.

Table 3. Background measures administered at T1 and T2 point for each group.

Group	T1 (T1)	T2 (T2)
Dyslexic DLD D-DLD CA	Gray's silent reading, TOWRE, WIAT listening comprehension, WASI block design / matrices	BAS spelling, TOWRE, CELF formulated sentences, PHAB naming speed / digit naming / semantic fluency / alliteration fluency / spoonerisms, WISC symbol search
RA LA/DLD LA/D-DLD	TOWRE, WIAT listening comprehension, WASI block design / matrices, CELF formulated sentences, WISC symbol search	

3.1 Matching/grouping: sight word efficiency

The task was administered and scored in line with the manual. In the TOWRE SWE task (Torgesen et al., 1999), participants read aloud as many real words as possible from a card in 45 seconds. This measured participants' ability to accurately and fluently decode real words within a given time. Raw scores were calculated based on the number of correct answers given within 45 seconds. Standard scores and age equivalents were then calculated for each participant. I chose to include the TOWRE as a test of word reading efficiency and grouping measure because it has good test re-test reliability (0.90-0.99) and provides standard scores for both sight word reading and phonetic decoding efficiency (PDE) separately over a wide age range (6 – 24 years). I chose to group / match on sight word reading rather than non-word reading. This is because sight word reading assesses real reading ability; children's ability to use all of their word reading skills. Nonword reading on the other hand relies on phonetic decoding and is not a measure of real reading. It taps phonological skills which are known to be impaired in dyslexic readers.

3.2 Matching / grouping: listening comprehension

The task was administered and scored in line with the manual. The WIAT-III listening comprehension task at T1 (Wechsler, 2005) comprised of three subsections: receptive vocabulary, sentence comprehension and expressive vocabulary. In the receptive vocabulary subsection, participants were read a word aloud and shown four pictures. They were asked to point to which picture matched the word. In the sentence comprehension subsection, participants were read aloud a sentence and shown four pictures. They were asked to point to which picture matched the sentence exactly. In the expressive vocabulary subsection, participants were read a short description of a word and shown a picture. They were asked to find the word or give the one word that meant the same thing as the description given by the experimenter e.g. “tell me the word that means a small place where clothes are stored”. Each task was discontinued after the participant returned six incorrect answers in a row. Raw scores were summed for each subsection and standard scores and age equivalents were calculated for all participants. The listening comprehension task was included as a test of oral language and grouping measure because it gives a single standard score that encompasses both expressive and receptive oral language skills. To meet the criteria for developmental language disorder, participants must display expressive and/or receptive language difficulties and this task allows both to be measured simultaneously. The task also provides standard scores from four years to 16 years 11 months covering the large age range of my groups. The task also has good test re-test reliability (0.80-0.95).

3.3 Grouping: NVIQ

The tasks were administered and scored in line with the manual. NVIQ was also assessed via the block design and matrix reasoning tasks from the Wechsler Abbreviated Scale of Intelligence – II at T1 (WASI-III; Psychological Corporation, 1999). Although NVIQ was not used as a grouping measure, scores were considered when deciding whether or not to include participants in the project. A composite score for NVIQ was created by combining scores from the two non-verbal subtests from the Wechsler Abbreviated Scale of Intelligence (WASI – III, Psychological Corporation, 1999); block design and matrix reasoning. The block design and matrix reasoning tasks were included because together they provide a standard score from

NVIQ. It was important to include a measure of IQ than had no verbal demands, and the WASI-III (Psychological Corporation, 1999) allows a standard score to be ascertained even if only a non-verbal subset of tasks are administered. The composite score has good to excellent test – retest reliability (0.79 – 0.90).

3.3.1 Block Design

In the block design task, participants have a set time in which to copy a block design. Designs are created from 3D blocks or cubes, with sides half red and half white. Designs increase in difficulty throughout the task. Scores are given for each design based on the speed in which it is completed. The task is discontinued after the participant fails to complete three designs in a row within the allocated time. Scores for each correct design are then summed.

3.3.2 Matrix Reasoning

In the matrix reasoning task, participants are asked to complete the missing piece in a pattern from the possible answers at the bottom of the page. Each missing piece completes the puzzle with logical progression. The task is discontinued after participants fail to complete four out of five consecutive puzzles. Raw scores are summed from correct puzzles.

3.4 Results

The remaining results for the grouping and matching measures are now listed. Some of the comparisons between impaired and ability level groups were listed in section 2.3. Impaired and CA groups were first compared in one-way ANOVAs. Planned contrasts were established a-priori to look at group differences. Comparisons between impaired and ability level groups were then made as separate t-tests. This was necessary as some participants in the RA group were reused to form the LA/DLD group and therefore could not be entered in to the same analysis. To control for the effect of multiple comparisons I used a Bonferroni corrected adjusted criterion (alpha) of 0.05/3 ($p < 0.0167$), for each comparison, to test for significance. This was chosen as I reasoned that each impaired group was compared to the CA group, an ability level group and an impaired group. Each time data was screened for skewness and kurtosis. This can be assumed normal unless expressly stated from now on and in subsequent chapters.

3.4.1 Matching / grouping: sight word efficiency

A between-subjects ANOVA with the independent variable group (D-DLD, DLD, dyslexic, CA) and the dependent variable SWE raw scores confirmed group differences, $F(3,86) = 33.85$, $p < .01$, r = 0.74. As expected, planned contrasts (Bonferroni corrected criterion of $p < .0167$) confirmed that the CA group scored higher than the dyslexic group, $t(86) = 8.15$, $p < .01$, $d = 2.30$, and the D-DLD group, $t(86) = 7.77$, $p < .01$, $d = 2.4$. The CA group performed similarly to the DLD group, $t(86) = 0.26$, $p = .80$, $d = 0.15$. The DLD group scored higher than both the dyslexic group, $t(86) = 5.94$, $p < .01$, $d = 2.29$, and the D-DLD group, $t(86) = -5.68$, $p < .01$, $d = 2.39$. The dyslexic and the D-DLD groups performed similarly, $t(86) = 0.33$, $p = .74$, $d = 0.08$. See Table 2.

3.4.1.1 Ability level comparisons

Independent samples t-tests confirmed that as expected, the older DLD group without literacy difficulty, scored higher than the LA/DLD group, $t(18) = 3.22$, $p < .01$, $d = 1.44$.The D-DLD group scored lower than the LA/D-DLD group, $t(54) = -4.37$, $p < .01$, $d = 1.17$,[4].

3.4.2 Matching / grouping: listening comprehension

A between-subjects ANOVA with the independent variable group (D-DLD, DLD, dyslexic, CA) and the dependent variable raw listening comprehension score confirmed group differences, $F(3,86) = 29.67$, $p < .01$, r = 0.71. Planned contrasts (Bonferroni corrected criterion of $p < .0167$) confirmed that the CA group performed similarly to the dyslexic group, $t(86)$ =

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[4] Where a reduced number of comparisons have been made between impaired and ability level groups, this reflects the fact that additional comparisons have been reported earlier in the text to highlight differences.

1.94, $p = .07$, $d = 0.55$. As expected, the CA group scored higher than the DLD group, $t(86) = 5.39$, $p < .01$, $d = 2.04$, and the D-DLD group, $t(86) = 8.33$, $p < .01$, $d = 2.54$. The dyslexic group also scored higher than both the DLD group, $t(86) = -4.09$, $p < .01$, $d = 1.37$, and the D-DLD group, $t(86) = -6.80$, $p < .01$, $d = 1.76$. The DLD group performed similarly to the D-DLD group, $t(86) = -0.82$, $p = .42$, $d = 0.29$, indicating an equal severity of language deficit. See Table 2.

3.4.2.1 Ability level comparisons

Independent samples t-tests showed that the RA group scored lower than the dyslexic group, $t(49.26) = 4.50$, $p < .01$, $d = 1.18$, but similarly to the D-DLD group, $t(46.24) = -0.54$, $p = .59$, $d = 0.15$.

3.4.3 Grouping: NVIQ

Scores for the block design and matrix reasoning tasks from the Wechsler Abbreviated Scale of Intelligence (WASI – III, Psychological Corporation, 1999) were used to create composite NVIQ scores for participants in each group. A between-subjects ANOVA with the independent variable group (D-DLD, DLD, dyslexic, CA) and the dependent variable standard NVIQ score revealed group differences, $F(3,86) = 7.33$, $p < .01$, r = 0.45. Planned contrasts (Bonferroni corrected criterion of $p < .0167$) revealed that the CA group scored higher than the two language impaired groups: DLD, $t(19.2) = 4.26$, $p < .01$, $d = 1.58$, D-DLD, $t(48.45) = 4.84$, $p < .01$, $d = 1.34$. The CA group performed similarly to the dyslexic group, $t(48.69) = 2.25$, $p = .03$, $d = 0.61$, but this tended towards significance. The dyslexic group performed similarly to the D-DLD, $t(54.79) = -2.16$, $p = .04$, $d = 0.57$, and DLD group, $t(26.96) = -1.79$, $p = .09$, $d = 0.57$. Interestingly the DLD and D-DLD group also performed similarly, $t(24.59) = -0.30$, $p = .77$, $d = 0.10$, suggesting any differences between the impaired groups are not due to differences in NVIQ ability alone. See Table 1.

4. Method: other task procedures

Impaired and CA participants completed measures at both T1 and T2. Although every effort was made to ensure that all participants completed both time points, 10 participants did not complete measures at T2. In total, 26 dyslexic, 10 DLD, 23 D-DLD and 21 CA participants completed measures at T2[5]. Impaired participants were matched to the same ability match at T1 and T2. Whenever data was missing for an impaired participant in a task at either T1 or T2 (see individual task results for participant inclusion) their corresponding ability match was also removed.

I wanted to ensure that participants in the ability level groups were still matched to impaired participants at T2. Impaired participants completed the SWE task at T2 and all participants also completed the formulated sentences subtest of the Clinical Evaluation of Language Fundamentals – IV (CELF-IV, Wiig, Semel, & Secord, 2003). These tasks were not used for matching purposes at T2. I compared SWE T2 raw scores for impaired groups to SWE scores for ability level groups. Independent samples t-tests confirmed that the RA group was still group-wise matched to the dyslexic group, $t(56) = -0.09$, $p = .93$, $d = 0.02$. The RA group also still provided a good match to the D-DLD group, t(55) = -0.17, p = .87, d = 0.05. See

Table *1* and Table 4. For CELF-IV (Wiig et al., 2003) comparisons between impaired and abiltiy groups at T2, see section 5.2.2.1.

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[5] Of the ten participants who were lost at T2, two were away on placement until the end of term, three had moved schools and couldn't be contacted, two withdrew from testing and three attended a school undergoing a merger with another school in which the new SENCO could not be contacted. The corresponding ability matches five from the LA/D-DLD group (164, 172, 178, 400, 406) and three from the RA group (140, 403, 200) were removed.

For SWE T2: three dyslexic participants now had standard scores above 90 (max 93), one DLD participant had a standard score of 90, one D-DLD participant had a standard score of 91, one CA participant had a standard score of 90. For formulated sentences: two participants in the dyslexic group had a scaled score of six, two D-DLD participants had a scaled score of eight.

Table 4: Mean (SD), raw and standard scores for the TOWRE T2 and CELF T2 by group.

Group	Raw Sight Word Efficiency T2	Standard Sight Word Efficiency T2		Raw Formulated Sentences	Standard Formulated Sentences	
	Mean(SD)	*Mean(SD)*	*Min-Max*	*Mean(SD)*	*Mean(SD)*	*Min-Max*
Dyslexic	64.73 (10.52)	83.42 (7.71)	63-93	48.59 (3.79)	9.18 (1.85)	6-12
DLD	83.50 (7.20)	98.5 (7.72)	90-115	39.4 (4.65)	4.9 (1.73)	1-7
D-DLD	63.78 (10.60)	81.04 (6)	67-91	40.25 (5.3)	5.2 (2.33)	1-8
CA	88.10 (8.58)	105.29 (9.46)	90-122	50.76 (3.22)	10.52(2.16)	7-14
RA	-	-	-	39.18 (6.07)	8.94 (2.28)	6-16
LA/DLD	-	-	-	40.3 (9.80)	8.7 (2.26)	6-13
LA/D-DLD	-	-	-	42.85 (6.67)	10.65 (2.85)	7-15

4.1 Other literacy Measures

Several other literacy measures were also included to assess participants, see

*Table **3*** for time point allocation and participant inclusion. This was to better understand the nature of the literacy ability of each group by highlighting the profiles of each group. Performance on the SWE task for impaired / CA participants was also compared over time. Tasks included SWE at T2, a spelling measure (T1), a reading comprehension measure (T1) and also two RAN tasks (T2). These tasks were completed by the CA and impaired groups only. This was largely due to time constraints, with the spelling and comprehension tasks taking longer to administer than other tasks. The comprehension task was also not suitable for use with younger children.

A measure of spelling was also included as participants with literacy difficulties often experience difficulties in spelling which can aid diagnosis. The measure allows us to confirm a literacy difficulty in children who showed milder SWE difficulties in screening. A comprehension measure was also include as comprehension difficulties are often seen in children with language disorders but not necessarily in children with literacy difficulty only. Comprehension is also highly related to WM, another area highlighting potential differences between groups (see chapter three). By including a measure of comprehension I can discuss it's relation to WM and define more clearly the different profiles of the two groups. Finally a

RAN measure was included as it subsumes several measures that are essential to literacy, including phonological and orthographic processing as well as processing and fluency (Norton & Wolf, 2012). Together these skills are integral to reading. Deficits in RAN are considered a key diagnostic feature of literacy difficulty, a third of the ‘dyslexic triad’ (Wagner & Torgesen, 1987).

I expected that (compared to the CA group), the dyslexic and D-DLD groups would experience difficulties in RAN but that the DLD group would not. I expected that all impaired groups would experience a difficulty in spelling (see Bishop & Snowling, 2004). I expected that that the D-DLD and DLD groups would experience a difficulty in comprehension due to its link to language.

4.1.1Spelling

The task was administered and scored in line with the manual. The spelling task was taken from the British Ability Scales III at T2 (BAS-III - Elliot & Smith, 2011). Children listened to an experimenter read a word aloud, before using it in a sentence and then repeating the word in isolation. Children had to write down the correct spelling of the word. Spellings were administered in blocks of ten until the final block which consisted of five words. Children started at a block appropriate for their age but moved backwards if they couldn’t complete it. A basal block (eight or more passes in a block) and ceiling block (two or fewer passes) were established. Correct items in-between were summed and raw and standard scores were calculated.

4.1.2 Reading Comprehension

The task was administered and scored in line with the manual. In the Grey’s silent reading comprehension (GSRT) task at T1 (Wiederholt & Blalock, 2000), participants had to read short stories before answering five multiple choice comprehension questions about the text. If the participant answered three out of the five questions correctly, they were allowed to progress to the next story. The task was not timed and instead participants were encouraged to take as long as they needed to complete the task. Raw scores and standard scores were calculated.

4.2 Other language measures

Other language measures were also included to better understand the language profiles of participants. I expected broader language difficulties in D-DLD and DLD than dyslexia.

The formulated sentences task was included as a measure of expressive syntax at T2 for the impaired and CA groups and also the younger ability level groups. This allowed me to check that the language level groups still provided a good match for the impaired groups at T2. It also allowed me to assess language ability over time. I also included the semantic fluency task to establish whether my groups were able to fluently use language.

I expected that the D-DLD and DLD group only will score lower than the CA group on both formulated sentences and semantic fluency tasks.

4.2.1 Formulated sentences

The CELF - IV (Wiig et al., 2003) formulated sentences task at T2 assessed expressive syntax. Participants were shown pictures and given a target word. They were then asked to create a sentence about the picture using the target word. Responses were recorded for scoring at a later time. All participants completed all of the items. Participants scored either one or two points per formulated sentence a ceiling was assumed after a participant failed to score on six sentences in a row. The task was not administered in complete agreement with the manual in so much as all items were administered for later scoring. Age appropriate start and stop points were not observed.

4.2.2 Semantic fluency

The semantic fluency task at T2 (PhAB - Frederickson, Frith, & Reason, 1997) was administered in line with the manual. However, standardised measures were not calculated (see section 3.5.1). Children had to name as many animals and then as many food items as they could in 30 seconds. Raw scores were totalled.

4.3 Phonological measures

A range of phonological measures were also administered largely to CA and impaired groups. This was to gain a fuller understanding of the phonological profiles of groups. Literacy and language impaired groups overlap predominantly in their shared phonological processing deficit (Bishop and Snowling, 2004). These measures highlight in which areas of phonological processing this overlap occurs.

Difficulty in PA is a corner stone of literacy impairment and again forms one third of the ‘dyslexic triad’ (Wagner & Torgesen, 1987). At the same time, many definitions centre on a difficulty in the fluent and accurate decoding of words / nonwords. Together my phonological measures provide a comprehensive assessment of literacy ability therefore. By including these tasks I can again confirm the presence or absence of difficulties in participants with less severe sight word reading difficulty.

I expect that the groups with literacy difficulty only (D-DLD, dyslexic) will show a difficulty in phonological measures. Having said this, DLD only groups may show an overlap in aetiology with D-DLD and dyslexic groups. To this extent they may show some phonological difficulty in tasks. We know that language only difficulty (absence of decoding difficulty) can occur both with and without phonological difficulty (Catts et al., 2005). I expect my DLD group will show some phonological difficulty and this will make them distinct from a PC group.

4.1.1 Phonetic decoding efficiency

The task was administered and scored in line with the manual. In the TOWRE phonetic decoding efficiency (PDE) task (Torgesen et al., 1999), participants had to read aloud as many nonwords as possible from a card in 45 seconds. This measured participant's ability to accurately and fluently decode nonwords. The CA and impaired participant completed the task at both T1 and T2; the ability level groups completed the task at T1 only see

*Table **3***.

4.2.2 Fluency – alliteration

The alliteration fluency task at T2 (PhAB – Frederickson et al., 1997) assessed phonological fluency. It was administered but not scored fully in line with the manual. Standardised measures were not calculated (see section 4.2.2). Children had to name as many words as they could in 30 seconds that started with the /k/ sound and then with /m/ sound. Words that were repeated did not count towards the final score. Raw scores were totalled.

4.2.3 Spoonerisms

The spoonerisms task at T2 (PhAB - Frederickson et al., 1997) was used to assess PA. It was administered but not fully scored in line with the manual. Standardised measures were not calculated (see section 4.2.2). Children completed as many items as they could in three minutes, out of a possible 10 items. These items required the child to replace the first sound in a word with a different sound. For example 'cat' with a /f/ sound gives 'fat'. Children were asked to name the resultant word for each item. In the second section children had three minutes to complete as many double spoonerisms as possible. This involved swopping the first sound in one word with the first sound in another word. For example 'black cat' gives 'clack bat'. The child was advised that these words might not be real words. Children scored a maximum of one point per item on the first section and two points per item on the second section. Testing was discontinued if the child failed to score on three items in a row in either section. Raw scores were summed.

4.4 Other measures

I have been also keen to assess potential confounds in participant performance. Therefore a processing speed task was included to assess whether differences in reaction time and processing could explain group differences. In line with previous studies, I expect that the children with language difficulties will experience difficulty in processing speed (Im-Bolter et al., 2006; Leonard et al., 2007; Miller, Kail, Leonard, & Tomblin, 2001) whereas this will be an area of strength for the dyslexic group (Breznitz, 2003). A screening questionnaire was also administered to assess comorbid attention deficits in each group.

4.4.1 Symbol Search

The Symbol Search task at T2 was taken from the Wechsler Intelligence Scale for Children – III (WISC-III; Wechsler, 1991) as a measure of orthographic processing speed. The task was administered and scored in line with the manual. Children had to identify whether a target shape was present or absent in a line of shapes. Participants had two minutes to circle yes or no for each line. A raw score of items correct and items incorrect was summed for each participant. Number incorrect was then subtracted from number correct to give an overall raw score. Scores for the symbol search task reflected both accuracy and response speed as participants had to complete as many items correctly as possible in two minutes.

4.4.2 Picture naming and digit naming

Several tasks were also included from the phonological assessment battery at T2 (PhAB; Frederickson et al., 1997). The tasks included two naming speed measures, picture naming and digit naming tasks. They assessed RAN and were administered and scored in line with the manual.

In the picture naming task, children were presented with two cards one after the other showing several rows of printed objects, including a door, a table, a box, a hat and a ball. Children had to name aloud the list of objects as quickly as possible from left to right without stopping at the end of each row. Children were told that if they made a mistake they should correct themselves and move on as quickly as possible. Children completed two object naming cards with a 30 second break in between and the time taken in seconds to complete each was summed. If a child made more than three uncorrected mistakes on a card this was recorded.

This process was then repeated but for naming digits instead of objects printed on a card. Standardised measures were not calculated for the tasks as the age range of the PhAB (Frederickson et al., 1997) only extends between five and eleven years, and the standardisation data are over 20 years old.

4.4.3 Swan Questionnaire

Parents completed a questionnaire assessing ADHD at the same time as the consent forma at T1. This was assessed because of the high prevalence of ADHD in dyslexia (see Wilcutt & Pennington, 2000) and the DSM tendency to group such disorders together (see Snowling & Melby-Levåg, 2016). The SWAN questionnaire (Swanson et al., 2012) provided a rating of the three sub-types of ADHD for each participant: ADHD inattentive subtype (ADHD-I), ADHD hyperactive –impulsive (ADHD-H/Im), ADHD combined (ADHD-C). Parents indicated on a scale of -3 to +3 how much they agreed with 18 statements. The questionnaire was not completed by parents 13 of the participants (5 dyslexic, 2 DLD, 3 D-DLD, 2 CA, 5 RA, 4 LA/D-DLD). The mean and SD were calculated for each subtype (ADHD-I, M = 0.07, SD = 1.38, ADHD-H/Im, M = -0.41, SD = 1.27, ADHD-C, M = -0.17, SD = 1.26) for the total participant group (N=138). Positive values indicated the presence of difficulty. Participants who scored one SD or more above the mean were considered to have moderate difficulty (Swanson et al., 2012).

Table ***5*** presents the summary scores and SD for each ADHD subtype for each participant group. The table also presents the percentage of participants in each group considered to be experiencing moderate difficulty. These were well within comorbidity estimates (approx. 30%) given for language and literacy impaired groups (Germanò, Gagliano, & Curatolo, 2010; Tomblin, Zhang, Buckwalter, & Catts, 2000).

Table 5: Mean / SD and prevalence of ADHD subtype by participant group

Group	ADHD-I			ADHD-H/Im			ADHD-C		
	Mean	SD	%	Mean	SD	%	Mean	SD	%
Dyslexic	.82	1.16	24.1	-.04	.90	10.3	.39	.93	20.1
DLD	.42	1.2	20	-.01	1.52	20	.20	1.34	20
D-DLD	.57	1.83	25.8	-.20	1.2	16.1	.18	1.80	19.4
CA	-.52	1.2	8.7	-.97	1.04	4.3	-.75	1.05	4.3
RA	-.38	1.08	6.9	-.45	1.02	6.9	-.42	1.01	6.9
LA/DLD	-.66	.87	0	-.59	1.01	0	-.62	.87	0
LA/D-DLD	-.30	1.02	6.5	-.60	.88	3.2	-.45	.91	6.5

5. Results: Other task results

I now step through the results for other background measures utilised in the thesis. Unless otherwise stated, a between-subjects ANOVA with the independent variable group (D-DLD, DLD, dyslexic, CA) and the dependent variables score (for each task) was utilised. This pattern continues through thesis. Planned contrasts use a Bonferroni correction of $p < .0167$).

5.1 Other literacy measures

I begin with the other literacy measures presented to CA and impaired groups only.

5.1.1 Sight word efficiency T2

Raw scores confirmed group differences, $F(3,76) = 33.93$, $p < .01$, r = 0.76. Planned contrasts confirmed, as expected, the CA group scored higher than the dyslexic group, $t(76) = 8.19$, $p < .01$, $d = 2.43$ and the D-DLD group, $t(76) = 8.29$, $p < .01$, $d = 2.42$. The CA group performed similarly to the DLD group, $t(76) = 1.23$, $p = .22$, $d = 0.58$. The DLD group scored higher than both the dyslexic, $t(76) = 5.19$, $p < .01$, $d = 2.08$, and D-DLD group, $t(76) = -5.36$, $p < .01$, $d = 2.18$. The dyslexic and the D-DLD groups performed similarly, $t(76) = -.34$, $p = .73$, $d = 0.09$. See Table 4.

5.1.1.1 Comparing across time points

Paired samples t-tests confirmed the CA group scored higher at T2 than T1, $t(20) = -4.87$, $p < .01$, $d = 0.78$, as did the dyslexic, $t(25) = -5.16$, $p < .01$, $d = 0.48$ and D-DLD group, $t(22) = -5.70$, $p < .01$, $d = 0.55$. The DLD group performed similarly at T1 and T2, $t(9) = -1.55$, $p = .16$, $d = 0.43$.

5.1.2 Spelling

Standard scores[6] confirmed group differences, $F(3,76) = 27.53$, $p < .001$, r = 1.04. Planned contrasts confirmed that, as expected, the CA group scored higher on the spelling task that both the dyslexic group, $t(76) = 8.15$, $p < .001$, $d = 2.02$, and D-DLD group, $t(76) = 7.62$, $p < .001$, $d = 1.92$. The CA group also scored higher than the DLD group, $t(76) = 3.24$, $p < .01$, $d = 0.99$. The DLD group scored higher than both the dyslexic group, $t(76) = 3.08$, $p < .01$, $d = 1.48$, and the D-DLD group, $t(76) = -2.79$, $p < .01$, $d = 1.33$. The dyslexic and the D-DLD groups performed similarly, $t(76) = 0.32$, $p = .75$, $d = 0.13$. See Table 6.

Table *6***:** Mean (SD) scores for other literacy, language, phonological and processing measures by group.

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[6] Note that unlike other measures (accept NVIQ), only standard scores were analysed for spelling. Different ages began the task at different blocks affecting raw scores substantially. Standard scores took this in to account.

Table 6: Mean (SD) scores for other literacy, language, phonological and processing measures by group.

Group	Standard Spelling	Raw Reading Comprehension	Raw Picture Speed	Raw Digit Naming	Raw Semantic Fluency	Raw Phonetic Decoding		Alliteration Fluency	Spoonerisms	Symbol Search
	Mean(SD)	*Mean(SD)*	*Mean(SD)*	*Mean(SD)*	*Mean(SD)*	*Mean(SD) – T1*	*Mean(SD) – T2*	*Mean(SD)*	*Mean(SD)*	*Mean(SD)*
Dyslexic	77.04(6.04)	28.97(12.36)	81.2(11.79)	48.84(12.62)	26.4(5.26)	23.86(8.74)	27.42(8.4)	13.48(4.01)	19.28(10.06)	28.54(6.81)
DLD	87.60(8.11)	30.30(9.14)	69.7(8.90)	37.5(5.82)	28.6(8.59)	43.4(10.65)	44.6(10.13)	15.8(4.32)	17.4(3.57)	30.50(5.97)
D-DLD	77.87(6.39)	22.64(8.06)	82.18(20.68)	51.77(12.34)	26.55(5.82)	23.86(10.06)	24.74(11.48)	13.41(5.11)	16.14(6.58)	24.61(6.39)
CA	99.10(14.25)	41.41(10.21)	65.38(9.36)	36.43(8.18)	32.67(6.54)	48(6.92)	51.10(5.61)	18.29(6)	24.43(4.52)	31.90(5.05)
RA	-	-	-	-	-	32(9.56)	-	-	-	20.19(4.82)
LA/DLD	-	-	-	-	-	37.6(9.52)	-	-	-	22.20(3.39)
LA/D-DLD	-	-	-	-	-	35.70(9.26)	-	-	-	20(4.99)

5.1.3 Reading comprehension

Data was missing from one CA participant at T1. Raw scores confirmed group differences, $F(3,85) = 13.92$, $p < .01$, r = 0.70. Planned contrasts confirmed, as expected, that the CA group performed better in reading comprehension than both the DLD, $t(85) = 2.84$, $p < .01$, $d = 1.15$, and D-DLD group, $t(85) = 6.41$, $p < .01$, $d = 2.04$. Interestingly the CA group also scored higher than the dyslexic group, $t(85) = 4.28$, $p < .01$, $d = 1.10$. The DLD group scored similarly to the dyslexic group, $t(85) = 0.35$, $p = .72$, $d = 0.12$, and the D-DLD group, $t(85) = -2.02$, $p = .05$, $d = 0.89$. The dyslexic group scored higher than the D-DLD group, $t(85) = -2.32$, $p < .01$, $d = 0.61$. See Table 6.

5.2 Other language measures

5.2.1 Formulated sentences

Data was missing from 13 participants (3 D-DLD, 7 dyslexic, 1 LA/D-DLD, 2 RA) in addition to participants missing from T2 entirely. This was largely due to an error in labelling recordings. Raw scores confirmed group differences, $F(3,64) = 30.39$, $p < .001$, r = 1.19. Planned contrasts confirmed that the CA group scored similarly to the dyslexic group, $t(64) = 1.56$, $p = .12$, $d = 0.62$, but higher that the D-DLD, $t(64) = 7.87$, $p < .001$, $d = 2.40$, and DLD group, $t(64) = 6.91$, $p < .001$, $d = 2.84$. The DLD group scored lower than the dyslexic group, $t(64) = -5.39$, $p < .001$, $d = 2.17$, but similarly to the D-DLD group, $t(64) = -0.51$, $p = .61$, $d = 0.17$. The dyslexic group scored higher than the D-DLD group, $t(64) = 5.91$, $p < .001$, $d = 1.81$.

5.2.2.1 Ability level comparisons

I compared scaled scores, for the formulated sentences task (CELF-IV at T2, Wiig et al., 2003), for the DLD and D-DLD group at T2 to scaled scores for the language level groups. Independent samples t-tests confirmed that the DLD group was group-wise matched to the LA/DLD group, $t(18) = -0.26$, $p = .80$, $d = 0.12$. The D-DLD group was also matched to the LA/D-DLD group, $t(38) = -1.36$, $p = .18$, $d = 0.43$. It was not necessary therefore to reassign ability groups at T2.

The dyslexic group scored higher than the RA group, $t(32) = 5.42$, $p < .001$, $d = 1.86$. The D-DLD group scored similarly to the RA group, $t(35) = .57$, $p = .57$, $d = 0.19$. See Table 4.

5.2.2 Semantic fluency

Data were missing from one dyslexic participant in addition to participants missing entirely from T2. Raw scores for the semantic fluency tasks confirmed group differences, $F(3,75) = 5.01$, $p < .01$, r = 0.45. Planned contrasts confirmed, as expected, that the CA group scored higher than the D-DLD group, $t(75) = 3.41$, $p < .01$, $d = 1.03$. Surprisingly, the CA group scored higher than the dyslexic group without language difficulties, $t(75) = 3.38$, $p < .01$, $d = 1.05$ and similarly to the DLD group with language difficulties, $t(75) = 1.69$, $p = .10$, $d = 0.53$. The other impaired groups performed similarly: DLD vs. dyslexic, $t(75) = 0.94$, $p = .35$, $d = 0.31$, DLD vs. D-DLD, $t(75) = -1.00$, $p = .32$, $d = 0.32$, dyslexic vs. D-DLD, $t(75) = -0.10$, $p = .92$, $d = 0.03$. See Table 6.

5.3 Phonological measures

I now detail the results for the phonological measures administered to participants including PDE, alliteration fluency and spoonerisms.

5.3.1 Phonetic decoding efficiency

PDE was administered to CA, impaired and ability level groups at T1. Impaired at CA participants also completed the task again at T2 allowing for comparison across time points.

5.3.1.1 Time point 1

Data were missing from one dyslexic participant at T1. Raw scores confirmed group differences, $F(3,85) = 44.94$, $p < .01$, r = 0.78. Planned contrasts confirmed, as expected, the CA group scored higher than the dyslexic group, $t(85) = 9.55$, $p < .01$, $d = 3.06$, and the D-DLD group $t(85) = 9.55$, $p < .01$, $d = 2.69$. The CA group performed similarly to the DLD group, $t(85) = 1.35$, $p = .18$, $d = 0.51$. As expected, the DLD group scored higher than both the dyslexic group, $t(85) = 5.90$, $p < .01$, $d = 2.00$, and the D-DLD group, $t(85) = -5.90$, $p < .01$, $d = 1.89$. The dyslexic and the D-DLD groups performed similarly, $t(85) = 0.00$, $p = 1.00$, $d = 0$.

The LA/DLD group scored similarly to the DLD group, $t(18) = 1.28$, $p = .26$, $d = 0.57$. The other impaired groups scored lower than their ability level groups: RA vs. dyslexic, $t(55) = -2.94$, $p <$

.01, $d = 0.78$, RA vs. D-DLD, $t(55) = -2.76$, $p < .01$, $d = 0.73$, LA /D-DLD vs. D-DLD, $t(54) = -4.90$, $p < .01$, $d = 1.31$. See Table 6.

5.3.1.2 T2

Raw scores confirmed group differences, $F(3,76) = 40.64$, $p < .01$, r = 0.78. Planned contrasts confirmed that, as expected, the CA group scored higher than the dyslexic group, $t(42.85) = 11.16$, $p < .01$, $d = 3.20$, and the D-DLD group, $t(32.57) = 9.80$, $p < .01$, $d = 2.92$. The CA group performed similarly to the DLD group, $t(11.70) = 1.89$, $p = .08$, $d = 0.79$. As expected, the DLD group scored higher than both the dyslexic group, $t(14.58) = 4.71$, $p < .01$, $d = 1.81$, and the D-DLD group, $t(19.37) = -4.97$, $p < .01$, $d = 1.83$. The dyslexic and the D-DLD groups performed similarly, $t(41.16) = -0.91$, $p = .37$, $d = 0.26$. See Table 6.

5.3.1.3 Comparing across time points

Paired samples t-tests confirmed that the CA, $t(20) = -3.71$, $p < .01$, $d = 0.46$, and dyslexic, $t(24) = -5.15$, $p < .01$, $d = 0.34$, groups scored higher at T2 than T1. Both language impaired groups performed similarly over time points: D-DLD, $t(22) = -1.99$, $p = .06$, $d = 0.19$, DLD ($t(9) = -0.93$, $p = .38$, $d = 0.12$.

5.4 Alliteration fluency

Data were missing from one D-DLD participant in addition to participants missing entirely from T2. Raw scores confirmed group differences, $F(3,75) = 4.84$, $p < .01$, r = 0.44. Planned contrasts confirmed that the CA group scored higher than both the dyslexic group, $t(75) = 3.36$, $p < .01$, $d = 0.96$, and the D-DLD group, $t(75) = 3.24$, $p < .01$, $d = 0.86$. The CA group scored similarly to the DLD group, $t(75) = 1.31$, $p = .19$, $d = 0.48$. Surprisingly the DLD group scored similarly to the dyslexic group, $t(75) = 1.30$, $p = .20$, $d = 0.56$, and the D-DLD group, $t(75) = -1.27$, $p = .21$, $d = 0.51$. The dyslexic group scored similarly to the D-DLD group, $t(75) = -0.01$, $p =.99$, $d = 0$. See Table 6.

5.4 Spoonerisms

Data was missing from one D-DLD participant in addition to participants missing entirely from T2. Raw scores confirmed group differences, $F(3,75) = 5.20$, $p < .01$, r = 0.46. Interestingly, planned contrasts revealed that the CA group scored higher than both language impaired groups: D-

DLD, $t(75) = 3.79$, $p < .01$, $d = 1.47$, DLD, $t(75) = 2.55$, $p < .0167$, $d = 1.73$. The CA group performed similarly to the dyslexic group but this tended very strongly towards significance dyslexic, $t(75) = 2.41$, $p = .018$, $d = 0.66$. The impaired groups all performed similarly: DLD vs. dyslexic, $t(75) = -0.73$, $p = .47$, $d = 0.26$, DLD vs. D-DLD group, $t(75) = -0.46$, $p = .65$, $d = 0.24$, dyslexic vs. D-DLD, $t(75) = -1.54$, $p = .13$, $d = 0.38$. See Table 6.

5.4 Other measures

5.4.1 Symbol Search

Raw scores revealed group differences, $F(3,76) = 5.56$, $p < .01$, r = 0.47. Planned contrasts confirmed that the CA group scored similarly to both the dyslexic group, $t(76) = 1.86$, $p = .07$, $d = 0.56$, and the DLD group, $t(76) = 0.59$, $p = .55$, $d = 0.25$. The CA group scored higher than the D-DLD group, $t(76) = 3.93$, $p < .01$, $d = 1.27$. The dyslexic group scored similarly to the DLD, $t(76) = 0.86$, $p = .40$, $d = 0.31$, and D-DLD groups, $t(76) = 2.23$, $p = .03$, $d = 0.60$, although this tended towards significance. The DLD group scored higher than the D-DLD group, $t(76) = 2.53$, $p < .0167$, $d = 0.95$.

Impaired groups scored higher than their ability level groups: dyslexic vs. RA, $t(45.01) = 5.10$, $p < .01$, $d = 1.42$, D-DLD vs. RA, $t(47) = 2.76$, $p < .01$, $d = 0.78$, D-DLD vs. LA/D-DLD, $t(44) = 2.73$, $p < .01$, $d = 0.81$, DLD vs. LA/DLD, $t(18) = 3.82$, $p < .01$, $d = 1.71$. See Table 6.

5.4.2 Picture naming speed

Raw scores confirmed group differences, $F(3,76) = 7.03$, $p < .01$, r = 0.53. Planned contrasts confirmed that the CA group were faster at naming pictures than the dyslexic group, $t(44.85) = -4.72$, $p < .01$, $d = 1.37$, and the D-DLD group, $t(30.05) = -3.69$, $p < .01$, $d = 1.10$. The CA group performed similarly to the DLD group, $t(18.66) = -1.24$, $p = .23$, $d = 0.47$. The DLD group were faster than the dyslexic group, $t(22.77) = -2.87$, $p < .01$, $d = 0.99$, and the D-DLD group, $t(30.92) = 2.66$, $p < .0167$, $d = 0.85$. The dyslexic group performed similarly to the D-DLD group, $t(33.34) = 0.73$, $p = .47$, $d = 0.21$. See Table 6.

5.4.3 Digit naming speed

Raw scores confirmed group differences, $F(3,76) = 10.48$, $p < .01$, r = 0.64. Planned contrasts revealed that the CA group were faster at naming digits than the dyslexic group, $t(76) = -3.81$, $p < .01$, $d = 1.15$, and the D-DLD group, $t(76) = -4.89$, $p < .01$, $d = 1.52$. The CA group performed similarly to the DLD group, $t(76) = -0.26$, $p = .80$, $d = 0.15$. The DLD group were faster than the dyslexic group, $t(76) = -2.74$, $p < .01$, $d = 1.14$, and the D-DLD group, $t(76) = 3.64$, $p < .01$, $d = 1.53$. The dyslexic group performed similarly to the D-DLD group, $t(76) = 1.26$, $p = .21$, $d = 0.31$. See Table 6.

6. Discussion

Table 7 shows the pattern of difficulty for impaired groups relative to CAs for each task. It reveals a clear pattern of impairment across the different groups. The following section summarises results and draws particular attention to results that were unexpected.

6.1 Literacy

For SWE (TOWRE – Torgesen et al., 1999), the pattern of results were as expected, following the same pattern at T1 and T2. The dyslexic and D-DLD groups experienced difficulty compared to both CA and DLD groups who in turn performed similarly to each other. This suggests a robust SWE deficit in the literacy impaired groups as predicted (Bishop & Snowling, 2004).

The RA group performed similarly to the dyslexic / D-DLD groups. The LA/D-DLD group scored higher than the D-DLD group. These groups are not matched for literacy. Instead conclusions about literacy appropriate performance in D-DLD can be made via comparisons to the RA group. The DLD group outperformed the LA/DLD group due to their age and lack of deficit.

Table 7: Summary of deficit, no deficit or trending strongly toward deficit, relative to CA group, for each measure, for impaired groups.

	Literacy			**Language**			**Phonology**			**Other**		
Group	Sight Word Reading	Spelling	Reading Comp.	Listening Comp.	Formulated Sentences	Semantic Fluency	Phonetic Decoding	Alliteration Fluency	Spoonerisms	NVIQ	Processing Speed	Naming Speed
Dyslexic	Deficit	Deficit	Deficit	No deficit	No deficit	Deficit	Deficit	Deficit	Trending	Trending	No Deficit	Deficit
DLD	No deficit	Deficit	Deficit	Deficit	Deficit	No Deficit	No Deficit	No Deficit	Deficit	Deficit	No Deficit	No Deficit
D-DLD	Deficit	Deficit	Deficit	Deficit	Deficit	Deficit	Deficit	Deficit	Deficit	Deficit	Deficit	Deficit

Interestingly, all CA and impaired groups improved from T1 to T2 except the DLD group. Several studies have found that early language difficulty is associated with later literacy difficulty (Bishop et al., 2000, Hulme et al., 2015; Torppa et al., 2010). The DLD group does not receive help in school for literacy and it is possible that over time their development in such stagnates. It is crucial therefore to consider that groups with language as their main difficulty may still be at risk of developing literacy deficits if unmonitored.

For reading comprehension, the CA group scored higher than all impaired groups. The dyslexic group scored higher than both the DLD and D-DLD groups, who in turn performed similarly. This suggests the dyslexic group has a less severe deficit. Traditionally children with dyslexia, a specific difficulty in decoding, do not have poor reading comprehension. Instead those who embody both deficits are often referred to as 'garden variety poor readers' (Nation & Snowling, 1998). However, children with dyslexia do not always have good comprehension. Comprehension difficulties arise in dyslexia often as a consequence of poor decoding. If children struggle with decoding they often have little capacity remaining for the extraction of meaning. If you take away the pressure of decoding, i.e. presenting text orally, then dyslexic readers do not have a problem with comprehension (Høien & Lundberg, 2000). This is the case for my group who do not show difficulty in the listening comprehension task (WIAT-III – Wechsler, 2005).

Spelling also highlighted expected differences between groups. The CA group scored higher than all three impaired groups. The DLD group performed better than both literacy impaired groups. Lastly, as expected children with dyslexia and D-DLD had difficulty in both RAN tasks (digit and picture naming). They performed similarly to each other. The DLD group performed better than both of these groups and similarly to the CA group.

6.2 Language

Results were similar for expressive and receptive language measures at T1 and T2, for listening comprehension (WIAT-III – Wechsler, 2005) and formulated sentences (CELF – IV, Wiig et al., 2003). Only the language impaired (DLD, D-DLD) groups showed a difficulty relative to CAs, performing similarly to each other. The dyslexic group outperformed both of the language impaired groups. Language impaired groups performed similarly to their respective pair-wise matches. Interestingly the RA group also formed a good group-wise match to the D-DLD group on both tasks. This is an ability level group that is group-wise matched for both literacy and language simultaneously to the D-DLD. As expected the dyslexic group outperformed the RA group due to their age and lack of difficulty.

For semantic fluency, as expected, the CA group scored higher than the D-DLD group. Surprisingly, the DLD group performed similarly to the CA group who in turn performed better than the dyslexic group. The impaired groups all performed similarly to each other. Fluency tasks assess multiple processes including executive function. Shao, Janse, Visser and Meyer (2014) found that performance on both phonemic and semantic fluency tasks can be predicted by verbal updating ability. Participants are required to constantly update the list of responses already given in WM in order to provide novel responses. Semantic fluency tasks also utilise categorisation and switching strategies (Troyer, 2000). For best performance, participants need to exhaust a list of words within a category before fluently switching to another category. This switching ability is an executive process (Miyake et al., 2000). Verbal updating and executive function seems to be an area of relative strength for DLD participants but not for dyslexic participants, see chapter 4. Snowling, Nation, Moxham, Gallagher and Frith (1997) also administered a similar semantic fluency task to adults with dyslexia. They found that participants had difficulty in the naming of animals but not food categories. I did not separately analyse the responses given for food and animal items in my task but this could also account also for the deficits seen in the dyslexic group.

6.3 Phonology

For phonetic decoding, at both time points, the CA and DLD groups scored higher than the language impaired groups who performed similarly to each other. The RA group had better decoding than both the dyslexic and D-DLD groups. The LA/D-DLD group also had better decoding than the D-

DLD group. The LA/DLD group performed similarly to the DLD group. The CA and dyslexic groups improved over time but the language impaired groups did not. This reinforces the robust deficit in phonology likely experienced in D-DLD groups. It also suggests that the DLD group do experience difficulties to some extent in phonology or that their developmental trajectory is not typical.

Alliteration fluency may also be further evidence of emergent phonological deficits in the DLD group. The CA group scored higher than the literacy impaired groups who performed similarly to each other. The CA group performed similarly to the DLD group but the DLD group also performed similarly to the dyslexic and D-DLD group. However as previously mentioned, fluency tasks utilise executive function (Shao et al., 2014; Troyer, 2000). EF seems to be an area of relative strength for DLD participants which may provide them with an advantage over other impaired groups.

For the spoonerisms tasks measuring PA, the CA group scored higher than both language (DLD, D-DLD) impaired groups. The difference between the CA group and the dyslexic group trended very heavily toward significance after controlling for multiple comparisons. The impaired groups performed similarly. This task highlighted a difficulty in PA for the DLD group. The spoonerisms task involves verbal WM processes, the ability to store phonemes and then process them by swapping them between words. Verbal WM is an area of relative strength for our DLD group (see chapter 3). Yet difficulties still persist in PA tasks. This highlights the substantive nature of underlying phonological difficulty in DLD. The DLD group cannot be considered a PC group therefore.

Profiles of phonological difficulty may have a lot to do with defining our groups and establishing whether participants in the DLD group will go on to develop additional literacy difficulty or not. Loucas et al. (2016) suggest that phonological processing difficulties distinguish between DLD children who do and do not experience additional reading impairments. Similarly, Catts et al. (2017) found that pre-school children with (and without) language difficulty that experienced a difficulty in PA were more likely to develop reading difficulty. Indeed research does suggest that DLD children without dyslexia have less severe phonological difficulties (Bishop, et al., 2009). The component model suggests that DLD can occur both in the presence and absence of phonological difficulty (Catts et al., 2005). It also suggests that children with DLD may or may not have phonological difficulties and that these difficulties, if present, are not necessarily the same as those shown in dyslexia (Pennington & Bishop, 2009). Interestingly this holds true for our groups. In the two tasks that our dyslexic groups experience difficulty in, compared to CAs (phonetic decoding, alliteration fluency) the DLD group do not. And vice versa, for the one task our DLD group do show difficulty in (PA), the dyslexic group only tend towards difficulty. It seems that our DLD group do experience very mild phonological difficulty In PA tasks only. This is not enough to cause a severe literacy difficulty however.

6.3 Other Tasks

The language impaired groups scored lower than the CA group for NVIQ. The dyslexic group performed similarly but this tended towards significance. Difficulties in NVIQ have been reported for language impaired groups with researchers calling to remove ‘typical NVIQ’ as a diagnostic criterion for language difficulty (Bishop, 2017). Typical NVIQ is largely considered a necessity for diagnosis of dyslexia as opposed to general reading difficulty but again many consider this so called discrepancy definition to be misleading (Stanovich, 1991). Those at risk of developing literacy difficulty for example have difficulty in NVIQ tasks (Gooch, Hulme, Nash, & Snowling, 2014). Other research has highlighted so called ‘Matthew effects’ in dyslexia. Whilst NVIQ and literacy seems to develop at a similar level in typical readers, evidence suggests that NVIQ becomes increasingly poor in dyslexic readers over time, with the gap widening (Ferrer, Shaywitz, Holahan, Marchione, & Shaywitz, 2010). Differences in NVIQ for my sample could be particularly highlighted then by the age of sample. Lastly evidence suggests that there is no need to differentiate between poor readers with either typical (traditional dyslexia) or low NVIQ. Siegel (1992) found that poor readers either with typical or low NVIQ performed similarly on measures of literacy, phonology, language and memory and that both groups performed below a CA group.

The language impaired groups performed similarly on the NVIQ measure suggesting any potential differences between these groups cannot be due to differences in NVIQ. The dyslexic group performed similarly to the DLD and D-DLD groups. All impaired groups scored lower than their respective ability matches suggesting an underlying deficit.

For the symbol search task, only the D-DLD group experienced difficulty relative to the CA group. This was expected with several studies suggesting participants with language impairment experience a deficit in processing speed (Im-Bolter et al., 2006; Leonard et al., 2007; Miller et al., 2001). The dyslexic group scored similarly to the DLD and D-DLD groups. The DLD group scored higher than the D-DLD group. The ability level groups all scored lower than their respective matches suggesting that processing speed is highly related to age. Processing speed in hugely variable in children with language difficulties and it is not necessary related to the severity of language difficulty experienced by the participant (Lahey, Edwards, & Munson, 2001; Windsor, Milbrath, Carney, & Rakowski, 2001). My language impaired groups experience similar levels of language difficulty but differ in their orthographic processing speed which is not uncommon. The variability in previous studies could have been due to the inclusion of both D-DLD and DLD participants within one group.

For the picture naming and digit naming assessing RAN, only the dyslexic and D-DLD groups scored lower than the CA group and similarly to each other. Interestingly my DLD group do not show difficulties, in RAN. Research suggests that DLD children without dyslexia have less severe phonological difficulties (Bishop et al., 2009). Bishop et al. (2009) found that a group of children with DLD only did not show decoding difficulties if they had intact RAN abilities. This group also experienced reading comprehension difficulties and early difficulty in phonology. This group bears a remarkable resemblance to my DLD group. Research suggests that the presence of RAN difficulties alongside other phonological difficulties in DLD are most likely to result in additional dyslexia (Vandewalle et al., 2012).

6.4 Summary of group difficulties

Table 7 summarises the deficits seen in each impaired group relative to the CA group. The dyslexic group can be identified by a pervasive difficulty in literacy and phonology. The D-DLD group showed deficits in all of the measures suggesting a wide range of difficulties in literacy, language, phonology and processing. The DLD group seems to be characterised by a pervasive deficit in language with the addition of mild spelling, PA and reading comprehension difficulty. DLD children also do not show improvement in SWE and PDE over time. Not all DLD children with these early difficulties will go on to develop additional literacy difficulty (D-DLD). I propose for DLD groups, intact processing, attention and CE processes afford alternative routes to literacy. The following chapters of this thesis now visits verbal and non-verbal STM, WM , EF, attention and CE processes in an attempt to understand the nature of the compensatory mechanisms utilised in DLD. It will also profile the relative areas of strength, weakness and commonalties seen in all three groups.

Chapter 3 - Verbal and nonverbal short-term and WM

1. General introduction

The aim of this study and the broader thesis is to profile underlying verbal and nonverbal cognitive impairments in both literacy and language impairment. I am interested in exploring the main facets of Baddeley's (2000) WM model, primarily the short-term stores, WM, EF, attention and the CE. This chapter focuses on the STM slave stores and WM processes that act on them. It asks whether dyslexic, DLD and D-DLD groups can be reliably distinguished by their performance in verbal and nonverbal STM and WM tasks. Do differences occur between the groups and if so at what juncture in STM / WM does this occur?

Verbal and nonverbal STM and WM have been well researched for both dyslexic and D-DLD groups. When assessing verbal STM, researchers often administer span tasks in which participants recall verbal information in serial order. Nonverbal STM tasks are more often divided in to those which require stationary item information recall (static tasks) and serial order recall (dynamic tasks).

Several studies have investigated STM and WM in both verbal and nonverbal domains simultaneously. Fewer studies have chosen to do such across different impaired groups. The following sections discuss studies that have combined verbal and nonverbal measures before discussing studies that address multiple impaired groups. It then goes on to describe a verbal (Experiment 1) and nonverbal (Experiment 2) STM / WM study for the groups.

1.0.1 Dyslexia

For dyslexia, difficulties arise in verbal but not nonverbal STM tasks. Liberman, Mann, Shankweiler and Werfelman (1982) found differences between a dyslexic and CA group for a verbal STM task, but no differences on two nonverbal static STM tasks. Similarly, Gould and Glencross

(1990) observed deficits for verbal but not nonverbal span tasks for dyslexic verses CA participants. Palmer (2000) administered verbal (digit span) and nonverbal (Corsi-blocks) span tasks to a dyslexic group, an RA and a CA group (14 years). The dyslexic group scored higher than the RA group on the digit span task but lower than the CA group. For Corsi-blocks, the dyslexic group scored higher than the RA group and similarly to the CA group. This suggests that the dyslexic group experience a delay in verbal STM but age appropriate nonverbal STM.

Other studies have included measures of both STM and WM simultaneously finding a similar pattern of results. Smith-Spark, Fisk, Nicholson and Fawcett (2003) administered verbal STM and WM tasks to dyslexic (25 years) and TD (20 years) participants. Participants completed two span tasks assessing STM (digit, word) as well as a letter updating task assessing WM / updating simultaneously (discussed in Chapter 4). Dyslexic participants scored lower than the CA group on all verbal measures, both STM and WM. For the verbal WM task, dyslexic participants were poorer at remembering items from the beginning of lists, suggesting a failure in the articulatory rehearsal processes of the phonological loop. For verbal information to enter LTM stores, intact rehearsal processes are required in the phonological loop (Baddeley & Hitch, 1974). This failure of primarily verbal STM has a knock on effect for the WM task. It is hard to remove verbal STM demands from any verbal WM / CE task. The CE is a domain general construct acting on information stored in either the verbal or nonverbal STM store respectively. Deficits in either of these temporary stores would necessarily mean a deficit in the corresponding WM task.

In a second experiment, Smith-Spark et al. (2003) administered nonverbal tasks to pick apart whether dyslexic participants experience a standalone deficit in WM or whether deficits are restricted to short-term stores. Dyslexic participants are not known for having nonverbal STM difficulties (Velluntino, 1979) and therefore difficulties in nonverbal WM would indicate a deficit in the domain general CE component of WM rather than the short-term store. For nonverbal measures, participants completed both a static STM task (pattern recall) and a dynamic STM task (location span), as well as a nonverbal WM / updating task (discussed in Chapter 4). They found that the dyslexic group performed similarly to the CA group on both static and dynamic versions of the nonverbal task. For the nonverbal WM task, no overall group differences were observed except for the longest sequence lengths. Even for the longest sequence lengths, group differences were only for first and second positions recalled, indicating a minimal deficit.

Detailed analysis at trial level for tasks however has revealed some nonverbal difficulties in dyslexic groups. Smith-Spark and Fisk (2007) worked with a group of dyslexic participants (20 years) and a CA group. Participants completed three verbal STM span tasks (digit, letter, word) and two span tasks assessing verbal WM (computation span, reading span). They also completed a dynamic span task assessing nonverbal STM (Corsi-blocks) and a spatial span task assessing nonverbal WM. Dyslexic participants scored lower than CAs on all verbal measures and also on the nonverbal WM task. Differences remained between groups for verbal and nonverbal WM tasks even when initial STM span scores were controlled for. Smith-Spark and Fisk (2007) also performed a more detailed analysis of the nonverbal STM task, calculating how many trials within a block were accurate for each participant. On further analysis, they found group differences in nonverbal STM. The dyslexic group recalled fewer trials overall than the CA group for nonverbal STM despite producing similar overall span lengths.

Other studies have found both verbal and nonverbal deficits but with nonverbal deficits only emerging for dynamic span tasks not static STM tasks. Wang and Gathercole (2013) administered verbal and nonverbal STM and WM tasks to dyslexic participants (8-10 years) and a CA group. Tasks included two span tasks assessing STM (digits forwards, dot matrix) and two WM tasks (digits backward, spatial span). Unlike other studies, Wang and Gathercole (2013) found overall deficits for dyslexia in all memory measures, both verbal and nonverbal STM and WM. Differences remained after controlling for STM spans in both domains. When comparing across modalities, the dyslexic group were as impaired in verbal STM / WM as they were nonverbal STM / WM.

Other studies have also produced similar results. Jeffries and Everatt (2004) looked at both verbal and nonverbal STM tasks and also verbal WM tasks in dyslexic (9-12 years) and CA participants. They administered two verbal STM span tasks, two nonverbal STM tasks (one static and one dynamic) and two verbal WM tasks. The dyslexic group scored lower than the CA group on all verbal measures. For nonverbal measures, the groups performed similarly. Varvara, Varuzza, Padovano Sorrentino, Vicari and Meghini (2014) worked with a dyslexic and a CA group (8 – 17 years). Participants completed a verbal STM task (word span) and a verbal WM task (NWR). They also completed a dynamic visual STM task (pattern span) and a dynamic spatial STM task (Corsi-block style task). The dyslexic participants scored lower than the CA group on all STM and WM measures.

Studies seem to suggest then that dyslexic participants experience a robust difficulty in verbal STM tasks. They also experience difficulty in verbal WM tasks primarily caused by initial deficits in the phonological loop. Less evidence exists for nonverbal difficulties in dyslexia suggesting this could be an area of relative strength for dyslexic individuals, (see Palmer, 2000 for evidence of visual recall strategies in dyslexia). Where nonverbal differences are highlighted, they are for dynamic (not static) nonverbal STM and WM tasks with high demands.

Finite analysis of nonverbal STM results, i.e. trial level rather than span level, may also reveal differences between dyslexic and CA groups. In a meta-analysis, Swanson, Zheng and Jerman (2009) assessed 88 studies looking at verbal and nonverbal STM and WM in dyslexia. They found that dyslexic groups mostly experienced difficulty in verbal STM and WM when IQ and reading level were controlled. Swanson et al. (2009) argue that nonverbal performance produces inconsistent results in the literature predominantly because of varying task demands, statistical analysis and participant profiles. It might be that slight nonverbal capacity limitations do exist in nonverbal memory but this is only highlighted in dynamic tasks with high demands. This is further supported by the fact that nonverbal differences are less evident in older University age participants (Smith-Spark et al., 2003; Smith-Spark & Fisk, 2007) who are arguably compensated with larger nonverbal STM / WM capacity.

1.0.2 D-DLD

Dyslexic and D-DLD groups share a deficit in verbal STM and WM. However some studies have suggested that D-DLD groups also experience additional nonverbal difficulties. These nonverbal difficulties though are not always evident and different studies have revealed different patterns of memory difficulty in D-DLD. Verbal deficits do seem to arise consistently however and are more pronounced than nonverbal difficulties.

Vugs et al. (2014) found that children with D-DLD (4 – 5 years) performed worse than CA children on three verbal STM span tasks (WM, digits forwards, word recall and nonword recall). This remained true when controlling for IQ, gender and age. For nonverbal STM they also administered a static (maze tracing) task and a dynamic span task. D-DLD participants performed worse on all nonverbal STM measures than the CA group. When comparing verbal and nonverbal tasks, larger effects were observed for verbal STM tasks. This suggests D-DLD groups experience a larger difficulty in verbal tasks than nonverbal tasks. Henry et al. (2012) found that D-DLD children and a group of low language functioning children, were impaired compared to CAs (9 – 12 years) on tasks assessing both verbal and nonverbal WM. This remained true after controlling for age and verbal and NVIQ. Low language functioning children were those who experienced difficulty in language but did not meet the criteria for D-DLD. The D-DLD and low language functioning group performed similarly. This suggests that even mild difficulties in language (like those in the low language functioning group) are linked to difficulties in both verbal and nonverbal WM. D-DLD groups might experience an underlying deficit in nonverbal memory skills (rather than a delay). Hick, Botting and Conti-Ramsden (2005a; 2005b) looked at verbal and nonverbal STM in SEN groups including a D-DLD (4 years) and CA group. Participants repeated a verbal STM span task (digit span) and a static nonverbal STM task (pattern recall) several times over the course of a year. For the digit span task, the D-DLD group scored lower than the CA group. The difference between the D-DLD and CA group remained constant over the year suggesting both groups were improving at a similar rate. For the pattern recall task, the D-DLD group performed similarly to the CA group overall. However, whilst the CA group improved over time, the D-DLD group did not, indicating nonverbal STM span was not improving at a typical rate in D-DLD groups. Nonverbal STM span is developmentally sensitive with younger children having significantly reduced spans (Vugs, Cuperus, Hendriks, & Verhoeven, 2013). An older sample would likely have revealed group differences. Furthermore, over time the children in the D-DLD group are likely to have fallen further and further behind, indicating an underlying deficit in nonverbal memory.

Other studies have failed to identify evidence for nonverbal deficits, even in older D-DLD participants. Briscoe and Rankin (2009) administered several span measures of verbal STM (digit span, word span, non-word span, word matching and listening recall), WM (digit span backwards) and a dynamic measure of nonverbal STM (block span). Participants were a D-DLD, CA (7 – 9 years) and language ability level group. Whilst D-DLD participants scored lower than the CA group on verbal STM and WM measures, they performed typically on nonverbal measures. D-DLD participants also scored lower than the language level group for verbal STM / WM suggesting a deficit in these skills. Lukács et al. (2016), administered several tasks designed to be close verbal and nonverbal parallels of each other. Participants included a D-DLD and CA group (8 years). For STM, the D-DLD group scored lower than the CA group on the verbal task but not the nonverbal task. For verbal WM, the D-DLD group scored lower than the CA group. When controlling for verbal STM ability, group differences in the verbal WM task disappeared however. D-DLD groups did not show a difficulty in nonverbal WM tasks when compared to CA participants.

Nonverbal memory difficulties then may only occur in a subgroup of those diagnosed with language difficulties. Archibald and Gathercole (2006a) assessed D-DLD children (7-11 years) on four verbal STM span tasks and three verbal WM tasks. They also administered two static and one dynamic nonverbal STM span task. Scores were compared to expected age-standardised scores and scores appropriate for language level for each participant. For the verbal STM and WM tasks, the D-DLD group scored lower than expected for their chronological age. They also performed lower than expected given their language age. This suggests they experience an underlying deficit in verbal STM and WM. Only a subgroup of D-DLD participants showed difficulties in the nonverbal STM task.

Participants with D-DLD however show a robust difficulty in verbal STM / WM. Deficits in nonverbal memory, although evident, are clearly less pronounced than those seen for verbal memory. It may be that only a subgroup of those with language difficulties experience nonverbal difficulties.

1.0.3 Comparing across disorders

Fewer studies still have looked at memory across multiple impaired populations. Whilst verbal difficulties seem to be consistent for both groups, evidence for nonverbal difficulties in dyslexia and D-DLD is less clear.

Helland and Asbjørnsen (2003; 2004) looked at nonverbal and verbal STM respectively. Participants included special educational needs (SEN) groups: a dyslexic only group, a D-DLD group and a CA group (12 – 13 years). Participants completed the digit span task (forward assessing STM/ backward assessing WM) with both serial order recall and free recall (Helland & Asbjørnsen, 2003). CA participants performed better than both the dyslexic and D-DLD groups for all conditions of the task (forward / backward, serial / free recall). Overall participants recalled more in free recall conditions. When this was broken down by group, the D-DLD group were found to perform poorly in both free recall and serial recall conditions of the backwards digit span task. This suggests that both D-DLD and dyslexic groups experience difficulty in tasks that require the serial order recall of verbal information. Verbal WM difficulties in D-DLD groups are arguably more severe as they arise for both free recall and serial recall conditions.

For the nonverbal measures Helland and Asbjørnsen (2004) distinguished between visual STM and spatial STM. Visual STM was assessed with a static pattern and dynamic symbol span task. Participants ordered pattern / symbol cards by presentation. For the spatial STM tasks, participants completed four tasks: block span, picture completion task, picture arrangement, object assembly as well as a figures task. For the visual STM tasks, there were no group differences in picture span. For symbol span, the dyslexic group scored lower than the CA group. For spatial STM, only the picture arrangement task highlighted differences, the CA group outperforming both the D-DLD and dyslexic group. It must be noted however that both the symbol and picture arrangement tasks likely incurred verbal demands. Symbols are nameable and the pictures contained easily nameable objects.

Cowan et al. (2017) compared a group of dyslexic participants to a group with D-DLD as well as a CA group (8 years). Participants completed verbal STM memory measures (NWR, digit span) and nonverbal STM measures (shape span, location span). These tasks were presented in a standard format or running format. For standard tasks trial lengths were constant within a block and increased gradually with each new block. For running tasks, trial lengths were indeterminate and varied with each trial. When matched for NVIQ and oral language, the Dyslexic and CA groups performed similarly on NWR and nonverbal STM measures. The dyslexic group scored lower on the standard and running digit span tasks. This suggests a pervasive underlying difficulty in verbal STM in dyslexia that persists even when controlling for NVIQ and oral language. The dyslexic group also scored lower than the CA group on the running version of the location span task. In a second analysis, the dyslexic group was matched to the D-DLD group for NVIQ. The D-DLD group performed worse than the dyslexic group on NWR. The groups performed similarly for all other measures. It seems that the D-DLD group experience greater difficulty in recalling phonological information in STM. Nonverbal tasks seem to highlight a similar level of performance in both impaired groups.

Schuchardt et al. (2013) worked with several groups of SEN participants including a dyslexic, D-DLD and CA group (9 years). Participants completed seven verbal STM span tasks and five nonverbal dynamic tasks. They also completed four WM / CE tasks including a dual span task (discussed in Chapter 4), and three verbal WM tasks; backward word span, backward digit span, counting span. For verbal STM, the CA group scored better than the dyslexic group on all measures except images span, one-syllable word span and three syllable word span. The D-DLD group scored lower than the CA group on all verbal measures, and lower than the dyslexic group on all measures except three-syllable nonword span. Across the board there were no differences between any of the groups for nonverbal STM measures. For verbal WM, the dyslexic group scored lower than the CA group on backward digit span and counting span. The D-DLD group scored lower than the CA group on all measures but lower than the dyslexic group for counting span.

Other studies have also failed to find nonverbal deficits. Everatt, Weeks and Brooks (2008) worked with several different SEN groups (11 – 13 years) including a dyslexic, D-DLD and CA group. They administered both a digit span forward / backward and Corsi-blocks task forward / backward. Traditionally the forward and backward versions of these tasks assess STM / WM respectively. Combined forward / backward span scores for both the verbal and nonverbal elements were presented. They found that both the dyslexic and D-DLD group scored lower than the CA group on the verbal measure. Both groups performed similarly to the CA group on the nonverbal measure.

Both groups undeniably experience difficulty in both verbal STM and WM tasks. Verbal difficulties seem to be more severe in D-DLD groups than dyslexic groups (Cowan et al., 2017; Schuchardt et al., 2013). Evidence for nonverbal difficulties is less pronounced in studies that have compared multiple impaired groups.

1.1 The current study

This chapter brings together verbal and nonverbal STM and WM assessment in three impaired groups, those with dyslexia, DLD and D-DLD. It also makes use of carefully selected age-matched controls (CA) plus separate younger language and literacy ability level groups. No previous study has brought together these impaired groups and younger ability level groups and assessed them in terms of STM and WM. Previous studies have only included CAs. This is a significant omission as, if the impaired participants are using poor verbal skills to support memory, then a more appropriate comparison is against other participants with the same level of verbal skill. This tells us whether their STM / WM ability is atypical or to be expected given their poor literacy or language skills. To assess verbal STM and WM respectively a digit span task from the BAS-III (Elliot & Smith, 2011) was administered both forwards and backwards at T1. As a nonverbal parallel to the digit span task the Corsi-blocks task was administered both forwards and backwards to assess nonverbal STM and WM respectively (Kessels, van den Berg, Ruis, & Brands, 2008). The digit span task is a staple of verbal STM and WM testing and is used repeatedly in studies assessing impaired populations. It exists in many standardised forms and has been found to consistently reveal group differences between literacy and language impaired groups in the literature. I chose to incorporate this measure as well as a nonverbal parallel to the task.

Research suggests that both dyslexic and D-DLD groups experience difficulty in verbal STM tasks (Helland & Asbjørnsen, 2004) and verbal WM tasks (Schuchardt et al., 2013). WM acts on information held in the STM stores. However it is also possible to experience a difficulty in the domain general CE that is independent of the short term store. According to the double jeopardy hypothesis, D-DLD impaired children experience difficulty in both the verbal short-term and also the domain general CE necessary for WM (Archibald & Gathercole, 2006a). They experience a double deficit that leads to more severe difficulties in verbal memory. Indeed research suggests that D-DLD groups experience greater verbal memory difficulty (Cowan et al., 2017; Helland & Asbjørnsen, 2004; Schuchardt et al., 2013).

However, others have argued that the hierarchical nature of WM makes this particularly hard to pick apart (Briscoe & Rankin, 2009). It is hard to ascertain whether or not the CE is independently impaired as any deficits in subordinate stores (phonological store) would necessarily implicate superordinate components (CE, WM). Briscoe and Rankin (2009) argue instead that difficulties in verbal WM for D-DLD groups are primary caused by problems in verbal STM. However, deficits in the two areas are dissociable. Studies examining individuals with ADHD and D-DLD plus ADHD found that language impaired groups had broader difficulties in both STM and WM. The ADHD group only experienced difficulty in the CE component but not the slave store (Hutchinson, Bavin, Efron, & Sciberras, 2012). Given the broader (verbal and nonverbal) nature (Vugs et al., 2013) and severity (Cowan et al., 2017) of deficits seen in D-DLD, a double deficit is likely.

As previously noted, it is unclear whether previous studies have tested groups with purer language deficits (I term DLD). Dyslexia and D-DLD share an overlap in both literacy and phonological difficulties and also an overlap in verbal STM difficulty. Verbal STM memory is inherently linked to literacy ability, with such a deficit forming one third of the dyslexic triangle (Ramus & Szankovits, 2008). At the same time, verbal WM deficits have been suggested as a clinical marker of language difficulty (Montgomery, 2000). Therefore it is hard to know whether verbal STM deficits exist in DLD.

Research surrounding nonverbal STM and WM in my impaired groups is less clear cut. Studies that focus on either dyslexia or D-DLD individually (vs. CA groups), tend to suggest nonverbal difficulties in D-DLD (Henry et al., 2012; Vugs et al., 2014) but limited nonverbal difficulties in dyslexia (Liberman et al., 1982; Smith-Spark et al., 2003). However studies that have compared multiple impaired groups (D-DLD and dyslexia vs. CA) suggest a lack of nonverbal difficulties (Everatt et al., 2008; Schuchardt et al., 2013). s. In the previous chapter I touched on the theory that DLD. Therefore I predict that participants in the DLD group will not experience a difficulty in verbal STM or WM. The deficits in this group will be less pronounced than those seen in dyslexic and D-DLD groups.

Given the age of the participants in this study and relative simplicity of the spatial span task employed, I predict that they will perform similarly to the CA group for nonverbal measures. Groups with language difficulties (DLD, D-DLD) are likely to be most impaired on nonverbal measures given their broader difficulties in the CE. Dyslexic groups score higher than RA groups on measures of verbal STM (Palmer, 2000). This suggests a delay in performance. Language impaired groups perform similarly to ability level matches (Montgomery, 2000). I predict that the dyslexic group will score higher than ability level groups. Groups with language difficulties will score closer to the level expected given their ability.

2. Experiment 1: Verbal STM and WM

Verbal STM and WM have been well researched in both literacy and language impaired populations with robust difficulties being highlighted in each. Evidence comes from both forward (STM) and backward (WM - serial order recall) span tasks. Stimuli are presented in blocks of trials which increase in length incrementally with each block. To measure verbal STM, participants recall the items in order. To measure WM, participants recall the items backwards – in reverse order. Span length is defined as the longest trial length at which participants pass a minimum number of trials. The most common verbal span tasks are digit, word / nonword, and sentence span tasks. It should be noted when discussing DLD in the literature that these groups likely experience additional phonological / literacy problems.

2.0.1 Dyslexia

Several researchers have utilised span tasks to measure verbal STM / WM in dyslexia (Bogaerts, Szmalec, Hachmann, Page, & Duyck, 2015; Booth et al., 2010; Brosnan et al., 2002; Jeffries & Everatt, 2004; Varvara et al., 2014) in both adult (Smith-Spark et al., 2003) and school age children (Saksida et al., 2016). They have found that dyslexic participants experience a pervasive difficulty in both verbal STM and WM. Due to the hierarchical nature of WM, deficits in verbal WM could be caused by a difficulty in the slave phonological store (STM) or by the CE (WM). Smith-Spark et al. (2003) tried to pull this apart concluding that difficulties likely stem first and foremost from the phonological loop component of the verbal STM store. Deficits in verbal WM then are a result of verbal STM difficulties rather than a CE difficulty.

Other studies have tried to pinpoint the exact nature of the verbal STM deficit in dyslexic participants (Beneventi, Tønnessen, & Ersland, 2009; Cowan et al., 2017; Hachmann et al., 2014; Majerus & Cowan, 2016; Perez, Majerus, Mahot, & Poncelet, 2012; Perez, Majerus, & Poncelet, 2013). They suggest that dyslexic participants experience an underlying deficit in the serial order recall of verbal information rather than item recall. Serial order recall requires participants to recall information in the same order as it was presented, measured often by span tasks. This is opposed item recall, the immediate recall of a stimulus, e.g. hearing a single nonword and then repeating it back immediately. Perez et al. (2012) found that dyslexic participants performed similarly to RA matches but worse than CAs on a verbal item recall (nonwords) STM task. This suggests that performance is impaired but appropriate for reading level. Performance on a verbal span task testing serial order recall however was lower than both the CA and RA group. This suggests that dyslexic participants experience an underlying deficit in the serial order recall of verbal information. Helland and Asbjørnsen (2003; 2004) found that dyslexic participants were able to recall more digits in free recall conditions that those requiring serial order. Together these studies suggest that serial order recall proves most difficult for dyslexic participants. Serial order recall is thought to make greater demands on the articulatory rehearsal process of STM (Majerus & Cowan, 2016).

2.0.2 D-DLD

Just as verbal STM is considered a marker of literacy impairment, verbal WM difficulty had been considered a marker of D-DLD (Montgomery, 2000). Deficits in both verbal STM and WM have been observed in D-DLD participants with studies using span tasks to highlight difficulties in children (Marton & Schwartz, 2003; Montgomery, Magimairaj, & Finney, 2010). Much like dyslexia, research in D- DLD has tried to pinpoint the source of the verbal STM / WM deficit. Gillam, Cowan and Marler (1998) looked at the performance of a D-DLD and CA group (10 years) on forward digit span tasks. The CA group recalled more digits from the ends of lists than the D-DLD group. Serial order recall requires intact rehearsal processes in the phonological loop, and so serial order recall deficits in D-DLD may suggest a phonological loop deficit. Gillam, Cowan and Day (1995) found the participants with D-DLD performed similarly to CA matches in digit span forwards tasks with free recall as opposed to serial recall. They argue that free recall doesn't implicate the phonological loop to the same extent as serial order recall. If D-DLD participants perform similarly to CAs in free recall tasks, then Verbal STM impairment likely stems from problems in verbal rehearsal processes. Results from WM studies paint a slightly different picture. Helland and Asbjørnsen (2004) found that a dyslexic plus D-DLD group were not facilitated by free recall in a verbal WM task but dyslexic participants were. With additional CE / WM demands D-DLD participants still experienced difficulty.

D-DLD participants then may also experience a problem in the CE component of memory that directly contributes to performance on WM tasks. Hoffman and Gillam (2004) assessed D-DLD and CA participants (8-10 years). Participants completed four WM tasks either a digit or location span task with either oral naming of stimuli colour or pointing to stimuli colour. All participants performed better when recall and colour identification were cross modal; i.e. recalling digits verbally but pointing to identify stimuli colour. This cross-modal advantage was less prevalent for the D-DLD group than the CA group in the pointing condition. This highlights a difficulty in allocating attentional resources in D-DLD for which the CE is responsible.

Evidence suggests that D-DLD children experience difficulty in verbal STM span tasks and WM tasks. Some studies suggest that D-DLD groups experience a deficit in verbal STM / WM (Briscoe & Rankin, 2009), scoring lower than both CA and language level matches. Other studies suggest that verbal STM and WM is appropriate for D-DLD groups given their language ability level (Montgomery, 2000). Montgomery (2000) administered a word span task to CA (9 years), D-DLD and a language ability level group (7 years) matched for receptive vocabulary. The word span task was completed under three load conditions. In the no load condition participants immediately recalled word lists (three to seven words in length) in any order. This task tapped verbal STM. Verbal WM was tested via single and dual load conditions which contained storage and processing elements. In the single load condition, words had to be recalled in size order (e.g. ant, dog, house). In the dual load condition words had to be recalled first by semantic category, and then by size within each category (e.g. skateboard, bike, bus, mouse, cat, horse). There were no group differences in the no load and single load conditions. In the dual load condition the CA group recalled more words than the D-DLD group. The D-DLD and language level group performed similarly. This suggests verbal WM ability is appropriate considering the language age of D-DLD participants.

2.0.3 Comparing across disorders

Overlapping difficulties in verbal STM / WM in dyslexia and D-DLD stem predominantly from common difficulties in articulatory rehearsal processes in the phonological loop. Additional difficulty in the CE may also contribute independently to the WM deficits seen in D-DLD. Whereas difficulties are resigned to the phonological loop for dyslexic participants (causing difficulty in verbal WM tasks), they are likely broader in D-DLD, extending to the CE and providing a double deficit in verbal WM. To this extent deficits seen in D-DLD are likely more severe than those seen in dyslexia. Dyslexic groups for instance perform better on verbal memory tasks than RA groups (Palmer, 2000) whereas D-DLD groups perform similarly to language ability groups (Montgomery, 2000). This suggests D-DLD performance is as expected given language age whereas dyslexic performance is higher than that expected given literacy age and closer to CA group performance. Both impairments seem to show larger difficulty in tasks with higher demands. Age and IQ also play a role in the severity of deficits observed in both disorders.

2.0.4 Hypotheses

In line with previous research (Helland & Asbjørnsen, 2004) I predict that the dyslexic and D-DLD group will show a difficulty in the temporary storage (STM) and processing (WM) of verbal information. Both the dyslexic and D-DLD group will recall shorter block lengths on the forwards and backwards digit span tasks than the CA group. In line with previous research, the D-DLD group will experience greater difficulty than the other impaired groups (Cowan et al., 2017; Helland & Asbjørnsen, 2004; Schuchardt et al., 2013). Very little research exists that includes DLD only groups. Strong links exist between literacy difficulty and verbal STM / WM. My DLD group experiences only mild difficulties in text level literacy such as spelling and comprehension (see chapter 2, section 5). The lack of literacy difficulties observed in my DLD group may be as a result of limited verbal STM difficulty. Having said this links also exist between oral language ability and vocabulary acquisition (Baddeley et al., 1998). Oral language difficulties in this group could also be underpinned by difficulties in verbal STM. In sum I cannot predict whether or not my DLD group will score higher or lower than my CA group on the digit span tasks.

In terms of ability level groups, dyslexic participants have been found to perform worse than RA groups on dynamic verbal STM measures (Perez et al., 2012). This suggests dyslexic participants experience a deficit in the serial order recall of verbal information. I predict the dyslexic group will produce lower digit span scores than the RA group. The RA group also provides a good reading age match to the D-DLD group. Both the dyslexic and D-DLD group experience an underlying deficit in phonology subsuming verbal STM, RAN and PA ability (Bishop & Snowling, 2004). Therefore I also predict the D-DLD group will produce lower digit span scores than the RA group reflecting an underlying deficit in verbal STM directly linked to literacy ability. Research comparing D-DLD groups to ability level groups is mixed. D-DLD groups have been found to perform worse than both CA groups and language level matches (Briscoe & Rankin, 2009) suggesting a deficit in verbal STM / WM However they have also been found to perform worse than CA groups but similarly to language level matches (Montgomery, 2000) suggesting a delay in verbal STM / WM. Again to the best of my knowledge no studies have compared purely language impaired (DLD) groups to language ability matches. I do not know whether or not the D-DLD and DLD groups will score higher or lower than their respective ability matched groups on the digit span tasks.

2.1 Method

I will now outline the participants, design and procedure for the digit span task forwards and backwards. These tasks were completed at T1 for the impaired and CA groups.

2.1.1 Participants

Of the 148 participants who completed measures for the thesis (outlined in chapter two, section 2), 144 took part in the verbal and nonverbal STM and WM tasks. Data were missing from two participants in the D-DLD group and one participant in the dyslexic group. Their subsequent

LA/D-DLD and RA matches were also removed from analysis. This left 28 dyslexic, 10 DLD, 26 D-DLD, 23 CA, 28 RA, 10 LA/DLD and 26 LA/D-DLD.

1.1.2 Design and procedure

For digit span task participants listened to a sequence of numbers presented aurally over headphones before repeating them in order (verbal STM) or reverse order (verbal WM). Number stimuli were a female voice normalised using Audacity Software. Forward and backward digit sequences were taken from the British Abilities Scale for children: Third Edition (BAS-III – Elliot & Smith, 2011). Digits were presented at a rate of one per second in line with the manual. Trials in the first block were two in length, the second three in length and so on. The longest block was eight numbers long. Each block contained five sequences apart from the seventh block which contained four and the eighth block which contained two. Before beginning experimental trials participants completed two trials of two digits in length. I used Opensesame version 2.8.0 to design and present the digits on a Toshiba Satellite Pro – C50 laptop. Participants received no feedback throughout the task. Digit span scores were calculated for each participant. To pass a block, and continue with the task, participants had to successfully recall two or more trials in a block. Digit span therefore equated to the highest block in which a participant passed two or more trials. Trials passed scores were also calculated for each participant; the sum of correct trails within blocks passed. I considered this a more sensitive measure of performance[7].

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[7] Other papers using span tasks have calculated scores that take in to account longest span length and total trials passed (see Kessels et al., 2000). It is possible for two participants to achieve the same span length (e.g. 5) but for one participant to score high on the trials passed measure (e.g. 21) and for the other to score low (e.g. 9). This is because participants only need to pass two trials out of five per block to pass it. Where one participant may correctly recall every trial in a block, another may only the recall the minimum to pass. Recalling every trial in a block makes greater demands of EF resources. For example inhibition,; participants have to ignore interference from a higher number of trials previously recalled correctly.

2.2 Results and discussion

Figure 4 shows the group means for forward and backward digit span tasks for the dependent variables block span and trials passed. The nature of the dependent variable had little impact on effects, therefore I present inferential statistics for span lengths and highlight differences in trials passed scores in footnotes. I applied a Bonferroni corrected criterion of $p < 0.0167$ to planned contrasts as per chapter two.

2.2.1 Verbal Short Term Memory: Digit span

Group differences in digit span were confirmed $F(3,83) = 7.13$, $p < .01$, r = 0.51. Planned contrasts confirmed that, as expected, the CA group achieved larger digit span scores than both the dyslexic group $t(83) = 3.90$, $p < .01$, $d = 1.12$ and the D-DLD group $t(83) = 4.18$, $p < .01$, $d = 1.11$. The DLD group performed similarly to the CA group, $t(83) = 1.83$, $p = .07$, $d = 0.73$. Verbal STM is inherently linked to literacy impairment and reading related skills. Our DLD group show difficulty in spelling, reading comprehension and PA. Their difficulties in these areas may not have been sufficient to cause a verbal STM deficit. It is also unlikely that their difficulties in oral language are underpinned by verbal STM difficulty. The impaired groups all performed similarly: dyslexic vs. D-DLD, $t(83) = -0.36$, $p = .72$, $d = 0.10$, DLD vs. D-DLD, $t(83) = -1.36$, $p = .18$, $d = 0.53$, dyslexic vs. DLD, $t(83) = 1.17$, $p = .27$, $d = 0.48$ as expected. This suggests the DLD group do produce low scores for verbal STM but not enough to differ from the CA group. This could parallel their minor literacy and reading related difficulties, see Figure 4.

Independent samples t-tests confirmed that the RA group achieved higher span scores than the dyslexic group as predicted, $t(54) = -2.87$, $p <.01$, $d = 0.78$ and the D-DLD group[8], $t(52) = -2.89$, $p < .01$, $d = 0.79$. This suggests that dyslexic and D-DLD groups experience a common underlying deficit

[8] Contrast for RA vs. D-DLD group for trails past was not significant, digits forward, $t(52) = -1.82$, $p = .08$, $d = 0.50$.

in STM that is inherently linked to their literacy ability. The DLD and D-DLD groups did not differ from their language ability matches; DLD vs. LA/DLD, $t(18) = -0.74$, $p = .47$, $d = 0.33$, D-DLD vs. LA/D-DLD, $t(50) = -0.17$, $p = .87$, $d = 0.05$, see Figure 4.

2.2.2 Verbal WM

A similar pattern of results was observed for impaired and CA groups for both digit span forward and backward tasks. Group differences were confirmed $F(3,83) = 9.79$, $p < .01$, r = 0.59. Planned contrasts confirmed that, as expected the CA group scored higher than both the dyslexic group, $t(83) = 4.31$, $p < .01$, $d = 1.32$ and the D-DLD group, $t(83) = 4.90$, $p < .01$, $d = 1.37$. Again the DLD group performed similarly to the CA group, $t(83) = 1.34$, $p = .18$, $d = 0.57$ which could reflect their proficiency in literacy. Unexpectedly, all impaired groups performed similarly; dyslexic vs. D-DLD, $t(83) = -0.69$, $p = .49$, $d = 0.17$, dyslexic vs. DLD, $t(83) = 1.91$, $p = .06$, $d = 0.75$, DLD vs. D-DLD, $t(83) = -2.40$, $p = .019$, $d = 0.86$, although this latter comparison tended towards significance, with the DLD group performing better than the D-DLD group. However this did not reach the Bonferroni adjusted criterion of $p < .0167$. We expected the D-DLD group to show greatest difficulty in the verbal WM task as evidence of a double deficit in verbal STM and the CE more generally. This was not the case however. The difference between the DLD and other impaired groups did tend towards significance which could evidence of proficient EF / CE skills, see Figure 4.

The impaired groups all performed similarly to their ability level groups; RA vs. dyslexic , $t(54) = -0.44$, $p = .66$, $d = 0.12$, RA vs. D-DLD, $t(52) = -1.03$, $p = .31$, $d = 0.28$, LA/DLD vs. DLD, $t(18) = 1.64$, $p = .12$, $d = 0.73$, LA/D-DLD vs. D-DLD, $t(50) = -0.97$, $p = .36$, $d = 0.26$, see Figure 4. This was not expected for reading ability level comparisons.

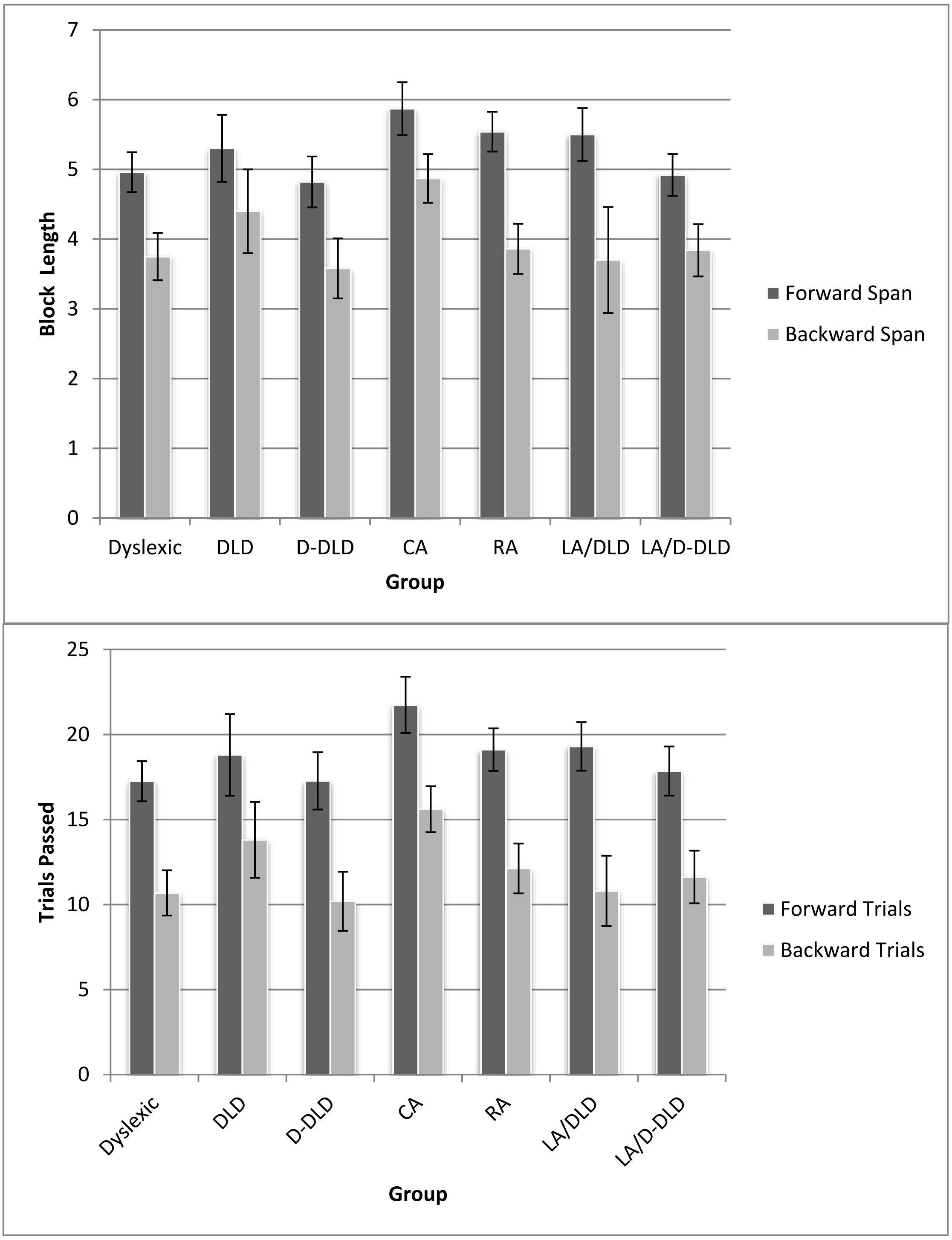

Figure 4: Group means for digit span scores, largest span and trials passed both forwards and backwards with confidence intervals (95%) in error bars.

3. Experiment 2: Nonverbal short-term memory and WM.

It is less clear whether both literacy and language impaired groups experience a difficulty in nonverbal STM / WM. Research from studies including dyslexic groups have presented mixed results. Whilst some studies reveal no difference between dyslexic and CA groups (Gould & Glencross, 1990; Liberman et al., 1982; Palmer, 2000) others have shown differences (Cowan et al., 2017; Helland & Asbjørnsen, 2003). Other studies have suggested that where differences do arise for dyslexic groups, this is only for complex tasks or tasks in which researchers have performed very detailed item analysis (Kibby et al., 2015; Smith-Spark & Fisk, 2007; Smith-Spark et al., 2003; Swanson et al., 2009). For language impaired groups, studies seem to predict a nonverbal difficulty more of the time than they do for dyslexia (Cowan et al., 2017; Helland & Asbjørnsen, 2003; Vugs et al., 2014). However, studies comparing across groups have also suggested that literacy and language impaired groups perform similarly to CA groups (Everatt et al., 2008; Schuchardt et al., 2013). It is possible that a certain threshold of difficulty is necessary to highlight nonverbal impairment in both groups but that this threshold is lower for language impaired groups who experience multiple difficulties.

3.0.1 Dyslexia

Nonverbal memory and processing may be an area of relative strength for dyslexic groups. Garcia, Mammarella, Tripodi and Cornoldi (2014) worked with a group of dyslexic children and a CA group (8 years). They administered dynamic STM (Corsi-blocks and colour span forwards) and WM span tasks (backwards). The dyslexic group performed similarly to the CA group. Palmer (2000) administered two image span tasks to a dyslexic, RA and CA group. One task used images that had phonologically similar names. The other used images that were visually similar. Visual and phonological similarity effects were calculated; a measure of performance drop off as stimuli becomes similar. The dyslexic group had a higher visual similarity effect than the RA and CA groups. Similar phonological similarity effects were observed across groups. Palmer (2000) suggests that dyslexic participants are relying heavily on visual techniques to be successful at the images span task, as opposed to recoding the images by their phonological name and storing the sequence list. The ability to utilise visual techniques is hampered when stimuli is visually similar.

Certain factors are likely to highlight difficulties in nonverbal memory more often for dyslexic groups (Cowan et al., 2017; Hachmann et al., 2014; Swanson et al., 2009). For example, where studies have found deficits, these are usually restricted to dynamic tasks that require the serial order recall of information rather than static or item tasks (Cowan et al., 2017; Varvara et al., 2014; Wang & Gathercole, 2013). Difficulties are also only likely to arise when the task demands are sufficiently high. Older compensated groups such as University students or those with high NVIQs are also less likely to exhibit nonverbal difficulties (Smith-Spark & Fisk, 2007; Smith-Spark et al., 2003).

2.0.2 D-DLD

Several studies suggest that memory difficulty in D-DLD groups extend beyond the verbal domain to the visual domain (Bavin et al., 2005; Henry et al., 2012; Hick et al., 2005a, 2005b; Vugs et al., 2014). However some studies have failed to find to nonverbal difficulties (Briscoe and Rankin 2009; Lukács et al., 2016).

Vugs et al. (2013) completed a meta-analysis of studies assessing nonverbal STM in D-DLD participants compared to CAs. They looked at 21 studies which included 32 nonverbal STM tasks. A moderate effect size was found for nonverbal STM difficulty (0.49) suggesting a deficit for D-DLD individuals. They also found that more severe nonverbal STM difficulty was associated with more severe D-DLD. They also looked at nine studies involving nonverbal WM measures. A larger effect size was found for nonverbal WM (0.63) tasks, suggesting a deficit for D-DLD individuals. This suggests that D-DLD experience more difficulty in nonverbal WM tasks than nonverbal STM tasks.

Nonverbal STM tasks require additional EFs to maintain attention (Baddeley & Hitch, 1974; Marton, 2008). It could be that D-DLD participants only experience a difficulty in nonverbal STM tasks to the extent that they require EF processes to maintain attention on target. Less demanding nonverbal STM tasks may not incur a deficit and may explain the mixed results in the literature. To this extent a difficulty in nonverbal STM for D-DLD participants then would not be inherent to the nonverbal STM store itself but arise as a consequence of limited EF resources. Studies have supported this to some degree. Marton (2008) for example found that a D-DLD group performed similarly to a CA group on nonverbal STM measures (when controlling for NVIQ) but scored lower for nonverbal WM measures. WM measures involve a larger amount of executive and attentional processes.

Deficits seen in nonverbal STM and WM for D-DLD groups could in fact have verbal origins. Gillam et al. (1998) suggest that D-DLD groups make use of verbal strategies when completing tasks with visually presented items. They found that D-DLD participants performed poorly compared to a CA group in digit span task with visually presented numbers. They argue that D-DLD participants have a difficulty in recoding and rehearsing visual items; more specifically, recoding the visual presentation of digits to an acoustic code for verbal STM rehearsal. They then struggle to recode information back to visual representations for matching to visual response keys on a screen. The process relies on verbal STM which we know to be impaired already in D-DLD. To this extent then nonverbal difficulties could in fact stem from verbal difficulties rather than standalone deficits. Having said this, the whole process requires participants to perform several complex mental operations and convert visual information into phonological codes. It requires additional WM processes and the use of the CE. There is a strong argument that these processes are also impaired in D-DLD participants which could equally lead to difficulty on the task.

Few studies have chosen to include ability level matches in their design. To the best of my knowledge this study is the first to combine both dyslexic, D-DLD and ability level groups in one study. In a second study Archibald and Gathercole (2006b) included similar nonverbal tasks but compared children with D-DLD to both CAs and younger language level matches. They assessed nonverbal STM and WM. The D-DLD group (9 years) performed similarly to the CA group and better than the language level group. This would suggest that nonverbal ability is age appropriate in D-DLD.

2.0.3 Comparing across disorders

Nonverbal STM seems to be an area of relative strength for dyslexic participants with studies not revealing a deficit (Gould & Glencross, 1990; Liberman et al., 1982; Palmer, 2000). Studies also suggest that dyslexic groups do not experience a difficulty in nonverbal WM unless tasks are particularly complex or analysis is particularly detailed (Smith-Spark et al., 2003). Having said this, some studies have revealed difficulties in nonverbal WM tasks such as the Corsi-blocks task utilised in this study (Vavara et al., 2014).

The evidence surrounding D-DLD is less clear but difficulties have been found in nonverbal STM (Vugs et al., 2014) and nonverbal WM (Henry et al., 2012). Clearer evidence exists for nonverbal deficits in older participants, with more severe language difficulties, when demanding tasks are used. Participants with low NVIQ also seem to experience greater difficulty (Cowan et al., 2017). Results from a meta-analysis (Vugs et al., 2013) suggest that both verbal STM and WM deficits are present in D-DLD groups. Several studies have failed to find both nonverbal STM and WM deficits in D-DLD groups (Archibald & Gathercole, 2006b; Briscoe & Rankin, 2009) whereas other studies have found difficulties only in WM tasks but not STM tasks (Marton, 2008). It could be that rather than a nonverbal storage deficit, participants with D-DLD only experience a difficulty in domain general EF and WM processes. Nonverbal STM tasks utilise EF processes more heavily than verbal tasks (Baddeley & Hitch, 1974). Therefore nonverbal difficulties may only arise when STM and WM tasks are particularly taxing on EF processes.

2.0.4 Hypotheses

I predict that the dyslexic group will perform similarly to the CA group on the Corsi-blocks forwards task (Gould & Glencross, 1990). Due to the relative simplicity of the task, I also predict that the D-DLD group will perform similarly to the CA group, due to limited EF involvement (Marton, 2008). I predict that EF is an area of relative strength for DLD groups and therefore I predict that the DLD group will also perform similarly to the CA group. If differences do occur between groups then the D-DLD group will likely experience the most difficulty and the DLD group the least, however I predict largely that impaired groups will show no impairment and equal performance.

I predict a similar pattern of results for the WM task assessed by the Corsi-blocks task backwards. I predict that the D-DLD group will score lower than the CA group (Henry et al., 2012). This will be due to increased EF and WM demands in the task. The D-DLD group will score lower than either of the other impaired groups.

For ability matches, I predict that the dyslexic groups score higher than their ability level group (RA) on both tasks as will the DLD (LA/DLD) group (Palmer, 2000) due to their lack of impairment and older age. If the D-DLD group do experience a difficulty on either the STM or WM task then I predict they will score similarly to their ability level matches (RA and LA/D-DLD). If they do not experience a difficulty then they will score higher (Archibald & Gathercole, 2006b).

3.1 Method

I now outline the participants, design and procedure for the Corsi-blocks task forwards and backwards. These tasks were completed at T1 for the impaired and CA groups. The ability level groups completed all experimental measures at one time point.

3.1.1 Participants

Participants were identical to those in Experiment One for Corsi backwards. One additional dyslexic participant and their ability match was included for the Corsi forwards task only (29 dyslexic, 10 DLD, 26 D-DLD, 23 CA, 29 RA, 10 LA/DLD and 26 LA/D-DLD).

3.1.2 Design and procedure

In the Corsi-blocks task, participants were presented with an array of nine blank squares on a white screen. These turned black one after another to form a sequence. Participants were then asked to recall the sequence either forwards, assessing STM, or backwards assessing WM. Participants indicated the sequence order by tapping a blank array of the blocks on screen. Block positions and sequence orders were replicated from Kessels, Van Zandvoort, Postma, Kappelle and De Haan (2000) for forwards spans and Kessels et al. (2008) for backwards spans. Dimensions, positions and distances between blocks were also replicated and scaled to fit on a Tesco Hudl 1 tablet. The tablet had a screen size of seven inches diagonally.

Each block sequence length was presented twice, and participants were required to pass one or more out of the two trials at each length to pass the block. Sequences started at two blocks in length and continued until nine blocks in length. Taps were recorded as correct or incorrect by the tablet. To score correctly, the participant had to touch the screen within the square. The task automatically discontinued if participants failed both trials at a block length. Participants were only to tap out sequences once and if an incorrect tap was registered within a sequence the whole sequence was automatically scored as incorrect. The task was designed and built using Opensesame version 2.8.0 with an android back-end. The task was then administered on a Tesco HUDL tablet.

Two scores were computed, a block span score and trials passed to parallel the scores obtained from the digit span task. This was after considering the procedure used by Kessel et al., (2008) in which they calculate a product score combining trials passed and span length.

3.2 Results

Figure 5 shows the group means for forward and backward Corsi-blocks tasks for the dependent variables block span and trials passed. The nature of the dependent variable had little impact on effects, therefore I present inferential statistics for span lengths and highlight differences in trials passed scores in footnotes, as above, using the same Bonferroni corrected criterion.

3.2.1 Nonverbal Short Term Memory: Block Span

Scores confirmed no differences between the groups, $F(3,84) = 2.39$, $p = .08$, r = 0.29[9], see Figure 5. Planned contrasts also confirmed no differences when multiple comparisons were taken in to account as expected. The impaired groups all performed similarly to their ability level groups: dyslexic vs. RA, $t(53.52) = 2.39$, $p = .04$, $d = 0.63$, D-DLD vs. RA, $t(53) = 0.46$, $p = .65$, $d = 0.12$; LA/DLD vs. DLD group, $t(18) = -0.76$, $p = .50$, $d = 0.35$, LA/D-DLD vs. D-DLD, $t(50) = 1.49$, $p = .14$, $d = 0.41$. This was not expected and I am unsure why this null result occurred. We expected older groups, if they experienced no difficulty, to outperform younger groups. Span measures may not be sensitive enough to reveal group differences. However I also included trials passed scores as a more sensitive measure to address this. See footnote 9.

3.2.2 Nonverbal WM: Block span

Scores revealed no group differences F(3, 83) = 1.68, $p = .18$, r = 0.25[10]. Planned contrasts confirmed this. This was not expected as I predicted the D-DLD group would experience a difficulty relative to all groups. However the EF demands of the task may not have been sufficient enough to reveal a group difference[10].The impaired groups all performed similarly to their ability level matches: dyslexic vs. RA, $t(54) = 2.04$, $p = .05$, $d = 0.55$, D-DLD vs. RA, $t(52) = 0.37$, $p = .71$, $d = 0.10$, DLD vs.

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[9] Unexpectedly trials passed scores revealed a group difference, F(3, 84) = 3.11, $p < .05$, r = 0.33 with planned contrasts revealing the CA group scored higher than the D-DLD group, $t(84) = 2.77$, $p < .01$, $d = 0.77$. T-tests also confirmed that the dyslexic group scored lower than the RA group, $t(56) = 2.62$, $p < .01$, $d = 0.69$. Trials passed scores require a greater degree of EF which is developmentally sensitive. These results highlight the proposed CE deficit in the D-DLD group.

[10] Interestingly, as expected trials passed scores revealed group differences, F(3, 83) = 2.8, $p < .05$, r = 0.32 with planned contrasts confirming that the D-DLD group scored lower than the CA group, $t(83) = 2.84$, $p < .01$, d = 0.83). Again trials passed scores require a greater degree of EF and this has revealed group differences.

LA/DLD, ($t(18) = 0.50$, $p = .63$, $d = 0.22$, D-DLD vs. LA/D-DLD, $t(50) = 0.93$, $p = .36$, $d = 0.26$. Again this was not expected and I am not sure why these null results occurred. See Figure 5.

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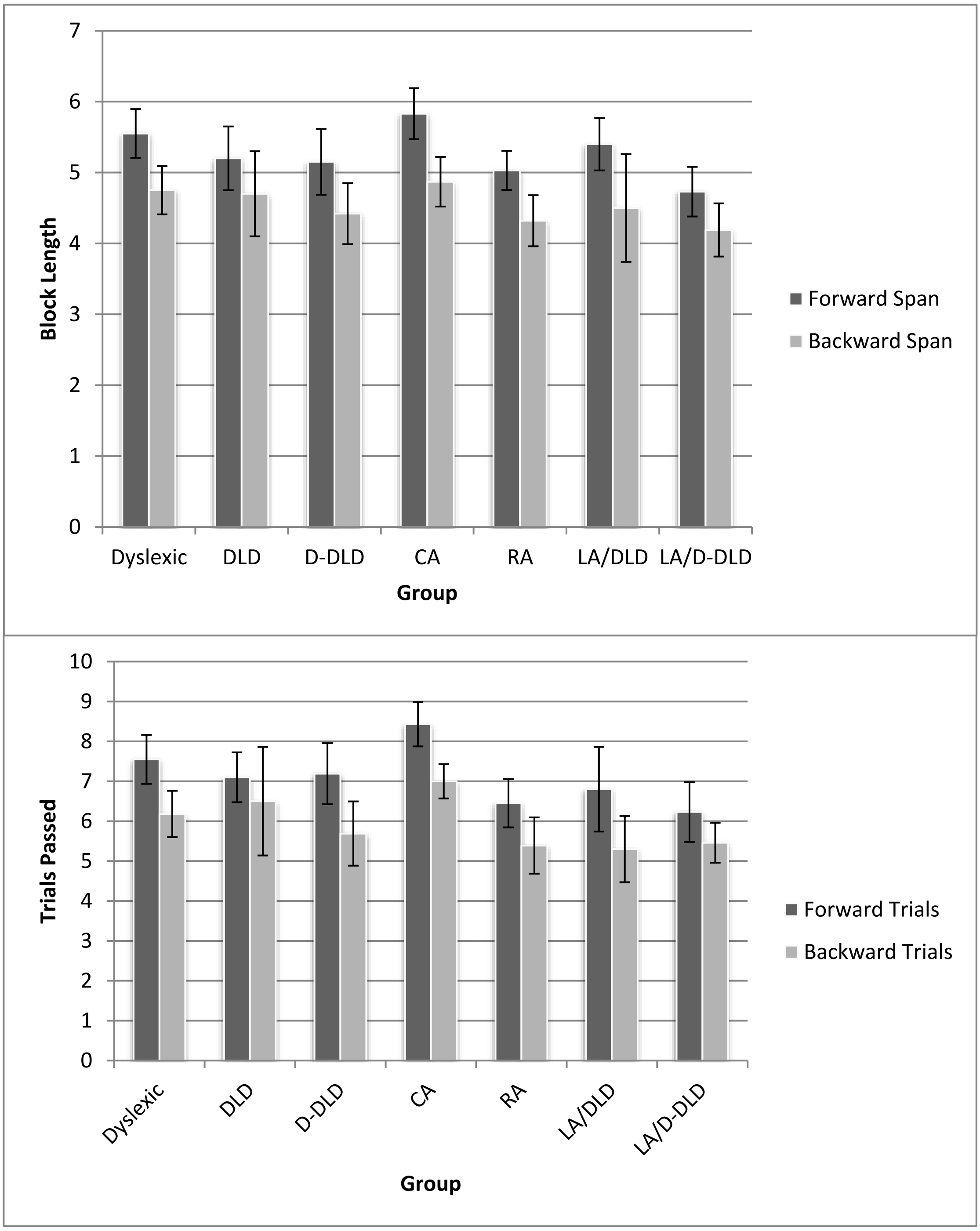


Figure 5: Mean group scores for Corsi-blocks for largest span length and trials passed forwards and backwards with confidence intervals (95%) in error bars.

4. Discussion

4.1 Summary of key findings

The group with dyslexia showed impairment compared to CAs in verbal STM and verbal WM supporting a wealth of previous literature in the area (Bogaerts et al., 2015; Booth et al., 2010; Brosnan et al., 2002; Jeffries & Everatt, 2004; Varvara et al., 2014). The dyslexic and D-DLD groups showed a similar level of impairment in both verbal STM and WM. The dyslexic group scored lower than the RA group for verbal STM but similarly for verbal WM. This suggests that dyslexic participants have a deficit in verbal STM that is causally related to their literacy difficulty. Performance on verbal WM tasks however is literacy level appropriate. The dyslexic group showed normal nonverbal STM and WM span again substantiating previous research (Garcia et al., 2014; Palmer 2000) and suggesting nonverbal STM/WM is an area of relative strength for dyslexic groups.

The D-DLD group showed impairments on verbal STM and WM again supporting a large body of literature with similar results (Marton & Schwartz, 2003; Montgomery et al., 2010). For verbal STM, the D-DLD group scored lower than the RA group matched for literacy level but similarly to the LA/D-DLD group matched for language ability. This suggests that their verbal STM ability is language age appropriate but lower than that expected given their literacy level. This suggest that their deficits in language are more severe than their deficits in literacy and fits with the theory that language is the primary deficit in D-DLD, paving the way for literacy deficits later (Snowling, Bishop & Stothard, 2000). At the same time however, the D-DLD group experience a deficit in verbal STM that is likely linked to their literacy difficulty. For verbal WM, the D-DLD group scored similarly to both the RA and LA/D-DLD groups suggesting verbal WM is appropriate given literacy and language age. The D-DLD group showed impairment in nonverbal STM and WM (trials passed only) in comparison to CAs. This fits with the theory that D-DLD groups experience a difficulty predominantly in EF and not in the nonverbal store itself. Only nonverbal STM and WM tasks that sufficiently tap executive resources will reveal deficits in D-DLD groups. Block span scores measure different skills to trials passed measures. To score highly in block span, a participant only needs to pass one out of two trials for several blocks. However, to score highly in trials passed, a participant must consistently score two out of two trials correct in a block. This undoubtedly puts greater pressure on executive resources as WM attempts to prevent greater interference from stored trials. A greater capacity is needed in addition to greater updating skills to refresh the store in time for new information. These pressures are reduced in block span scores. The CA group is better at storing more information correctly overtime and have better resources to facilitate this than the D-DLD group.

The DLD group did not show a difficulty in any of the verbal or nonverbal STM or WM tasks. This suggests that verbal and nonverbal STM and WM are all areas of relative strength for the DLD group. Having said this, they did performed similarly to the D-DLD and dyslexic groups (who were impaired) for verbal tasks. The DLD group did not show difficulty on nonverbal STM / WM compared to controls. The difference between the DLD group and the other impaired groups tended toward significance for nonverbal WM. This supports the theory that the DLD group have advanced CE skills that may be helping prevent the development of a literacy difficulty.

All of the ability level groups performed similarly to their impaired groups for nonverbal STM and WM who in turn performed similarly to CA groups (with the exception of the D-DLD group for trials passed measures only). This suggests, tentatively that the ability level groups scored similarly also to CA groups (although this wasn't tested). It could be then that then, that the Corsi-blocks tasks, both forwards and backwards were relatively insensitive to developmental variation in this age group. For the nonverbal task participants only completed two trials per block. This was in contrast to five trials per block for the digit span task. A greater number of trials may have revealed more differences between groups requiring greater EF resources.

4.2 Limitations

After piloting the nonverbal touch screen task with several participants, it became clear that it was possible to perform poorly by simply not completely the task carefully enough. Participants had to carefully watch a block sequence before tapping it out on a screen. To register a correct tap participants had to tap within the block itself. Sometimes participants tapped around the block or on the line and not within it. On occasion participants mapped out the correct sequence but this was not registered as correct due to inaccuracies in tapping. One tap in a sequence outside the square would result in the whole trial being scored incorrect. Hence, scores may be an underestimate of true ability, particularly for individuals with poor motor control.

A second limitation in comparing the measures is that the trials passed measure for verbal STM and WM is more sensitive than the trials passed for nonverbal STM and WM. There are five trials in a verbal task block vs. two trials in a nonverbal task block. Potential differences in the nonverbal tasks are not highlighted as clearly by the trails measure as they are for the verbal task. It is likely that greater differences in nonverbal ability may have been highlighted for groups if blocks had of comprised of more trials.

4.3 Conclusions

It seems that both the D-DLD and dyslexic group share a deficit in verbal STM that is responsible for literacy difficulties experienced. The DLD group do not show a difficulty in verbal STM that likely helps buffer them against developing a literacy difficulty. D-DLD groups experience additional difficulty in the CE impairing them on nonverbal tasks requiring EF.

4.4 Thesis Map

At the end of each experimental chapter I include a thesis map to summarise my main findings in relation to the WM model (Baddeley 2000). This map builds with each chapter giving overview of the difficulties experienced at each stage of the model by my impaired groups. Figure 6 gives an overview of the pattern of verbal and nonverbal STM / WM difficulty in my impaired groups.

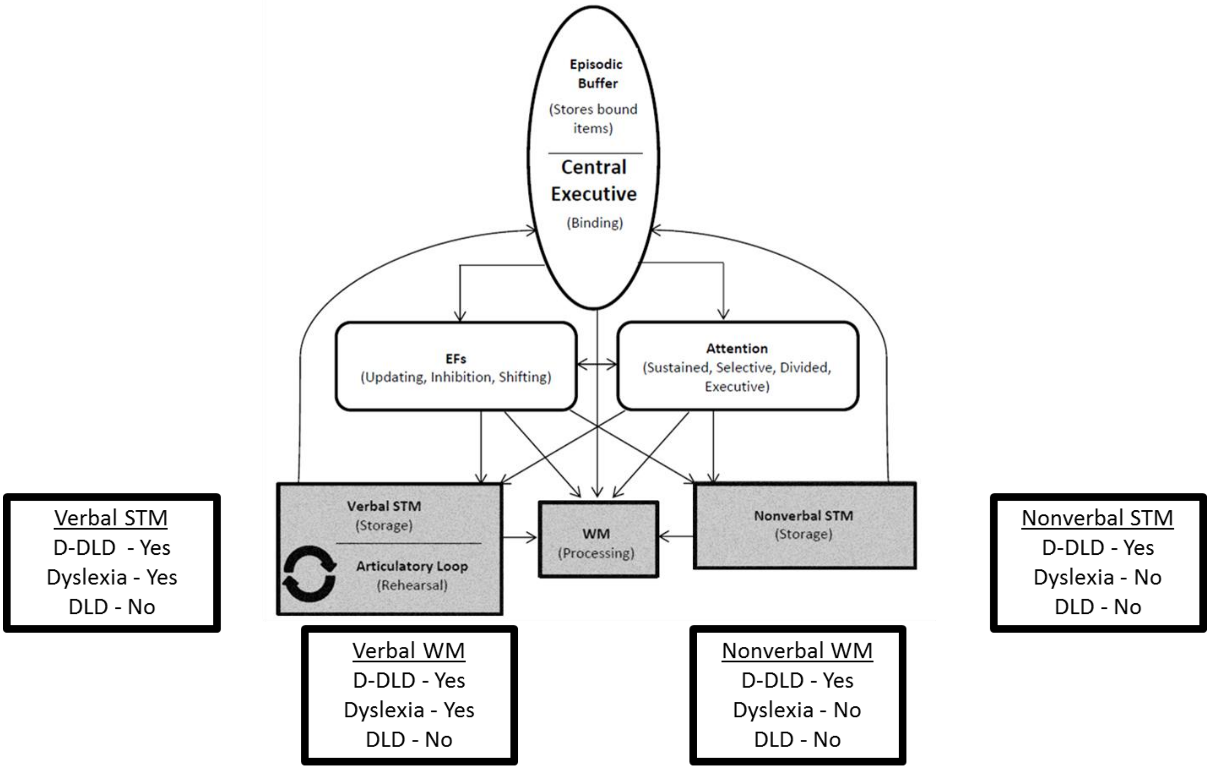


Figure 6: Summary of difficulty (Yes / No) for each group in STM and WM tasks.

Chapter 4 – Verbal and nonverbal updating and inhibition

1. General Introduction

In this chapter verbal and nonverbal EF is addressed, in particular inhibition and updating of WM. In their seminal paper, Miyake et al. (2000) noted three main processes common to most goal directed tasks. These included updating, inhibition and shifting of attention (the latter of which is discussed in chapters five and six).

Updating concerns the specific mechanism responsible for refreshing WM and changing its contents. When information in WM is no longer relevant it can be discarded and replaced with new more relevant information for the task at hand. The mechanism responsible for monitoring and refreshing the contents of WM is the EF of updating. It allows information to be re-ordered and new information to be incorporated (Im-Bolter et al., 2006). By their very nature, WM tasks necessarily involve an updating element. The challenge is to pinpoint a task that can extract the variance in performance due specifically to updating ability rather than capacity or processing speed of WM more generally. Only a handful of papers have examined verbal and nonverbal updating simultaneously in dyslexic and D-DLD groups.

Inhibition refers to the ability to ignore irrelevant information. It occurs at multiple levels, neurological, cognitive and behavioural. At the behavioural level it requires effortful control and is therefore considered an ‘intended’ response (Miyake et al., 2000). It is most commonly divided in to prepotent response inhibition (inhibition for dominant internal responses), distractor inhibition (inhibition for external conflicting stimuli) and proactive interference (inhibition for previously learned information).

For impaired groups, a larger body of research exists focusing on verbal and nonverbal STM / WM than verbal and nonverbal inhibition / updating. Despite this, some studies have considered these EFs simultaneously. I begin by outlining studies looking at dyslexic or D-DLD / DLD groups specifically in terms of updating and inhibition. We then outline studies that have compared across multiple EFs and then multiple groups. I then present two experiments. The first examines verbal and nonverbal updating and the latter examines verbal and nonverbal inhibition.

1.0.1 Dyslexia

1.0.1.1 Updating

Overall, studies suggest that dyslexic participants experience difficulty in verbal tasks, but only in nonverbal tasks when EF demands are high or analysis is detailed at the trial level (Smith-Spark et al., 2003).

Dyslexic participants only experience a disadvantage in nonverbal updating tasks when tasks can be facilitated by verbal strategy. Göthe, Esser, Gendt and Kliegl (2012) administered verbal and spatial updating tasks to dyslexic children (8 years) and CAs. For spatial updating, participants viewed coloured animals on a grid. Participants were required to mentally move target animals around the grid in line with instructions. Each trial could include up to four updating operations. At the end participants indicated where in the grid the target animal would be. In the verbal task, participants viewed a fruit basket. They added or subtracted fruit in line with the updating instructions. They then indicated the total number of target fruit. Göthe et al. (2012) argue that these updating operations make heavy use of the phonological loop to store number and fruit labels and to perform the mental operations of addition and subtraction. However, the dyslexic group showed lower performance on the updating task with both verbal and nonverbal stimuli. This unexpected difficulty in the nonverbal task may have been a result of confounds. For example, participants who labelled animal pictures might have been advantaged by using a verbal strategy.

Similarly, dyslexic participants may only experience a difficulty in nonverbal tasks when executive demands are particularly high or detailed analysis at the trial level has highlighted group differences. Smith-Spark et al. (2003) assessed both verbal and nonverbal updating as part of a wider WM study in dyslexic and CA groups (20 – 25 years). In a verbal letter updating task, participants had to listen to lists of letters of unknown lengths. They were then required to repeat back the last six letters. Overall, dyslexic participants performed worse than the CA group. In the nonverbal updating task, squares were highlighted sequentially on a grid. Participants were required to recall the position of the last four highlighted squares in order. The number of updates required varied from zero to six. Overall there were no differences between the dyslexic and CA group. However, dyslexic participants did perform more poorly when the maximum number of updates were required (i.e., six). Dyslexic participants had greater accuracy for locations at the end of the series to be recalled, than at the beginning. Smith-Spark et al. (2003) suggest this reflects a more general capacity or executive processing limitation in dyslexic participants.

Smith-Spark and Fisk (2007) attempted to replicate these findings in a later paper. Whilst findings for verbal updating remained the same, nonverbal updating produced less conclusive results; overall the dyslexic group performed similarly to the CA group and this persisted even at longer sequence lengths. This suggests nonverbal deficits are not clear for dyslexic groups.

Overall then, whilst dyslexic participants show a pervasive difficulty in verbal updating (Smith-Spark et al., 2003), difficulty with nonverbal updating is limited. Nonverbal deficits are only highlighted when task demands are high or verbal strategy can be employed.

1.0.1.2 Inhibition

Links have been made between inhibition and literacy generally (Friedman & Miyake, 2004), and inhibition and dyslexia specifically (Chiappe, Siegal, & Hasher, 2000).

Difficulties may arise according to the type of inhibition required. Dyslexia has been linked with poor prepotent response inhibition and resistance to distractor information (Brosnan et al., 2002; Chiappe et al., 2000; Reiter et al., 2004). Distractor inhibition embodies additional attentional processes. In distractor inhibition tasks, participants have to complete a task whilst also ignoring competing elements that might make the task difficult. An example would be a group embedded figures task. In these tasks participants have to search for a figure (a kite for example) in a complex array of other distractor images that closely resemble the target. The distractor images are highly similar and often overlap with the target making it difficult to orientate attention immediately to the target image. Participants must employ selective attention processes to correctly search the stimulus area and discern the target shape from the other distractors. They must also sustain their attention over time as they visually search the target area and check each distractor image. Wang, Tsai and Yang (2012) compared the performance of children (11 years) with dyslexia to a CA group. They administered three verbal and one nonverbal tasks assessing distractor inhibition. The dyslexic group performed worse than the CA group on two out of three verbal measures but also on the nonverbal measure.

Dyslexic participants may only experience difficulty in inhibition tasks in which they cannot employ alternative nonverbal strategies. In a second pair of tasks, Wang et al. (2012) assessed prepotent response inhibition. They administered a verbal Stroop task in which participants had to name the colour of the ink whilst ignoring the automatic response of reading the colour word. In a verbal quantity task, participants had to name the number of digits displayed on a screen and ignore the content (i.e. “444” = three not four). Dyslexic participants scored lower than the CA group for the Stroop task but not the quantity inhibition task. For the quantity inhibition task, participants may be making use of spatial strategies. This latter task arguably carries fewer conflicting demands than the Stroop task in which participants have to name a colour but also prevent themselves naming a colour simultaneously. There is a closer conflict of responses for the Stroop task than the task in which digit names are inhibited for size estimations.

In summary, dyslexic participants seem to experience difficulty in both prepotent response and distractor inhibition regardless of modality. Task complexity seems to be the biggest factor in determining whether or not dyslexic participants experience a difficulty.

1.0.1.3 Multiple EFs

Often, papers will administer either inhibition or updating tasks as a part of larger test batteries. Whilst this is relatively common for inhibition measures, it is less common for updating measures to be included simultaneously. This is surprising given the link between inhibition, updating and WM (Miyake et al., 2000). Research that has included updating and inhibition tasks in the same group seem to suggest multiple deficits for verbal measures. Lee Swanson et al. (2006) worked with four groups: dyslexic (typical - verbal IQ, low - word reading and reading comprehension), poor readers (low - IQ, wording reading, comprehension), PCs (typical - IQ, word reading, low - comprehension) and a CA group (13 years). Participants completed measures assessing verbal updating and prepotent response inhibition. For inhibition, participants completed random number and letter generation tasks. Random generation tasks assess inhibition as participants have to first generate stimuli in order ‘1, 2, 3, 4’ before then randomly generating them, avoiding this. For updating participants completed a running memory task, recalling the last four digits in a sequence of unknown length. For both inhibition and updating, the CA group scored higher than all three impaired groups, who all performed similarly to each other. This suggests that dyslexic groups do experience a difficulty in verbal inhibition and updating simultaneously.

1.0.2 D-DLD

1.0.2.1 Updating

Research looking at updating ability specifically in D-DLD groups is not well developed. Whilst many studies have considered WM in language impairment, only a few have chosen to concentrate on the updating component of WM specifically. To the best of my knowledge no study has compared both verbal and nonverbal updating processes in isolation in D-DLD groups. Instead, some research has focused on administering larger batteries of EF tasks (including inhibition and updating) for D-DLD groups with verbal and nonverbal demands (see section 1.0.2.3).

1.0.2.2 Inhibition

Greater attention has been paid to inhibition than updating tasks in D-DLD groups. Inhibition deficits in D-DLD groups span a wider range than those seen in dyslexic groups. In a recent review Marton, Eichorn, Campanelli and Zakarias (2016) assessed a variety of different types of verbal and nonverbal inhibition assessed by a variety of different paradigms. They found a wide range of difficulty covering distractor, prepotent and proactive inhibition.

Possibly the most robust deficits for D-DLD groups are found in verbal and nonverbal distractor, followed by prepotent response inhibition tasks. Spaulding (2010) found that children with D-DLD (4 – 6 years) were impaired in both verbal and nonverbal stop-signal tasks assessing prepotent response inhibition. D-DLD participants performed poorly compared to a CA group. Scores correlated highly with individual language scores. For proactive interference, Henry et al. (2012) found that D-DLD children and a group of low language functioning children, were impaired compared to CAs (9 – 12 years) on a test of nonverbal motor inhibition. This difference persisted when age, nonverbal and verbal IQ were taken into account. Participants were required to either copy an experimenter by making the same hand action or inhibit this copying action and perform an opposite action. For a verbal version of the task, participants had to produce either an identical response to the examiner (car-car, doll-doll) or inhibit copying and produce the opposite answer (doll-car, car-doll). Performance was similar for the CA, D-DLD and also a low language functioning group.

However, the nature of the deficit in D-DLD groups is hard to assess. As with many studies working with D-DLD groups, relatively few incorporate language level matches. Ability level designs are important as they allow us to establish whether performance for impaired groups is typical for language ability, delayed compared to CA controls or evidence of a severe underlying deficit. Marton et al. (2016) suggests that difficulties in distractor and proactive inhibition are pervasive across a wide age range and indicate a deficit for D-DLD participants; difficulties in prepotent response inhibition are less evident in older children (although see Everatt et al., 2008). They found that D-DLD children (10-14 years) performed similarly to CA controls and faster than language level groups in an auditory stop signal task assessing prepotent response inhibition (Marton, Campanelli, Scheur, Yoon, & Eichorn, 2012). In a second task, of nonverbal distractor inhibition, participants had to identify a target pattern from a selection whilst ignoring distractors. Potential answers were either shown simultaneously or after a delay. For simultaneous conditions (high distraction) both CA and language level matches outperformed the D-DLD group.

It is clear then that other factors such as age likely play a large role in whether or not deficits in inhibition are seen for groups with developmental disorders. At the same time, certain types of inhibition may prove more difficult than others. Participants with D-DLD seem to show a wider variety of difficulty in inhibition for both verbal and nonverbal tasks than dyslexic groups. Yet is it particularly difficult to make these conclusions when very few studies compare literacy and language impaired groups directly. The next section summarises studies which have attempted this.

1.0.2.3 Multiple EFs

Research assessing multiple EFs suggests that D-DLD groups do not consistently experience difficulty in both inhibition and updating tasks. Im-Bolter et al. (2006) worked with D-DLD children and a CA group (7-12 years) also matched for gender and NVIQ. They administered measures of inhibition and updating. For the updating task, a nonverbal task N-back task was administered in which participants had to identify whether a stimulus matched a target N-positions previously (0, 1 or 2). Responses for both targets and non-targets were recorded as RTs. The D-DLD and CA groups performed similarly for 0-back (target identification). For 1-back, the CA group outperformed the D-DLD group. For the 2-back condition all groups found the task equally difficult reaching showing a floor effect. For distractor interference, participants completed a nonverbal anti-saccade task assessing prepotent response inhibition. Participants with D-DLD were less able to inhibit eye movements than a CA group.

In another study, Lukács et al. (2016), developed several verbal and nonverbal versions of tasks designed to only tap either one modality or the other. Included in their battery were verbal (letters) and nonverbal (geometric shapes) N-back tasks (1-back, 2-back) which were administered to a CA and D-DLD group (8 years). Hits and false alarms (incorrectly indicating a target presence) were measured. For 1-back, there were no group differences for verbal and nonverbal tasks. For nonverbal, 2-back, false alarms only, the CA group outperformed the D-DLD group. Lukács et al. (2016) also administered verbal and nonverbal parallels of Stroop task to measure pre-potent response inhibition. No group differences were found for either type of Stroop tasks; however participants also failed to show the typical Stroop effect in either versions of the task. For the verbal inhibition and updating task, the D-DLD group did score lower than the CA group in initial analyses looking at group differences. However these differences disappeared when baseline verbal STM ability was covaried. This suggests that differences can be explained by differences in baseline verbal ability. Baseline nonverbal STM was not covaried in the nonverbal EF tasks as the groups did not show a difference in the nonverbal STM task to begin with. Interestingly, the D-DLD group still showed difficulty in nonverbal versions of the updating task compared to the CA group. This cannot be due to differences in nonverbal STM ability between the D-DLD and CA group. This suggests the D-DLD group do show a difficulty in the domain general CE and EF independent of the nonverbal STM store.

1.0.3 Comparing across disorders

1.0.3.1 Inhibition

Very few studies have chosen to work with both dyslexic and D-DLD groups simultaneously which can make it hard to draw conclusions across task modalities. One study included verbal and nonverbal measures of inhibition as part of a larger battery with dyslexic, D-DLD and CA groups (11-13 years; Everatt et al., 2008). The study suggests that D-DLD groups experience more problems in inhibition tasks than dyslexics and that these occur in verbal and nonverbal domains. Participants were screened for both language and literacy difficulty. The D-DLD group showed difficulty in language, word reading comprehension, RAN, PA and spelling. Participants completed a verbal and nonverbal Stroop task assessing prepotent response inhibition. Whilst the dyslexic participants performed the same as the CA group on both tasks, the D-DLD group experienced a difficulty in verbal inhibition compared to the CA group. Results for nonverbal inhibition were marginally significant (p = 0.053) for the D-DLD group, suggesting some difficulty.

In another study Helland and Asbjørnsen (2000) worked with children with dyslexia (13 years), a D-DLD group and a CA group. The groups completed a Stroop task assessing prepotent response inhibition and a Wisconsin Card Sorting Task (WCST). The WCST places high executive demands on participants. It measures proactive interference as well as cognitive flexibility. It asks participants to continually switch between rules and ignore previous rules. The dyslexic and D-DLD groups both showed difficulty on the tasks, however, the group with D-DLD showed greater difficulty. This suggests that the D-DLD group have a greater impairment that the dyslexic group on tasks requiring EF even if they are verbal in nature like the Stroop task. This supports the notion of a double deficit for D-DLD children who experience greater impairment than dyslexic groups due to difficulties in STM stores and the CE.

1.0.3.2 Updating

For updating, Cowan et al. (2017) administered verbal (running digit span) and nonverbal (running location and running shape span) measures assessing updating in CA, dyslexic and D-DLD groups (8 years). For each 'running' task, participants had to recall items in order that appeared at the end of lists. List lengths were long and unknown to participants. Cowan et al. (2017) adopted two different matched designs throughout the study. For the first they matched participants in the CA and dyslexic only groups for NVIQ and oral language ability (creating 67 pairs). For this comparison dyslexic participants with higher NVIQ were utilised. The dyslexic group scored lower than the CA group on running digit span and running location span. A second matched-pairs design was then adopted, participants in the dyslexic, D-DLD and CA groups were matched for NVIQ (creating 28 pairs of dyslexic-CA and D-DLD-CA participants). Participants now included those with lower NVIQs across groups. On the running digit span and running location span tasks, the CA, dyslexic and D-DLD groups performed similarly. This suggests that NVIQ is important for updating ability. It seems the three groups hit floor on the updating measures when all matched for NVIQ. Only in groups with higher NVIQ do you begin to see group differences.

1.0.4 Summary

In sum, it seems that dyslexic deficits in updating are restricted to verbal tasks or tasks that contain easily named stimuli. Deficits may also been seen for literacy impaired groups with low NVIQ (Ackerman & Dykman, 1993). When nonverbal deficits do arise, they tend to be distinct, appearing only when executive or capacity demands are high or verbal strategy is facilitative (Göthe et al., 2012; Lee Swanson et al., 2006; Smith-Spark et al., 2003). For the D-DLD group, the distinct lack of literature in the area makes it difficult to draw firm conclusions. However, it does seem that D-DLD participants experience a deficit in nonverbal updating tasks that does not appear as readily for dyslexic groups (Im-Bolter et al., 2006; Lukács et al., 2016). Results for verbal updating are hard to interpret. Often CA and impaired groups perform similarly on updating measures not due to nil difference in ability but rather because the task is too hard for all groups causing floor effects (Im-Bolter et al., 2006). Cowan et al. (2017) for instance found that group differences only emerged when participants had higher NVIQ.

Results are harder to summarise for inhibition tasks due to the several types (prepotent, distractor, proactive) tested in the literature. EF processes and the CE system that governs them are both domain general (Miyake et al., 2000). What makes an inhibition task verbal or nonverbal is the modality of the stimuli. Information is stored in temporary short-term stores and processed in WM. It is within this memory system that EFs can act on information. Again the hierarchical structure of WM means it is necessary to consider the proficiency participant groups in tasks that involve the slave sub systems. If dyslexic participants have a deficit in verbal STM for example, this is likely to impact verbal inhibition. At the same time I can look at processes such as proactive interference holistically and make conclusions about the process as a whole rather than considering verbal or nonverbal processes separately.

Having said this, the literature concerning inhibition in my impaired groups is more extensive than that for updating. Unfortunately it also presents a rather mixed picture for both of my groups. For dyslexic groups, deficits have been found in verbal and nonverbal tasks assessing distractor inhibition (Brosnan et al., 2002; Van der Sluis, de Jong, & van der Leij, 2007; Wang et al., 2012). Other studies haven't found a deficit in verbal distractor inhibition (Landerl et al., 2009; Rubinsten & Henik, 2006). Whilst some studies have found a deficit for verbal prepotent response inhibition even in older groups (Lee Swanson et al., 2006; Wang et al., 2012), others have not replicated this result

(Everatt et al., 2008; Jefferies & Everatt, 2004). Research also suggests a relative proficiency for nonverbal prepotent response inhibition (Everatt et al., 2008). Participants with dyslexia also seem to have a relative proficiency for tasks requiring verbal proactive interference (Jefferies & Everatt, 2004). In sum, dyslexic participants seem to have the most consistent difficulty with verbal tasks that require distractor inhibition. However, the results surrounding prepotent response inhibition are very mixed.

A wider range of deficits are seen for D-DLD groups in inhibition that seem to extend further to both verbal and nonverbal domains (Marton et al., 2016). Deficits have been found in verbal (Seiger-Gardner & Brooks, 2008) and nonverbal (Marton et al., 2012; Weyandt & Willis, 1994) distractor inhibition. However, other studies have failed to replicate this for verbal tasks (Gray, Reiser, & Brinkley, 2012). D-DLD participants are only susceptible to verbal distractors to the extent that they can process them (Bishop & Norbury, 2005; Brooks, Seiger-Gardner, & Sailor, 2014). Distractors, such as nonword primes, will not cause as much interference as familiar primes that a participant knows are related to the target and can process. However, other studies have also failed to find deficits in nonverbal distractor tasks (Im-Bolter et al., 2006). Younger groups (4 years) have been found to struggle with both verbal and nonverbal prepotent response inhibition (Finneran et al., 2009; Spaulding, 2010). Marton et al. (2012) argue that prepotent response difficulties are only present in younger groups with D-DLD, with several studies failing to find difficulties in older groups (Marton et al., 2012; Marton, Campanelli, Eichorn, Scheuer, & Yoon., 2014; Noterdaeme, Amorosa, Mildenberger, Sitter, & Minow, 2001; Tropper, 2009). However, in a recent meta-analysis, Pauls and Archibald (2016) found a range of inhibition difficulties for D-DLD groups that weren't mediated by age or severity of language deficit. Furthermore, other studies have found verbal and nonverbal prepotent difficulties in older groups (6-10 years - Bishop & Norbury, 2005; 10 – 13 years - Everatt et al., 2008). Difficulties have also been highlighted in tasks involving verbal (Marton et al., 2014; Marton, Kelmenson, & Pinkhasova, 2007) and nonverbal (Henry et al., 2012; Roello, Ferretti, Colonnello, & Levi, 2015; Weyandt & Willis, 1994) proactive inhibition for D-DLD groups. But again other studies have failed to replicate this for verbal (Henry et al., 2012) tasks. It seems then that a wider range of difficulties are observed over a range of types if inhibition for D-DLD participants as compared to dyslexic participants. These deficits also seem to extend to both verbal and nonverbal domains which may be a result of wider difficulty in verbal and nonverbal STM / WM in D-DLD groups – see chapter three.

1.1 The current study

The current study aims to contrast verbal and nonverbal EF skills in groups with either literacy / language only or comorbid difficulties. To the best of my knowledge, no study has looked at both inhibition and updating in literacy and language impaired groups simultaneously. Further, no study has included ability level groups, which are necessary to establish whether potential difficulties are evidence of a delay or deficit in impaired groups. We now go on to describe two experiments each with verbal and nonverbal parallels for updating then inhibition.

2. Experiment 1 – Updating

For updating tasks, for dyslexic groups, deficits seem to be limited to complex tasks with verbal stimuli. Difficulties seem to extend further for groups with D-DLD, to both the verbal and nonverbal domains. This logically follows from the results obtained in chapter two (sections, 2.2, 3.2). If updating works on WM which in turn works on STM, then a pattern of deficits should necessarily follow through. We found deficits were restricted to verbal tasks for dyslexic participants for STM and WM but that difficulties extended to the nonverbal domain for the D-DLD group. To test this, verbal and nonverbal parallels of an N-back task (0-back, 1-back, 2-back) were administered based on Im-Bolter et al. (2006) at T2. The original nonverbal task consisted of non-nameable dot patterns. The novel verbal parallel uses carefully matched, orally presented nonwords.

2.1 Experiment 1a: Nonverbal updating

2.1.1 Hypotheses

For the 0-back condition, participants are assessed on their ability to identify the presence of a target, yes or no, not under time restraints (other than a time out after 2500ms). This baseline condition is particularly simple and previous research suggests that impaired groups do not struggle in 0-back conditions (Im-Bolter et al., 2006). Therefore I predict that there will be no differences between the CA and impaired groups, or between the impaired groups and each other on the 0-back condition. Impaired groups will score higher than their respective ability level groups due to age.

Previous research suggests that for 1-back conditions, group differences do emerge (Im-Bolter et al., 2006). For the nonverbal task, I predict, compared to the CA group, that the dyslexic and DLD groups will not experience a difficulty in nonverbal updating but that the D-DLD group will. The D-DLD group will score lower than both the DLD and dyslexic group. In comparisons with ability level groups I predict that the dyslexic group will score higher than the RA group. The D-DLD group will score similarly to both the RA and LA/D-DLD groups suggesting a performance that is appropriate for their ability level. The DLD group will score higher than the LA/DLD group.

For the 2-back level, previous research (Im-Bolter et al., 2006) suggests that task demands become particularly difficult for all groups, including the CA group, often causing floor effects. To this extent I predict that there will be no differences between the CA and impaired groups, or between the impaired groups and each other on the 2-back condition. There will be no differences between the impaired and ability level groups.

2.1.2 Method

2.1.2.1 Participants

In addition to sample attrition at T2, the data from nine participants was lost or corrupted due to technological difficulty. Where a participant was removed from one level (i.e. 0-back) their subsequent scores for the 1-back and 2-back were also removed. Participants were included if they had results for only the verbal or nonverbal versions of the task as it was reasoned that statistical cross modal comparisons should not be performed (i.e. different skills being utilised in each modality).

For the dependent variable I used a composite score, *d* prime (*d'*), for 0, 1 and 2-back levels which takes in to account participant ability to correctly identify targets and avoid false alarms and misses. High *d'* indicates that participants were highly sensitive to responding to targets. We calculated *d'* in line with the procedure recommended by Breadmore and Carroll (2016). For further information on how to calculate *d'* see Stanislaw and Todorov (1999). When discussing accuracy from here forwards, *d'* sensitivity will form the dependent variable.

To begin with *d'* was calculated for verbal 0-back trials on all eligible participants (N=129). The mean d' for the nonverbal 0-back was 3.23 (SD .71). Participants were removed (from all levels of the task) if their nonverbal 0-back score was less than 2SD below the mean (less than 1.81); matches were also removed. When a match served as both an RA and LA/DLD match, they were removed from the corresponding group to the participant with a low *d'* but remained as a match to other impaired participant. We screened participants on performance in the 0-back as it was reasoned that this was the baseline condition. Performance in the 1-back and 2-back levels of the tasks instead are due to task manipulation. Scores for *d'* were also calculated for 1-back and 2-back conditions. One DLD participant was due to be removed as their ability match had a low *d'* score. Instead of losing an additional participant in this small group, another RA participant with the same language age was repurposed as an LA/DLD match, but only for the nonverbal analysis. This left a total of 123 eligible participants belonging to the following groups, 20 D-DLD (20 LA/D-DLD), 23 Dyslexic (23 RA), 9 DLD (9 LA/DLD), 19 CA.

2.1.2.2 Design and procedure

To test nonverbal updating, I utilised the N-back task developed by Im-Bolter et al. (2006). The task was provided by their research team and run using E-Prime 2 Software (Schneider, Eschman, & Zuccolotto, 2012). The stimuli consisted of a three dot pattern (total of 9 different patterns). Patterns were presented sequentially. Participants had to indicate whether the dot pattern matched the pattern displayed N positions earlier. For each stimulus item, participants had to indicate whether the stimulus was a target or not by pressing either 'Yes' or 'No'. Response keys were programmed on the '.' and '/' keys of the laptop (Toshiba Satellite Pro – C50) keyboard which was used to administer the task. A sticker with a 'Y' or 'N' covered the keys. If no response was received after 2500ms then the task moved on automatically and registered an incorrect response. Participants received immediate feedback aurally as to whether or not their response was correct. Each level of the task was administered one after the other. At the start of each level participants completed a practice block before proceeding to the experimental block. Each experimental block contained 20 target and 34 non-target trials. The computer recorded correct and incorrect responses for both target and non-target trials and this was used to calculate *d'* for each level of the task.

The task had three levels. In the simplest, baseline, 0-back level, participants indicated whether or not the stimulus on screen was the target (three dots in a horizontal line). The target was displayed at the beginning of the task. The baseline condition assessed participants target identification / response accuracy. In the 1-back condition participants had to indicate if the stimulus on screen matched a pattern displayed one position earlier. This required participants to constantly update the contents of their WM. In the most complex 2-back condition, participants had to indicate whether the stimulus matched the pattern displayed two positions ago. This required participants to constantly keep at least three patterns in mind at all times and update this as the task progressed. See

Figure ***7*** for a schematic of the nonverbal updating task.

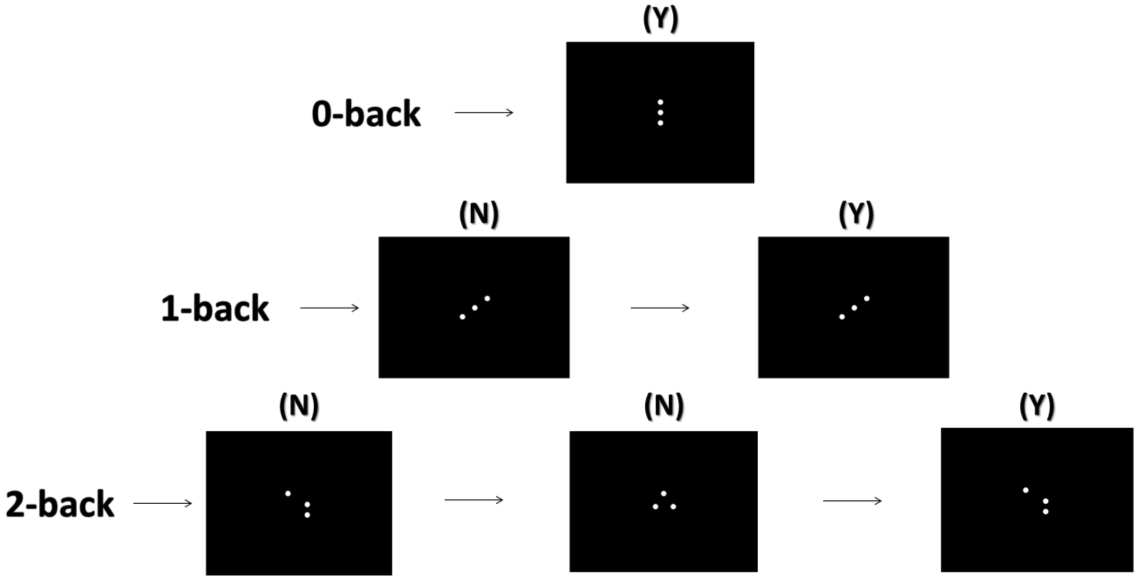


Figure 7: Schematic depicting the nonverbal updating task levels, 0-back, 1-back, 2-back.

2.1.3 Results and discussion

Performance was investigated on the on the 0-back, 1-back and 2-back levels of the task separately. Results, (see Figure 8) were analysed in same way as for previous tasks, beginning with ANOVAs to assess the performance of impaired and CA groups before progressing to t-tests to assess ability level matches. As before, to control for multiple comparisons, a Bonferroni adjusted alpha level was adopted for significance threshold ($p < .0167$). For both updating measures an ANCOVA for the 1-back and 2-back levels was included. In these analyses performance was covaried for the 0-back condition to control for baseline performance. A more lenient Bonferroni adjusted alpha level of $p < .025$ was adopted as planned comparisons for each group were made only between an impaired and CA group. Ability level matches were not examined using the ANCOVA as the groups were not independent of each other; see chapter two, section 3.2, for a justification.

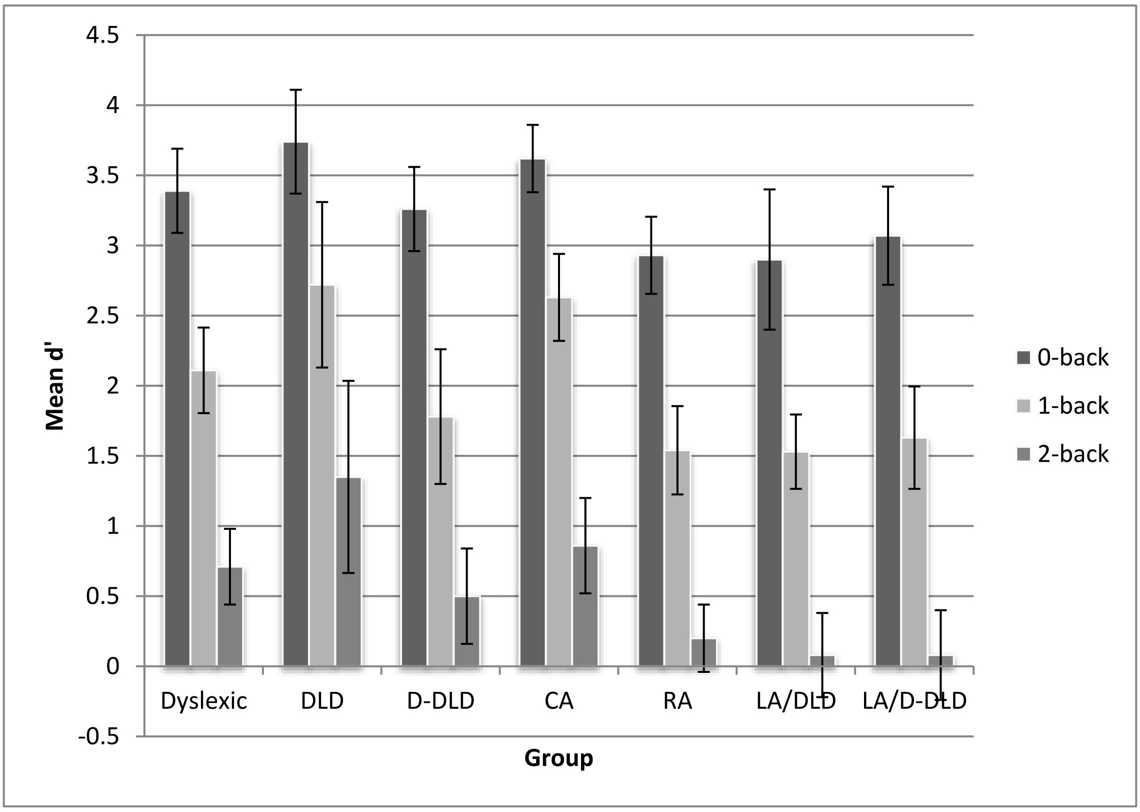


Figure 8: Mean d' for nonverbal 0-back, 1-back and 2-back tasks for each group with confidence intervals (95%) in error bars.

2.1.3.1 Nonverbal 0-back

As expected, given the simplicity of the task, there were no group differences at baseline, $F(3,67) = 1.91$, $p = .14$, $r = 0.09$. Planned contrasts confirmed that there were no differences between the CA and impaired or impaired groups and each other. Unexpectedly, the RA group performed similarly to both the dyslexic, $t(44) = 2.37$, $p = .02$, $d = 0.69$ (although this tended towards significance) and D-DLD group, $t(41) = 1.69$, $p = .10$, $d = .52$, as did the LA/D-DLD and D-DLD group, $t(38) = 0.86$, $p = .39$, $d = 0.27$. We do not know why these null effects occurred. However effect sizes indicate a lack of power in the analysis. The DLD group performed better than the LA/ DLD group, t(16) = 3.10, $p < .01$, d = 1.47 which I expected due to age differences. See

*Figure **8***.

2.1.3.2 Nonverbal 1-back

There was a significant effect of group on *d'*, $F(3,67) = 4.93$, $p < .01$, r = 0.47. Planned contrasts confirmed that, as expected, the CA group performed similarly to the dyslexic group $t(67) = 2.07$, $p = .04$, $d = 0.77$ and the DLD group, $t(67) = -0.27$, $p = .78$, $d = 0.13$, but were more sensitive than the D-DLD group $t(67) = 3.30$, $p < .01$, $d = 0.99$. This suggests the D-DLD group only have a difficulty in nonverbal EF tasks. This supports the idea that the D-DLD group experience domain general CE difficulty. The D-DLD and the dyslexic group performed similarly ($t(67) = 1.36$, $p = .18$, $d = 0.37$) which was not expected and I am unsure of why this null result occurred. The DLD group were more sensitive than the D-DLD group ($t(67) = 2.91$, $p < .01$, $d = 1.03$) as expected suggesting an advantage in EF. The DLD and dyslexic groups performed similarly as expected ($t(67) = 1.92$, $p = .06$, $d = 0.83$).

We also ran an ANCOVA with nonverbal 0-back performance as the covariate. The covariate, nonverbal 0-back performance, was significantly related to nonverbal 1-back performance, $F(1, 66) = 18.18$, $p < .001$, $\eta_2 = .22$. There was not a significant effect of group on nonverbal 1-back performance after controlling for the effect of nonverbal 0-back performance, $F(3, 66) = 2.92$, $p = .04$, $\eta_2 = .18$. After controlling for verbal 0-back ability, special contrasts revealed that the CA group were still more sensitive than the D-DLD group, $F(1, 66) = 7.08$, $p = .01$, $\eta_2 = .10$. This suggests that their nonverbal updating difficulty cannot be explained by baseline nonverbal ability. It is further evidence toward a separate CE deficit in the group. The CA group performed similarly to the dyslexic group, $F(1, 66) = 2.81$, $p = .10$, $\eta_2 = .04$ and the DLD group, ($F(1, 66) = 0.003$, $p = .96$, $\eta_2 < .001$). The D-DLD group now performed similarly to the DLD group ($F(1, 66) = 4.71$, $p = .03$, $\eta_2 = .07$) although this tended heavily towards significance. When baseline nonverbal ability is taken in to account, the difference between the D-DLD and DLD group begins to disappear. However this result is very close to significant. Suggesting for the most part that difference between DLD and D-DLD groups cannot be explained by baseline nonverbal ability (see section 2.1.3.3). The DLD group performed similarly to the dyslexic group ($F(1, 66) = 1.88$, $p = .18$, $\eta_2 = .03$). The D-DLD group performed similarly to the dyslexic group ($F(1, 66) = 1.29$, $p = .26$, $\eta_2 = .02$).

As predicted, the dyslexic group were more sensitive than the RA group, $t(44) = 2.72$, $p <.01$, $d = 0.80$ who in turn performed similarly to the D-DLD group, $t(41) = .89$, $p = 0.37$, $d = 0.27$. The D-DLD group performed similarly to the LA/D-DLD group, $t(38) = 0.52$, $p = .61$, $d = 0.16$. The DLD group were more sensitive than the LA/DLD group, $t(16) = 4.21$, $p < .01$, $d = 1.99$. See

Figure ***8***.

2.1.3.3 Nonverbal 2-back

Group differences were revealed, $F(3,67) = 3.16$, $p < .05$, $r = 0.38$. Planned contrasts confirmed that all but two of the groups performed similarly which was predicted. The exception was the D-DLD group who were less sensitive than the DLD group, $t(67) = 3.00$, $p < .004$, $d = 1.04$. This suggests that under the highest updating load, the DLD group do show superior EF skills as compared to the D-DLD group.

We also ran an ANCOVA with nonverbal 0-back performance as the covariate. The covariate, nonverbal 0-back performance, was significantly related to nonverbal 2-back performance, $F(1, 66) = 6.09$, $p = .02$, $\eta_2 = .08$. However, there was no significant effect of group on nonverbal 2-back performance after controlling for the effect of nonverbal 0-back performance $F(3, 66) = 2.02$, $p = .12$,

η_2 = .08. After controlling for nonverbal 0-back ability, special contrasts confirmed a similar pattern to above with all groups performing similarly with the exception of two: CA vs. dyslexic, $F(1, 66)$ = 0.12, p = .73, η_2 = .002, CA vs. D-DLD, $F(1, 66)$ = 1.12, p = .29, η_2 = .02, CA vs. DLD group, $F(1, 66)$ =2.66, p = .11, η_2 = .04, D-DLD vs. dyslexic, $F(1, 66)$ = 0.61, p = .44, η_2 = .01, DLD vs. dyslexic, $F(1, 66)$ = 3.72, p = .06, η_2 = .05. The DLD group were more sensitive than the D-DLD group, $F(1, 66)$ = 5.97, p = 0.02, η_2 = .08. Under the highest updating load, the DLD group do show superior nonverbal updating compared to the D-DLD group and this cannot be explained by baseline ability. This again suggests the DLD group have superior EF and CE processes which enable updating compared to the D-DLD group.

The RA group were less sensitive than the dyslexic group, $t(44)$ = 2.90, p =.006, d = 0.86 which was not expected, but performed similarly to the D-DLD group as expected, $t(41)$ = 1.53, p = .13, d = 0.47. The LA/DLD were less sensitive than the DLD group which was not expected, $t(16)$ = 3.92, p = .001, d = 1.83. As expected, the LA/D-DLD group performed similarly to the D-DLD group $t(38)$ = 1.87, p = .07, d = 0.60. It seems that the 2-back condition is developmentally sensitive and that our groups did not hit floor. The D-DLD group is performing lower and closer to their literacy and language age than the dyslexic and DLD groups. See Figure 8.

2.2 Experiment 1b - Verbal updating

2.2.1 Hypotheses

Similar to predictions for the nonverbal version of the task, I predict there will be no differences between the CA and impaired groups or between the impaired groups and each other. This is due to the simplicity of the 0-back condition (see section, 2.1.1), (Im-Bolter et al., 2006). Impaired groups will score higher than their respective ability level groups due to age.

For the verbal task 1-back task I predict, compared to the CA group, that both the dyslexic and D-DLD group will experience a difficulty in verbal updating. D-DLD and dyslexic groups will perform similarly but worse than the DLD group. The DLD group will not show a deficit in verbal updating. In comparisons with ability level groups I predict that dyslexic and D-DLD group will score lower than the RA group. The D-DLD group will score similarly to the LA/D-DLD groups suggesting a performance that is appropriate for their language level. The DLD group will score higher than the LA/DLD group.

For the 2-back level, similar to predictions made for the nonverbal task (see section 2.1.1) I predict there will be no differences between CA and impaired groups, or between the impaired groups and each other. There will be no difference between impaired and ability level groups.

2.2.2 Method

2.2.2.1 Participants

Data was screened similarly for both nonverbal and verbal versions of the task (see section 2.1.2). The mean *d'* for verbal 0-back was 2.65 (SD.55). Participants were removed (from all levels of the task) if their nonverbal 0-back score was less than 2SD below the mean (less than 1.55), matches were also removed. When a match served as both an RA and LA/DLD match, they were removed from the corresponding group to the participant with a low *d'* but remained as a match to the other impaired participant. This left a total of 122 eligible participants belonging to the following groups, 19 D-DLD (19 LA/D-DLD), 22 Dyslexic (22 RA), 10 DLD (10 LA/DLD), 20 CA.

2.2.2.2 Design and procedure

To assess verbal updating, a verbal version of the used in Im-Bolter et al. (2006) was developed. This was designed to match as closely as possible the nonverbal version. To this extent I used the same program and substituted dot patterns for verbal stimuli. Subsequently each level of the task (0-back, 1-back, 2-back) consisted of 20 target trials and 34 non-target trials. Each level also contained a practice phase to begin. The stimuli consisted of nonwords designed to parallel the dot stimuli of the nonverbal task. Each dot was assigned a phoneme according to its position and this was used to create the nonwords. The nonwords were: /nās/ , /pāt/ , /wām/ , /rāg/ , /kol/ , /dowf/ , /jīy/ , /hūb/ , /vez/, /vōz/ . The task was scored and administered in the same way as the nonverbal version. See

*Figure **9*** for a schematic of the verbal updating task.

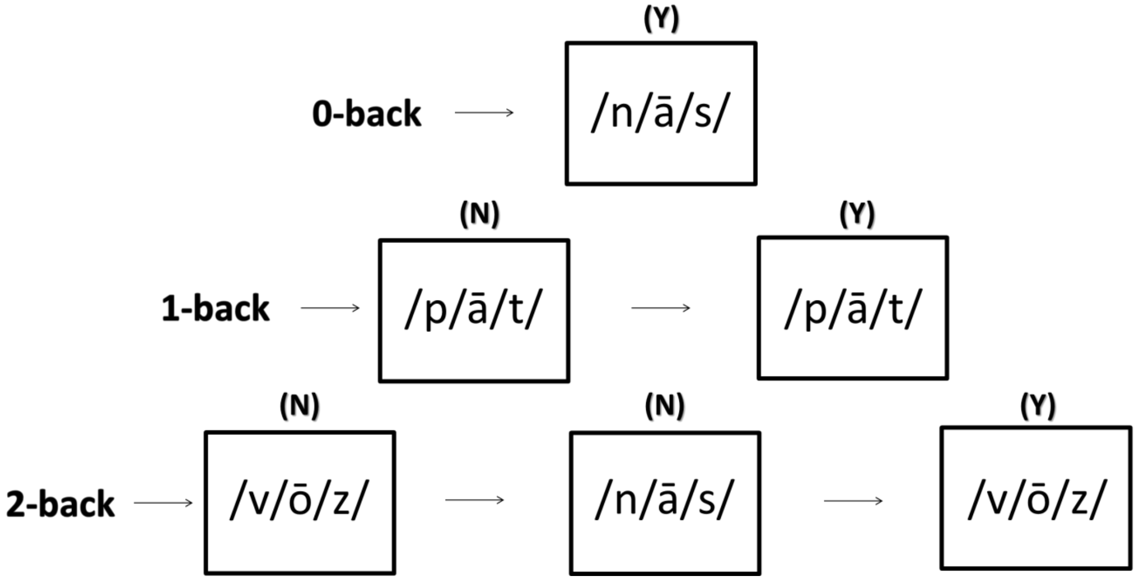


Figure 9: Schematic depicting the verbal updating task levels, 0-back, 1-back, 2-back.

2.2.3 Results and discussion

We investigated performance on the verbal task in the same way as for the nonverbal task.

See

*Figure **10*** for mean group d' for verbal 0-back, 1-back and 2-back conditions separately.

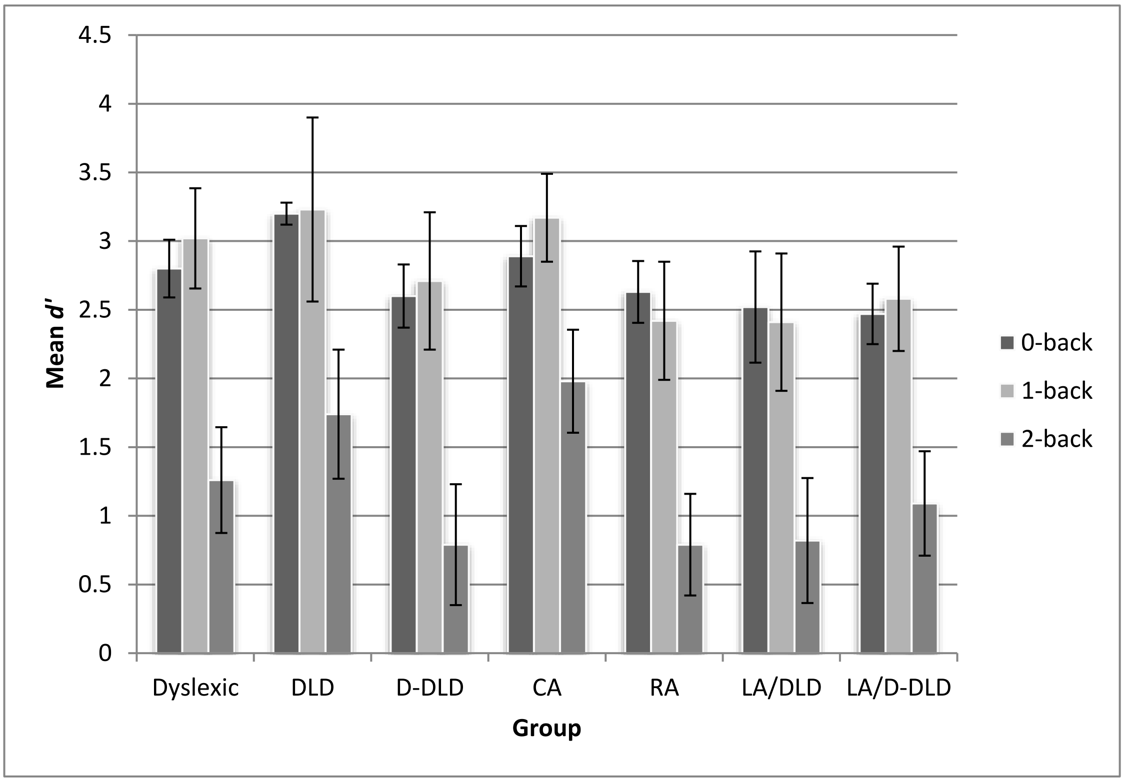


Figure 10: Mean d' for verbal 0-back, 1-back and 2-back tasks for each group with confidence intervals (95%) in error bars.

2.2.3.1 Verbal 0-back

There was a significant effect of group, $F(3,67) = 4.24$, $p = .008$, r = 0.44. Planned contrasts confirmed that the CA group performed similarly to the dyslexic group, $t(39.38) = 0.687$, $p = .50$, $d = 0.19$, and the D-DLD group, $t(36.94) = 1.91$, $p = .07$, $d = 0.61$, as expected given the simplicity of the task. Surprisingly, the DLD group performed better than the CA group, $t(22.3) = -2.74$, $p < .0167$, $d = 0.89$, the D-DLD group, $t(21.74) = 5.25$, $p < .001$, $d = 1.76$, and the dyslexic group, $t(25.93) = 3.87$, $p < .001$, $d = 1.20$, which was not expected. This suggests the DLD group have better baseline verbal target identification, or are better able to keep an auditory target in mind over a long period of time. The target is only played once aurally at the beginning of the experiment. Participants have to remember this whilst making online comparisons between the target and stimuli. This is a verbal WM skill and seems to be an area of strength for DLD groups. The D-DLD and the dyslexic group performed similarly, $t(37.97) = 1.29$, $p = .20$, $d = 0.43$ as expected.

As expected, most of the impaired groups performed similarly to their ability level groups: RA vs. dyslexic, t(42) = 1.13, *p* =.27, d = 0.33, RA vs. D-DLD, t(39) = -0.16, *p* = .88, d = .06, LA/D-DLD vs. D-DLD, t(36) = 0.87, *p* = .39, d = 0.28. There was one exception; the DLD group were more sensitive than the LA/ DLD group, t(9.74) = 3.73, *p* < .004, d = 1.66, due to their relative proficiency in the task. See

Figure ***10***.

2.2.3.2 Verbal 1-back

Unexpectedly, there were no group differences, F(3,67) = 1.21, *p* = .31, r = 0.23. Planned contrasts also revealed no significant differences.

Figure ***10*** shows that performance on the 0-back and 1-back levels of the verbal task were similar. Participants reported that the verbal version of the task was easier than the nonverbal version. This is likely due to the additional EF needed to keep nonverbal targets in mind. Verbal tasks allow for the use of the phonological loop, an inbuilt rehearsal process in verbal STM. This affords a larger verbal STM capacity than nonverbal STM capacity in participants. It could be that the groups all found the task relatively simple and therefore group differences were not revealed.

We also ran an ANCOVA with verbal 0-back performance as the covariate. The covariate, verbal 0-back performance, was significantly related to verbal 1-back performance, $F(1, 66) = 11.62$, $p < .01$, $\eta_2 = .15$. There remained no significant effect of group on verbal 1-back performance after controlling for the effect of verbal 0-back performance, $F(3, 66) = 0.319$, $p = .812$, $\eta_2 = .01$. Again special contrasts confirmed no difference between any of the CA and impaired groups.

All of the ability level groups performed similarly to their respective impaired groups when adopting the adjusted Bonferroni correction ($p < .0167$): RA vs dyslexic group, $t(42) = 2.20$, $p =.03$, $d = 0.66$, RA vs. D-DLD, $t(39) = 0.93$, $p = .36$, $d = 0.29$, LA/D-DLD vs. D-DLD, $t(36) = 0.42$, $p = .68$, *d* =

0.14, LA/DLD vs. DLD, $t(18) = 2.21$, $p = .04$, $d = 0.99$. This was unexpected but again likely due to task insensitivity.

2.2.3.3 Verbal 2-back

There was a significant effect of group, $F(3,67) = 7.33$, $p = <.001$, r = 0.57. Planned contrasts revealed that the CA group were more sensitive than the dyslexic group, $t(67) = 2.80$, $p < .01$, $d = 1.06$, and the D-DLD group, $t(67) = 4.42$, $p < .001$, $d = 1.35$. The DLD group performed similarly to the CA group, $t(67) = -0.74$, $p = .46$, $d = 0.33$. The D-DLD and the dyslexic group performed similarly, $t(67) = 1.78$, $p = .08$, $d = 0.53$. The DLD group were more sensitive than the D-DLD group, $t(67) = 2.90$, $p < .01$, $d = 1.20$. The DLD group performed similarly to the dyslexic group, $t(67) = 1.51$, $p = .14$, $d = 0.63$. We did not expect to see differences between the groups on the 2-back task due to expected floor effects. However these results follow given the findings from the 1-back condition. It seems that the verbal task is easier than the nonverbal task. Instead of difficulties being highlighted in the 1-back condition (as in the nonverbal task) the differences are highlighted in the more difficult 2-back level. It fits with our prediction for 1-back, that the dyslexic and D-DLD groups would show difficulty compared to CAs. This is likely due in part to their difficulty in storing verbal information and also processing it.

We also ran an ANCOVA with verbal 0-back performance as the covariate. The covariate, verbal 0-back performance, was not significantly related to verbal 2-back performance, ($F(1, 66) = 1.11$, $p = .30$, $\eta_2 = .02$). There remained a significant effect of group on verbal 2-back performance after controlling for the effect of verbal 0-back performance, $F(3, 66) = 5.78$, $p < .001$, $\eta_2 = .21$. After controlling for verbal 0-back ability, special contrasts revealed that the CA group performed better than the dyslexic group, $F(1, 66) = 7.25$, $p < .01$, $\eta_2 = .10$, and the D-DLD group, $F(1, 66) = 16.42$, $p < .001$, $\eta_2 = .20$). The DLD group performed similarly to the CA group, $F(1, 66) = 0.91$, $p = .35$, $\eta_2 = .01$. The impaired groups all performed similarly: dyslexic vs. D-DLD, $F(1, 66) = 2.51$, $p = .19$, $\eta_2 = .04$, DLD vs. D-DLD, $F(1, 66) = 5.12$, $p = .03$, $\eta_2 = .07$, DLD vs. dyslexic, $F(1, 66) = 1.32$, $p = .26$, $\eta_2 = .02$.

Differences were no longer apparent between D-DLD and DLD group suggesting the superior performance of the DLD group in the 0-back condition is responsible for differences in 2-back.

As expected all of the impaired groups performed similarly to their corresponding ability level group apart from the DLD group; RA vs. dyslexic, $t(42) = 1.82$, $p = .08$, $d = 0.55$, RA vs. D-DLD, $t(39) = 0.01$, $p = 1.00$, $d = 0.01$, LA/D-DLD vs. D-DLD, $t(36) = -1.09$, $p = .28$, $d = 0.44$. The DLD group were more sensitive than the LA/DLD group, $t(18) = 3.21$, $p = .005$, $d = 1.44$. Again this is likely due to the high performance of the DLD group on the 0-back level. See

Figure ***10***.

2.3 Experiment 1 discussion

Only the D-DLD group showed a difficulty on the nonverbal task which was only evident in the 1-back level of the task. This remained after controlling for baseline nonverbal ability, suggesting that group difference cannot be accounted for by differences in nonverbal target identification. Instead this is evidence of a deficit in nonverbal EF processes and the CE separate to nonverbal memory processes. The DLD group performed better than the D-DLD group suggesting proficient nonverbal updating skills. It supports my theory that this group has proficient EF / CE skills.

For the verbal task the DLD group performed better than all groups (even the CA group) on baseline verbal target identification. To be successful at the baseline condition participants have to keep a target (which is only presented once aurally) in mind over a long period of time. They also have to make online comparisons between this target and stimuli being presented. This is a verbal WM skill and it could be that the DLD group are proficient in this area. It may be compensating against the development of literacy difficulty in the DLD group. As expected both the dyslexic and D-DLD groups showed a difficulty on the nonverbal updating task.

I now turn my attention to inhibition and the second of our two studies assessing EF.

3. Experiment 2 – Inhibition

For inhibition, as with other EF tasks, it seems that dyslexic groups experience the most difficulty when tasks make use of the verbal STM store. See Figure 3 for the interrelationship between EF and temporary stores. Difficulties for dyslexic groups are narrower, appearing mostly in tasks assessing distractor inhibition. However this may be because distractor inhibition tasks often embody additional attentional demands such as sustained and selective attention. To that extent I have avoided the use of distractor inhibition tasks in this thesis to try and reduce task impurity. For D-DLD groups inhibition difficulties seem much more pervasive across types and seem to extend to both verbal and nonverbal domains. For both groups, there seems to be least consistency in the results seen for prepotent response inhibition which warrants further investigation.

Response inhibition involves the suppression of automatic responses. To this extent it is quite different to both distractor and proactive inhibition which involves no longer relevant information remaining acting and interfering with current WM processes. Prepotent response inhibition has clear intuitive links to literacy (Chiappe et al., 2000). Reading, for typical groups over time becomes an automatic process. At the same time it also requires control processes such as prepotent response inhibition to prevent incorrect information entering awareness (e.g. cat automatically activating similar words such as cot) (Walczyk, 2000). If these processes are poor in dyslexic readers it could contribute to the confusion or substitution of words. Groups that share literacy difficulty then may also share a difficulty in prepotent response inhibition. For this reason, this chapter will now focus on prepotent response inhibition presenting a Stroop task (verbal) and Simon task (nonverbal).

In the Stroop / Simon tasks at T1 participants are presented with a stimulus and asked to identify a target feature of it. Other aspects of the stimuli are more automatic than the target and will typically illicit an incorrect response from participants. The classic Stroop paradigm presents colour words (blue, green etc.) in coloured ink. Participants have to ignore the colour word but name the colour of the ink. The colour of the ink can be congruent (same as the word) or incongruent (different to the word). Naming the coloured word is more automatic than naming the ink and so participants are slower to respond and make more mistakes in incongruent trials when this information is conflicting. The Simon task was developed as a nonverbal parallel to this. We expect that groups with literacy difficulty will share a difficulty in verbal prepotent response inhibition. Those with language difficulty primarily will also exhibit difficulties in nonverbal tasks.

3.1 Experiment 2a: Nonverbal inhibition

3.1.1 Hypotheses

To test nonverbal inhibition I administered an arrow Simon task. Predictions are made in relation to accuracy and RT scores, for both congruent and incongruent trials. Accuracy scores were *d'* scores.

We predict that a Simon effect will be observed for the verbal and nonverbal tasks respectively for both accuracy and RT scores (Simon & Berbaum, 1990). That is, participants will perform faster, and be more accurate in congruent trials than incongruent trials. Only incongruent trials cause prepotent interference, i.e. the need to supress an automatic response that conflicts with the correct response. Congruent trials on the other hand should be facilitative in that the correct response is aided by another facet of the stimuli. Therefore, for congruent trials, for *d'* and RT, I predict that there will be no group differences between the CA and impaired groups and the impaired groups and each other. Impaired groups will perform similarly to ability level groups for d' but will be faster for RT responses. This will be due to age-related differences in RT with children becoming faster with age (Nicolson & Fawcett, 1994).

For incongruent trials, for both d' and RT, I predict, that the dyslexic and DLD groups will not experience a difficulty compared to the CA group (Everatt et al., 2008). The D-DLD group will experience a difficulty compared to the CA group (Everatt et al., 2008; Henry et al., 2012; Spaulding, 2010). DLD and dyslexic groups won't show a difficulty and will perform similarly to each other but higher than the D-DLD group (Helland & Asbjørnsen, 2000).

In terms of ability level groups, for *d′*, I predict that the dyslexic group will score higher than the RA group due to age. The DLD group will also score higher than the LA/DLD group. The D-DLD group will score similarly to both the RA and LA/D-DLD groups suggesting a performance that is appropriate for their ability. For RT, the impaired groups will react faster than ability level groups.

3.1.2 Method

3.1.2.1 Participants

Participants in the CA, D-DLD, DLD and dyslexic groups completed inhibition measures at T1. Of the 148 unique participants who completed measures for the thesis, 142 took part in the nonverbal inhibition task. One participant in the dyslexic group did not complete the inhibition measure. Their subsequent ability match in the RA group was also removed from analysis. Data was also missing for two LA/D-DLD participants and so there subsequent matched D-DLD participants were also removed. This left 28 dyslexic (28 RA), 10 DLD (10 LA/DLD), 26 D-DLD (26 LA/D-DLD) and 23 CA participants.

Similarly to the updating measures, I calculated the overall *d′* across both congruent and incongruent trials for each participant to assess how reliably participants responded to the direction of the arrow. High *d′* indicates that participants were highly sensitive to task manipulation, identifying the direction of the arrow whilst ignoring the spatial location on the screen (left or right). Participants who had an overall *d′* 2SD below the grand mean (2.77, SD 1.24) were removed on the basis that they were not sensitive to task manipulation (identifying the direction of the arrow stimulus). This excluded eight additional participants in total: two participants in the dyslexic group (and their RA matches), two participants in the RA group (and their matched participants in the dyslexic group). We then calculated *d′* for both congruent and incongruent trials separately.

3.1.2.2 Design and procedure

Participants saw a series of arrows appearing on either the left or right of a screen. They had to indicate as quickly and as accurately as possible, whether they thought the arrow was facing left or right, whilst ignoring the position of the arrow (i.e. right or left side of screen). The arrow

Simon task was based on the arrow Simon task presented in Bialystok (2006). Experimental stimuli were yellow arrows that appeared in horizontal centre of the screen, either to the left or right side of the screen. Arrows were either congruent (left facing arrows on the left side of the screen and vice versa) or incongruent (right facing arrows on the left side of the screen and vice versa), see Figure 11. For the experimental phase, a total of 120 trials were split in to three blocks of 40 trials. Each block contained an even distribution of left / right facing, congruent / incongruent arrows. In total each block contained 20 left facing arrows, and 20 right facing arrows, within which 10 were congruent and 10 incongruent. The trial order within each block was created by randomly using a number generator. The trial and block order remained constant for each participant. The experiment only continued when a response via touch screen response had been registered. Participants completed four practice trials in which they saw one of each type of trial, one congruent and one incongruent, left or right facing arrow.

The nonverbal Simon task was designed and built using Opensesame version 2.8.0 with an android back-end. The task was then administered on a Tesco HUDL (seven inch) tablet.

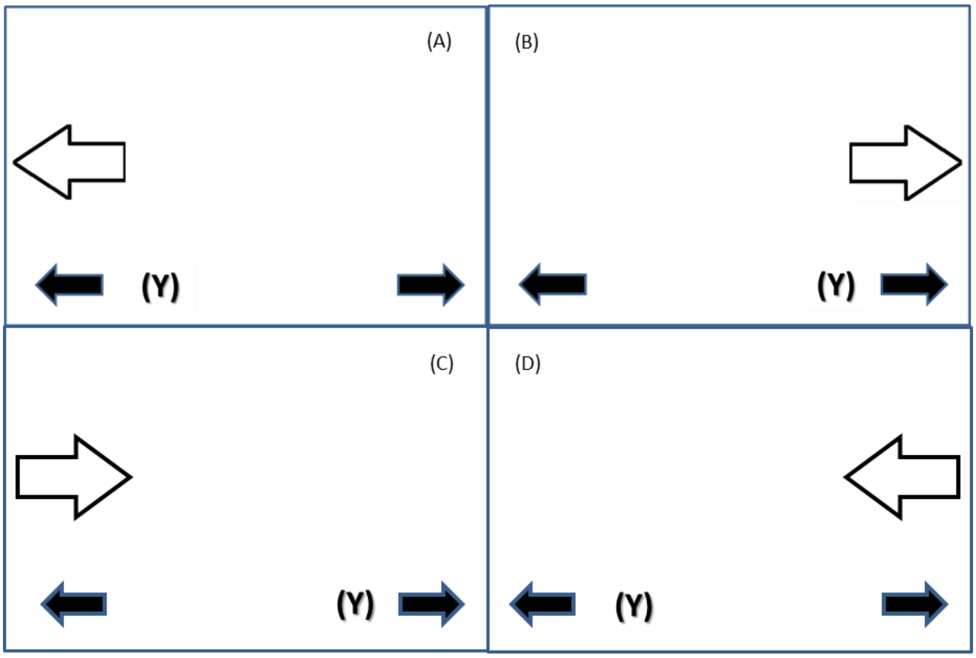
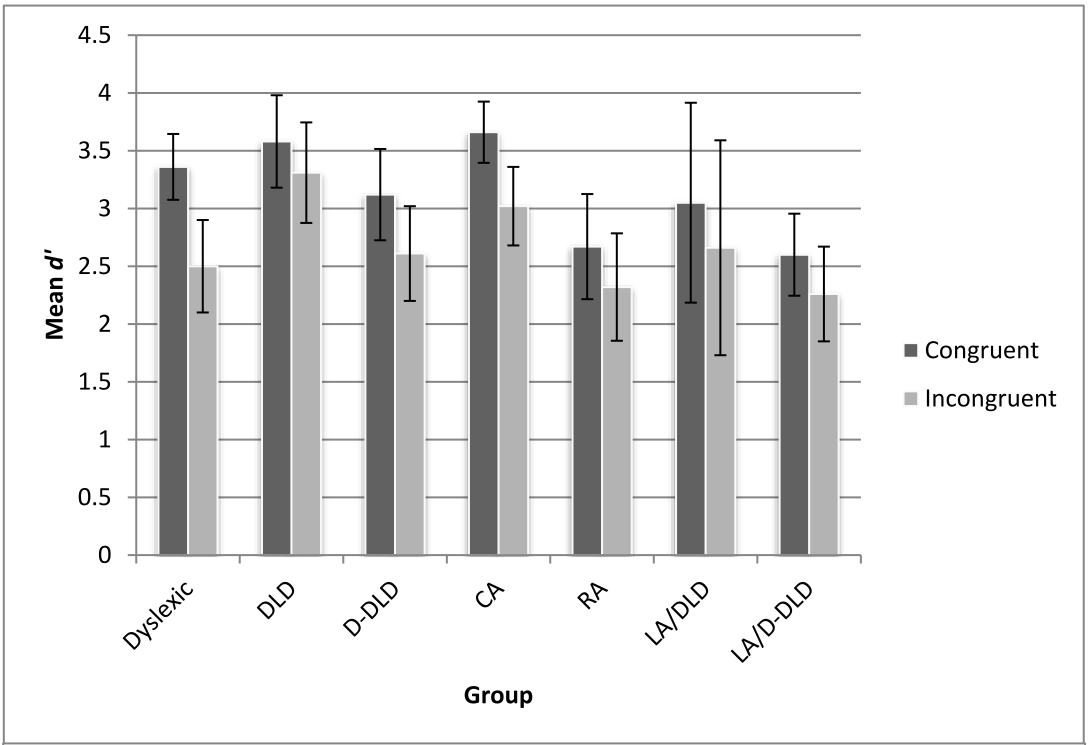


Figure 11: Schematic depicting the nonverbal Simon task. Images A and B show congruent trials, C and D show incongruent trials.

3.1.3 Results and discussion

Macleod (1991)suggests that criteria for the removal of outliers should result in the removal of no more than 3 - 5% of total trials. The paper suggests typically RTs less than 300ms would be considered an impulse and greater than 1500ms a distraction. However, this criterion was too stringent for my data resulting in the removal of 10.36% of trials. My population is not a typical population and therefore I adopted a less stringent upper cut off for removal which removed the recommended percentage (<5%) of trials. The less stringent criteria adopted was that used in Kane and Engle (2003) in which trials less than 200ms are removed as are trials greater than 3SD above individual participant RT means. This takes in to account individual performance / impairment. Therefore trials with latency of more than 2500ms and less than 200ms were removed. This resulted in a total number of 764 trials being removed which equated to 4.12% of total trials See

*Figure **12*** for mean d' and mean RT for congruent and incongruent trials for each group.



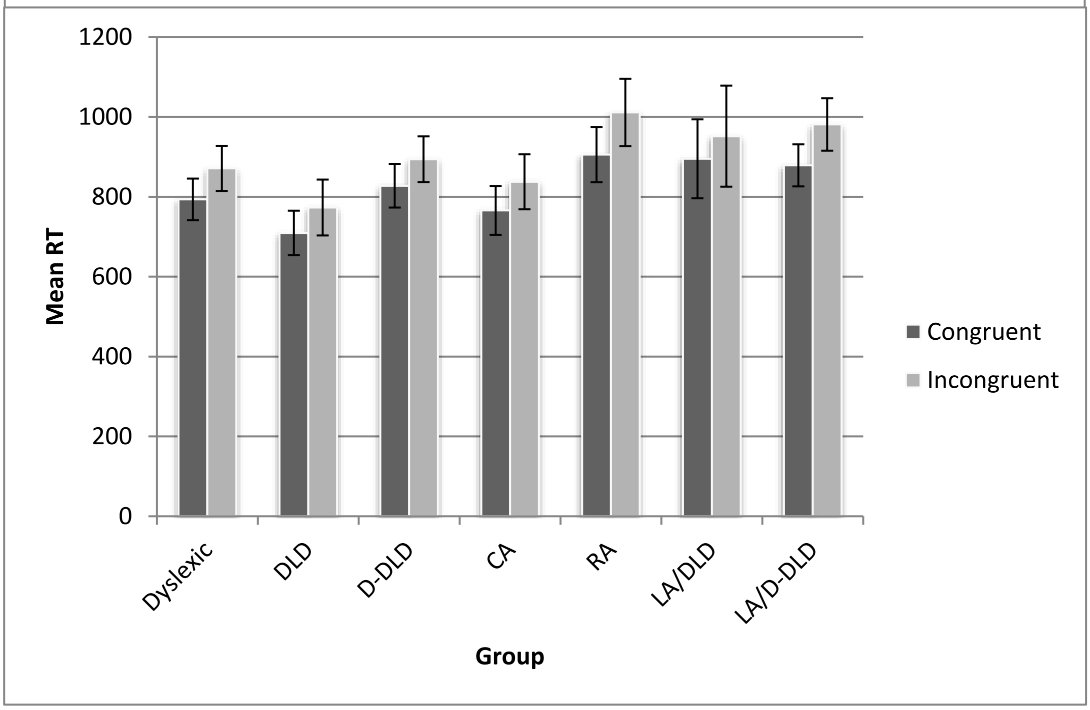


Figure 12: Mean group *d'* and RTs for congruent and incongruent trials for the Simon task with confidence intervals (95%) in error bars.

3.1.3.1 Accuracy

As expected, a mixed ANOVA for impaired / CA groups confirmed a main effect of congruency, with participants performing more accurately in the congruent (M=3.40, SD = .78) than the incongruent trials (M=2.78, SD=.96), $F(1, 79) = 42.08$, $p < .001$, $r = 0.59$. There was no main effect of group $F(3, 79) = 2.67$, $p = .05$, $r = 0.30$ or interaction between group and congruency, $F(3, 79) = 1.77$, $p = .16$, $r = 0.24$. This confirmed the presence of a Simon effect and that groups were sensitive to the task manipulation. See Figure 12.

As expected, congruent only trials confirmed there were no group differences $F(3, 79) = 2.30$, $p = .08$, $r = 0.30$. Planned contrasts also confirmed no group differences. The dyslexic group scored higher than the RA group ($t(38.94) = 2.66$, $p <.0167$, $d = 0.76$). As expected the other groups performed similarly to their ability level groups: D-DLD vs. RA, $t(48) = 1.55$, $p = .13$, $d = 0.44$, D-DLD vs. LA/D-DLD, $t(50) = 1.95$, $p = .06$, $d = 0.54$, DLD vs. LA/DLD, $t(18) = 1.25$, $p = .23$, $d = 0.56$. This suggests that most of the groups perform similarly on congruent trials as no inhibition is required.

Unexpectedly, incongruent trials revealed that there were no group differences $F(3,79) = 2.26$, $p = .06$, $r = 0.32$. Planned contrasts also failed to reveal any group differences. We expected the CA group to score higher than the D-DLD group but this was not the case. It could be that the executive demands of the task were not enough to reveal a difference between the D-DLD and CA group. All of the impaired groups performed similarly to their ability level groups not as expected. D-DLD vs. LA/D-DLD, $t(50) = 1.16$, $p =.25$, $d = 0.33$, D-DLD vs RA, $t(48) = 0.93$, $p = .36$, $d = 0.26$, DLD vs. LA/DLD, $t(12.70) = 1.43$, $p = .17$, $d = 0.64$, Dyslexic vs. RA, $t(46) = 0.63$, $p = .54$, $d = 0.17$. I am are not sure why this null result occurred.

3.1.3.2 Reaction Time

As expected, a mixed ANOVA for impaired / CA groups confirmed a main effect of congruency, (F1, 79) = 107.43, p < .01, r = 0.76, with congruent trials producing faster RTs (M = 786.42, SD = 134.35) than incongruent trials (M = 857.14, SD = 143.96). There was no main effect of group (F1, 79) = 2.18, p = .10, r = 0.28) and no interaction between group and trial type (F3, 79) = .22, p = .88, r = 0.10. This confirmed a Simon Effect as above, see Figure 12.

As expected, there were no group differences in RTs for congruent only trials $F(3,79) = 2.20$, p = .09, r = 0.29. Planned contrasts also confirmed no group differences. As expected, the RA group produced slower RTs than the dyslexic group, $t(46) = -2.68$, p < .01, d = 0.77; the LA/DLD group also produced slower RTs than the DLD group, $t(18) = -3.70$, p <.01, d = 1.66. This is likely due to age differences between the groups which wasn't expected. The other impaired groups performed similarly to their ability level groups which was expected: D-DLD vs RA, t(48 = -1.79, p = .08, d = 0.51, D-DLD vs. LA/D-DLD, $t(50) = 1.43$, p =-1.31, d = 0.36. This suggests that the D-DLD group do react slower but at a rate appropriate for both literacy and language age.

There were no group differences in RTs for incongruent only trials $F(3,79) = 2.00$, p = .12, r = 0.28. Planned contrasts also revealed no group differences. We expected the D-DLD group to show longer RTs as evidence of interference. It may be again that the task doesn't place enough demands on EF for the D-DLD group to experience difficulty. The D-DLD group do not show difficulty in simple nonverbal tasks. The impaired groups all responded faster than their ability level groups as expected: RA vs. dyslexic, $t(40.19) = -2.86$, p < .01, d = 0.83, LA/DLD vs. DLD, $t(14.04) = -2.80$, p <.01, d = 1.25, D-DLD vs RA, $t(48) = -2.39$, p < .01, d = 0.67, D-DLD vs. LA/D-DLD, $t(50) = -2.08$, p < .0167, d = 0.60.

3.2 Experiment 2b: Verbal inhibition

3.2.1 Hypotheses

A verbal Stroop task was administered to assess verbal inhibition. Predictions are made in relation to accuracy and RT scores, for both congruent and incongruent trials, accuracy scores were d' scores.

Similarly to the nonverbal task, I predict a Stroop effect. Participants will perform faster, and be more accurate in congruent trials than incongruent trials (MacLeod, 1991). Therefore, for congruent trials, for *d′* and RT, I predict that there will be no group differences between the CA and impaired groups and the impaired groups and each other. Impaired groups will perform similarly to ability level groups for d' and RT.

For incongruent trials, for both *d′* and RT, I predict, that both the dyslexic and D-DLD group will experience a difficulty compared to the CA group (Everatt et al., 2008; Lukács et al., 2016; Wang et al., 2012). The DLD group will not show a deficit in verbal inhibition compared to the CA group. The DLD group will score higher than the D-DLD and dyslexic groups. For ability level groups, for *d′,* I predict that dyslexic and D-DLD group will score similarly to the RA group as their performance on the verbal task will be appropriate for literacy age. Similarly, the D-DLD group will score similarly to the LA/D-DLD group. The DLD group will score higher than the LA/DLD group due to their age. For RT, impaired groups will react faster than their ability level groups.

3.2.2 Method

3.2.2.1 Participants

Participants in the CA, D-DLD, DLD and dyslexic groups completed inhibition measures at T1. Of the 148 participants who completed measures for the thesis, 146 took part in the verbal inhibition task. One participant in the dyslexic group completed partial T1 measures and so did not complete the Stroop task. Their subsequent ability match in the RA group was also removed from analysis. This left 28 dyslexic (28 RA), 10 DLD (10 LA/DLD), 28 D-DLD (28 LA/D-DLD) and 23 CA participants. Data was treated in same fashion as for the nonverbal task. I calculated the overall *d′,* across both congruent and incongruent trials for each participant. This was to assess how reliably participants responded to whether the voice stimulus was male or female. High *d′* indicates that participants were highly sensitive to task manipulation, identifying the gender of the voice regardless of the word stimulus gender. Participants who had an overall *d′* 2SD below the grand mean (2.02, SD 0.79) were removed on the basis that they were not sensitive to the task manipulation. This excluded six additional participants in total: one participant in the LA/D-DLD group (and their matched participant in the D-DLD group), one participant in the D-DLD group (and their matched participant in the LA/D-DLD group) and two CA participants (group wise matched).

3.2.1.2 Design and procedure

The verbal Stroop task was designed as a verbal parallel to the nonverbal Simon task. To that extent it used the same experimental template (I.e. number / type of trials) as the nonverbal task taken from Bialystok (2006). I substituted the nonverbal stimuli (arrow images) for verbal parallels (voices) played aurally. The inspiration to use male and female voices (saying boy or girl) came from Green and Barber (1981). Participants were required to listen to voices over the headphones and indicate, as quickly as possible, whether they thought the voice was male or female, whilst ignoring the gender of the word. Experimental stimuli were made up of five different male voices and five different female voices. Utterances were either congruent (a male voice saying the word boy, a female voice saying the word girl) or incongruent (a male voice saying the word girl, a female voice saying the word boy).

Each male and female voice provided both a congruent and incongruent sound file which were normalised using Audacity and had white noise removed. For the experimental phase, a total of 120 trials were split in to three blocks of 40 trials. Each block contained an even distribution of male / female, congruent / incongruent, voices one to five. In total each block contained 20 male items and 20 female items, within which 10 were congruent and 10 were incongruent and within which two of each were voice 1, 2, etc. The trial order within each block was created by randomly ordering these 40 sound files using a number generator. The trial and block order remained constant for each participant. For each trial, sound files were set to play for 1000ms.

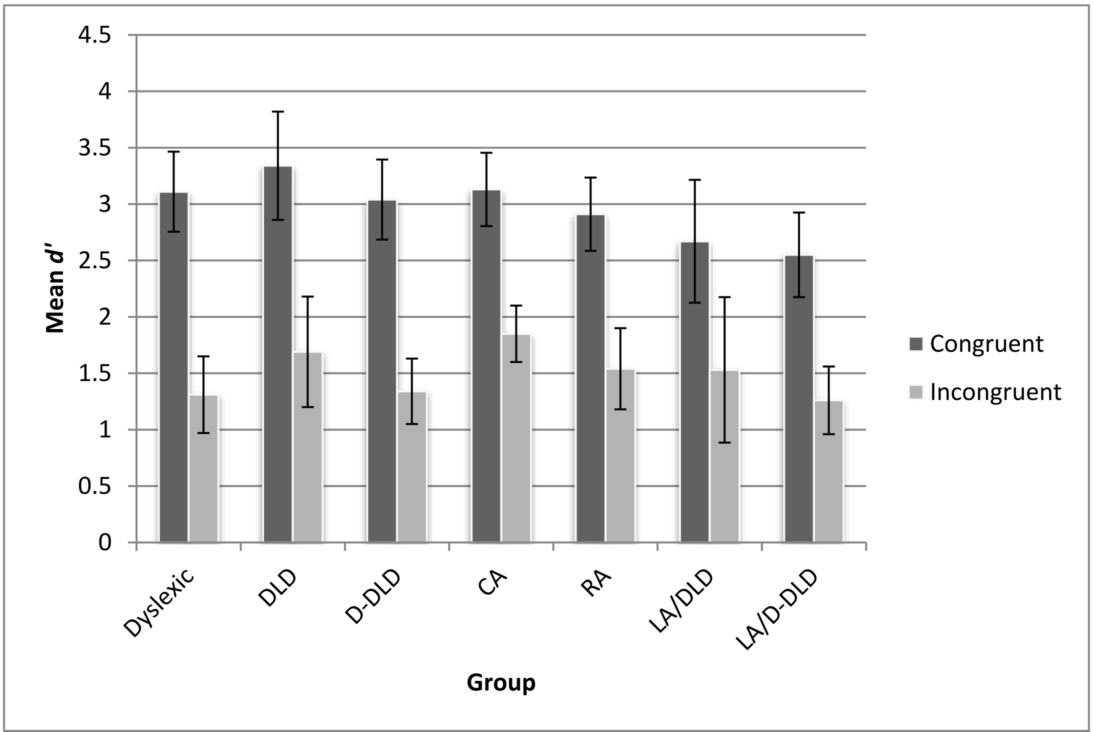
The experiment only continued when a response via keyboard press had been registered. A response of ‘female’ was recorded by pressing the ‘V’ key (covered with a picture of a girl) and a response of ‘male’ was recorded by pressing the ‘B’ key (covered with a picture of a boy).

Opensesame did not record responses until the sound file had finished (or until after duration of 1000ms from trial onset). Participants occasionally responded whilst the sound file was still playing and the response was not registered. Participants were told that they should repeat their last response as quickly as possible if the task did not move on.

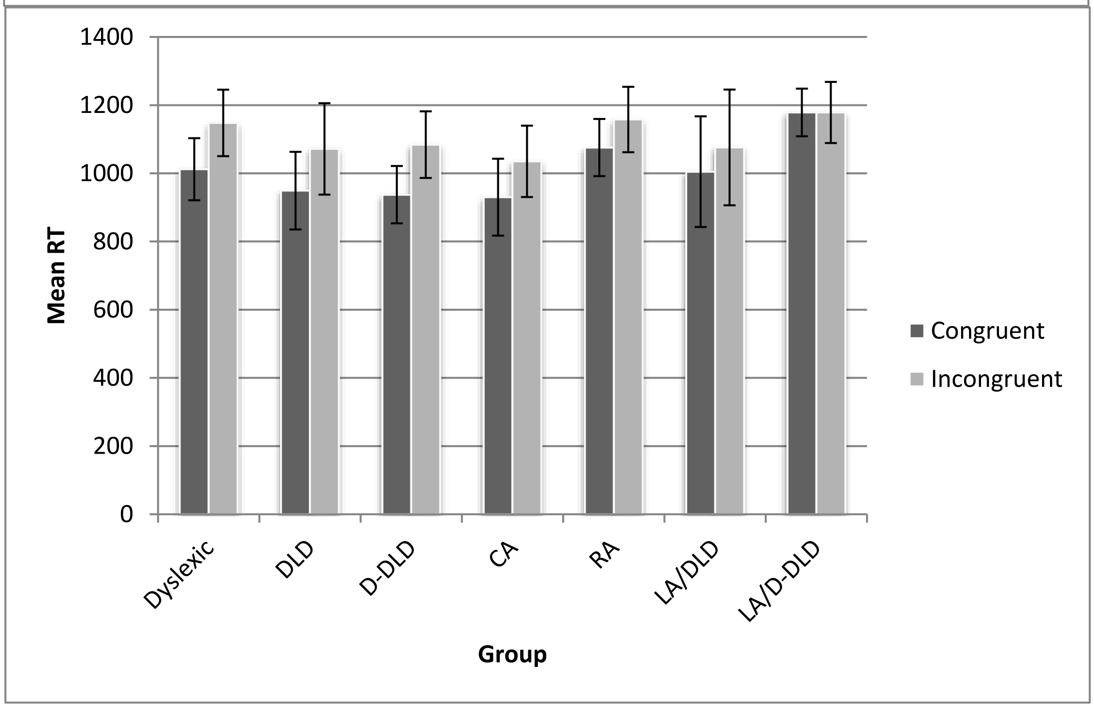
Participants completed four practice trials in which they heard one of each type of trial, one congruent and one incongruent male voice and one congruent and one incongruent female voice. Every effort was made at this stage to ensure that participants fully understood the task requirements before moving on. The task was designed and built using Opensesame version 2.8.0 with an xpyriment back-end. The task was administered on a Toshiba Satellite Pro L850-1DV laptop.

3.2.3 Results and discussion

For RT analysis, trials were trimmed in accordance with Kane and Engle (2003) and also the nonverbal results outlined in section 3.1.3 of this chapter. Trials that exceeded 3SD from the individual participant's mean RT were removed, as were trials less than 200ms and incorrect trials. This resulted in a total number of 815 trials being removed which equated to 4.82% of total trials. Again this was in line with the nonverbal results and the percentage recommended by Macleod (1991). The percentage of trials removed for the verbal task was similar to that removed from the nonverbal task (4.12%). We then calculated *d'* and RTs for both congruent and incongruent trials separately. See Figure 13 for mean d' and RTs respectively.



4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Mean *d'*
Dyslexic
DLD
D-DLD
CA
RA
LA/DLD
LA/D-DLD
Group
Congruent
Incongruent



1400
1200
1000
800
600
400
200
0
Mean RT
Dyslexic
DLD
D-DLD
CA
RA
LA/DLD
LA/D-DLD
Group
Congruent
Incongruent

Figure 13: Mean group *d'* and RTs for congruent and incongruent trials for the Stroop task with confidence intervals (95%) in error bars.

3.2.3.1 Accuracy

As expected, a mixed ANOVA with impaired / CA groups confirmed a main effect of congruency with participants performing more accurately in the congruent (M=3.12, SD = .82) than the incongruent trials (M=1.50, SD=.76), $F(1, 81) = 229.3$, $p < .001$, r = 0.86. There was no main effect of group $F(3, 81) = 1.45$, $p = .23$, r = 0.22 or interaction between group and congruency $F(3, 81) = 1.42$, $p = .24$, r = 0.22. This confirmed the presence of a Stroop effect and that groups were sensitive to the task manipulation, Figure 13.

As expected, there were no group differences in congruent only trials $F(3, 81) = 0.33$, $p = .80$, $r = 0.11$. Planned contrasts confirmed no group differences. All of the impaired groups performed similarly to their ability level matches as expected: dyslexic vs. RA, $t(54) = 0.81$, $p =.42$, $d = 0.22$, D-DLD vs. RA, $t(52) = 0.52$, $p = .61$, $d = 0.14$, D-DLD vs. LA/D-DLD, $t(50) = 1.95$, $p = .06$, $d = 0.55$, DLD vs. LA/DLD, $t(18) = 2.09$, $p = .05$, $d = 0.94$. This confirms that interference did not occur in the congruent only trials.

As expected, there were group differences in incongruent trials, $F(3,81) = 2.84$, $p < .04$, $r = 0.32$. Planned comparisons confirmed that the CA group had higher accuracy than both the dyslexic group, $t(81) = 2.53$, $p < .0167$, $d = 0.36$, and the D-DLD group, $t(81) = 2.38$, $p < .0167$, $d = 0.34$ as expected. This suggests that both the D-DLD and dyslexic group experience difficulty in verbal EF. The DLD group performed similarly to the CA group also as expected, $t(81) = 0.57$, $p = .57$, $d = 0.11$. This suggests that the DLD group have proficient verbal EF skills which may buffer them against developing additional literacy difficulty.

The impaired groups all performed similarly: dyslexic and D-DLD, $t(81) = -0.12$, $p = .90$, $d = 0.01$, dyslexic and DLD, $t(81) = 1.39$, $p = .17$, $d = 0.25$, D-DLD and DLD, $t(81) = 1.29$, $p = .20$, $d = 0.24$. I suspected the DLD group may outperform the dyslexic and D-DLD groups due to proficient EF skills but they did not. All of the impaired groups performed similarly to their corresponding ability level groups: dyslexic vs. RA, $t(54) = -0.95$, $p = .35$, $d = 0.25$, D-DLD vs. RA, $t(52) = -0.90$, $p = .37$, $d = 0.20$, DLD vs. LA/DLD, $t(18) = 0 .46$, $p = .65$, $d = 0.16$), LA/D-DLD vs. D-DLD, $t(50) = 0.37$, $p = .71$, $d = 0.07$. This was expected for all ability level groups apart from the DLD and LA/DLD group. It suggests that the dyslexic and D-DLD groups perform at a level which is appropriate for their ability.

3.2.3.1 Reaction Time

As expected, a mixed ANOVA confirmed a main effect of congruency $F(1, 81) = 144.09$, $p < .01$, $r = 0.80$, with congruent trials producing faster RTs ($M = 961.55$, $SD = 221.97$) than incongruent trials ($M = 1091.54$, $SD = 236.62$). There was no main effect of group ($F3$, 81) = 0.85, $p = .47$, $r = 0.17$). There was also no interaction between group and congruency (F3, 81) = 0.90, $p = .45$, $r = 0.17$). This confirmed a Stroop effect as above, Figure 13.

RTs confirmed that there were no group differences in congruent only trials as expected, $F(3, 81) = 0.73$, $p = .54$, $r = 0.16$. Planned contrasts confirmed no group differences. The impaired groups performed similarly to the ability level groups as expected: dyslexic vs. RA, $t(54) = -1.05$, $p = .30$, $d = 0.28$, D-DLD vs. RA, $t(52) = -2.39$, $p = .04$, $d = 0.65$, DLD vs. LA/DLD, $t(18) = -0.64$, $p = .53$, $d = 0.28$, D-DLD vs. LA/D-DLD, $t(50) = -2.11$, $p = .05$, $d = 0.59$. This confirms that interference did not occur in the congruent only trials.

There were no group differences in incongruent only trials, $F(3,81) = 0.96$, $p = .42$, $r = 0.18$. Planned contrasts confirmed no group differences. All of the impaired groups performed similarly to their corresponding ability level groups: dyslexic vs. RA, $t(54) = -0.15$, $p = .88$, $d = 0.04$, D-DLD vs. RA, $t(52) = -1.11$, $p = .27$, $d = 0.30$, D-DLD vs. LA/D-DLD, $t(50) = -1.47$, $p = .15$, $d = 0.41$, DLD vs. LA/DLD, $t(18) = -0.05$, $p = .97$, $d = 0.02$. These results for incongruent RTs were not expected. However group differences were seen in incongruent trials for *d'*. Often differences between groups will become apparent in either RT or *d'* sensitivity but not both which may explain our results.

3.3 Experiment 2 discussion

For the nonverbal inhibition task, no group differences were revealed between D-DLD and CA groups. I had expected to see difficulties in the D-DLD group compared to the other groups. It could be that the executive demands of the task were not large enough to reveal deficits in the D-DLD group. D-DLD participants do not experience a nonverbal memory of processing deficit. Instead they experience a difficulty in the domain general CE which controls EF. Task demands must be high enough to illicit the use of EF and this may not have been the case for our nonverbal task.

For the verbal task, as expected, the dyslexic and D-DLD groups showed a difficulty compared to the CA group. We expected this following the verbal STM deficit seen for both groups. Verbal EF necessarily acts on the verbal STM and so it was expected that verbal difficulties would follow through in to verbal inhibition tasks.

6. General Discussion

6.1 Summary of key findings

For the updating measures group differences only really became apparent in the 1-back (nonverbal) and 2-back (verbal) conditions. Similarly for inhibition, group differences were only really apparent in accuracy measures rather than RT measures. The following discussion focuses on these elements therefore.

The dyslexic group showed difficulty in verbal but not nonverbal updating measures compared to the CA group which supports previous literature (Smith-Spark et al., 2003; Smith-Spark & Fisk, 2007; Wang et al., 2012). Differences between the dyslexic and CA group remained for verbal updating even after controlling for baseline ability. This suggests differences are not explained by differences in verbal ability. They performed similarly to the RA group suggesting that updating ability is appropriate given literacy age. This is in contrast to verbal STM deficits (see chapter three) which are impaired relative to RAs and CAs indicating a deficit. It is likely therefore than any difficulties in verbal updating are a result of faulty verbal STM processes. A similar profile was seen for verbal inhibition, with the dyslexic group scoring lower than the CA group but similar to RAs. The dyslexic group showed similar performance to the D-DLD group on verbal and nonverbal EF tasks.

The D-DLD group showed difficulty in both verbal and nonverbal updating compared to CAs which supports previous literature (Henry et al., 2012; Im-Bolter et al.,2006; Lukács et al., 2016; Spaulding, 2010).Differences remained between the CA and D-DLD group for verbal updating even after controlling for baseline ability. This suggests group differences are not explained by baseline verbal ability. The D-DLD group performed worse than the DLD group for the verbal updating task suggesting they experience the largest deficit. This supports a double deficit for D-DLD groups in verbal tasks requiring verbal STM and EF. The D-DLD group also showed a difficulty in verbal inhibition compared to CAs. They performed appropriately for literacy and language ability.

The DLD group, were not impaired in verbal or nonverbal updating compared to CAs. They also performed better than both the dyslexic and D-DLD groups on nonverbal tasks. Only the D-DLD group showed difficulty relative to the CA group for nonverbal updating. Therefore the DLD group may actually show a relative proficiency in nonverbal updating, although not significantly more than the CA group. This supports the idea that DLD groups have a relative proficiency in EF skills that buffer them against literacy difficulty. They also scored higher than the LA/DLD group for both measures which gives more weight to this argument. It is interesting to note that in the 0-back, baseline verbal updating condition, the DLD group scored higher than the CA group. This was unexpected. The baseline condition requires participants to identify verbal targets and it could be that this ability is linked to another factor that aids DLD groups in literacy development. To be successful at the 0-back participants have to keep a target in mind and make online comparisons to this over time. This is a verbal WM skill and results from chapter two suggest that the DLD group are not impaired in this. WM requires EF and again this may be evidence of strong EF ability in DLD. The DLD group did not show a difficulty in verbal inhibition compared to the CA group. They also performed similarly to the other impaired groups. This again suggests that they may experience slight difficulty in tasks which tap verbal stores.

For nonverbal inhibition none of my impaired groups showed a difficulty relative to CAs. There were no real differences between any of the groups for any type of trial. This extended to limited differences between the younger ability level groups and the older impaired groups also. Looking at mean d’ scores for the nonverbal task, see Figure 12, scores for all groups were high, much higher than the d’ scores seen for verbal inhibition, see Figure 13. d’ scores of two or less are considered to be within a typical range (Macmillan & Creelman, 2004). Whilst my verbal scores adhere to this, scores for nonverbal inhibition are much higher, suggesting that participants scored correctly a large percentage of the time, for both congruent and incongruent trials.

It may be then that nonverbal inhibition deficits do exist in my impaired groups but that the task is too easy to reveal them. I was expecting the D-DLD group to show a deficit relative to other groups. This is certainly the case for nonverbal updating, so it is strange that the pattern isn’t also seen in inhibition. Therefore it is likely that the results were the product of the task and that it was simply too easy to reveal group differences. Having said this research has suggested that only younger groups with D-DLD experience a difficulty in prepotent response inhibition (Marton et al., 2012). A difficulty is observed for verbal tasks indicating D-DLD groups do experience difficulty in prepotent inhibition. It seems then that the impaired groups are producing more ceiling effects in nonverbal tasks than verbal tasks. This seems logical given the age of the groups. If the groups have experienced verbal difficulties throughout life then they may well have had to compensate nonverbally, developing these skills.

6.2 Limitations

We also experienced some technological design difficulties for the Stroop task. If participants responded too quickly, i.e. before the sound clip had finished playing, then responses did not register. This was not uncommon as participants often responded from the first phoneme of the word automatically due to the task manipulation. To an extent this did not affect results as responses with very short latencies were removed. If the task didn't move on (indicative of a response that was too quick), participants had to quickly repress their response. Again responses that were too long were also removed but it is likely that some of these 'represses' fell in between both of these cut offs. Next time I would try to rectify this by recording responses from stimulus onset rather than offset.

Similarly to the nonverbal STM / WM tasks, the lack of differences in the nonverbal inhibition task could have been due to task demands. It seems that participants hit ceiling in nonverbal inhibition. In future I would like to rectify this by administering a more complex nonverbal inhibition task. I believe that this would then highlight nonverbal inhibition differences in my groups. For example the arrows that appear on the left and right of the screen (facing left and right) could be both black and red. Participants would be required to respond / indicate the direction of the black arrows but not respond to the red arrows. This would be similar to a go no go task. This would provide a more complex inhibition task. However this also introduces other issues of task impurity. The task would now be measuring two types of inhibition, both distractor and prepotent response.

6.3 Conclusions

The dyslexic and D-DLD groups show a difficulty in verbal updating and inhibition which is likely caused by underlying deficit in verbal STM. The D-DLD group shows additional difficulty in nonverbal updating suggesting a wider problem in tasks requiring domain general EF. The D-DLD group experience a double deficit in both tasks tapping verbal STM and EF. The DLD group show proficiency in verbal and nonverbal tasks supporting a proficiency in domain general EF.

6.4 Thesis Map

Figure ***14*** shows the updated thesis map for this chapter, incorporating EF measures in to the figure.

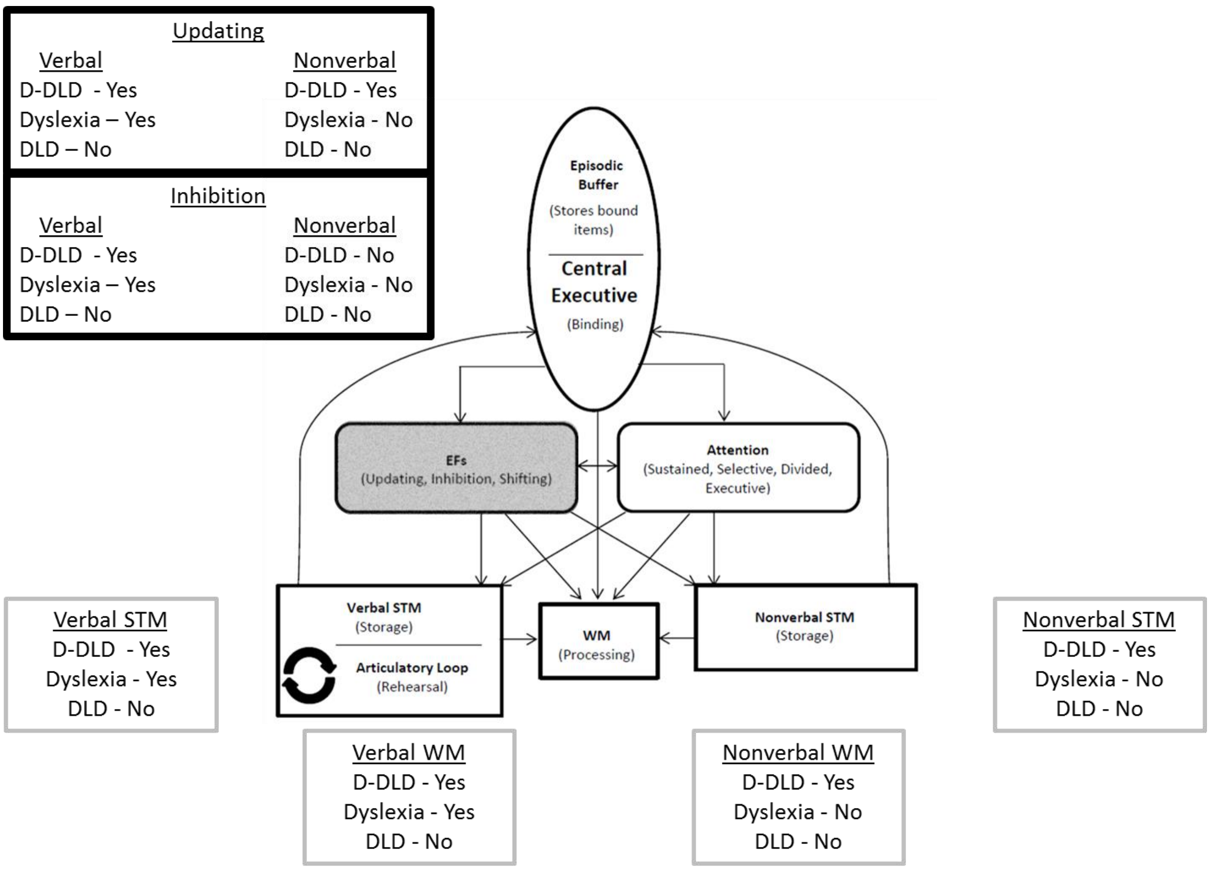


Figure 14: Summary of difficulty (Yes. No) for each group in EF tasks.

Chapter 5 - Attention

1. General introduction

This chapter focuses on two types of attention; sustained attention and selective attention, Experiment 1 and 2 respectively at T2. Attentional mechanisms are controlled by the CE (Baddeley, 2012). They develop early on and underlie more complex processes such as EF (Garon, Bryson, &

Smith, 2008). EFs and attentional processes interact with each other homogenously, enabling WM and acting on information in the short-term stores, Figure 3.

Sustained attention is the continued attention to stimuli over a prolonged period of time. Selective attention is the ability to narrow the focus of attention and select certain stimuli over others. A problem in attention research is that these abilities necessarily conflate one or more processes and therefore are particularly hard to test in isolation (Moores et al., 2003). For instance, sustained attention or maintaining a focus inherently requires an ability to inhibit and ignore irrelevant or distracting information. Similarly selective attention not only requires participants to narrow their focus but also use processes such as shifting to move this focus of attention from one stimulus to the next. Inhibition and shifting are more often discussed in relation to EF over attention.

A similar problem lies in the use of terminology. Several researchers have postulated the existence of several different types of attention all with varying and overlapping titles. As an example, one researcher may describe selective attention (Finneran et al., 2009), another may describe orientating attention (Makovski, Sussman, & Jiang, 2008). Both processes involve a narrowing or attentional focus. It is difficult to know whether the terms are synonymous or the latter is referring more to the shifting or executive aspects of selective attention or vice versa. This problem exists for all types of attention with each being attributed several different labels.

Whilst some researcher make distinctions between selective, sustained and executive attention, others have blended terms to discuss selective sustained attention (Hanson & Montgomery, 2002; Kapa, Plante, & Doubleday, 2017; Spaulding et al., 2008). In papers that blend these terms, researchers often administer tasks thought to asses both elements of attention. In this chapter, where possible I will discuss the literature in relation to sustained and then selective attention separately.

It is difficult to ascertain which attention processes are separable from others. Sustained attention necessarily requires the participant to first focus their attention selectively but then maintain this for a long period of time. At the same time both of these attentional processes are likely governed by a third type of attention, executive attention, which is responsible for choosing which processes to allocate resources to. For this reason it is better to consider attention as a complex, unitary concept which changes to meet the demands of the situation. At times attention is required to act selectively and at others it is required to divide resources to both select and maintain focus on a task.

Experiment 1 focuses on sustained attention and Experiment 2 selective attention. In previous chapters a distinction had been made between verbal and nonverbal tasks. This chapter (and the remaining chapter) moves away from this. EFs and the CE are domain general acting on verbal or nonverbal stimuli in STM stores. Attention processes are also domain general. For attention, tasks often embody both verbal and nonverbal elements simultaneously. I have tried where possible in the literature to indicate if a task has predominantly verbal or nonverbal demands. However, I have mostly concentrated on tasks that tap one certain type of attention or another.

2. Experiment 1 – Sustained attention

A task often used to assess sustained attention is the Continuous Performance Task (CPT). Whilst CPT tasks vary in the type of stimuli used or the length of the task / trials, they all adhere to the same basic format. Participants have to maintain their focus on a task over a long period of time that is often boring or repetitive. The have to identify targets and sometimes inhibit responses to foils or stop signals. In tasks requiring target identification / ignoring foils, more than one measure can be extracted. Hits and misses of a target measure sustained attention whilst false alarms (responding incorrectly to distractors / foils) indicate a deficit of selective attention (Wang, Tsai, & Yang, 2013).

2.0.1 Dyslexia

Several studies have suggested that sustained attention is an area of relative strength in dyslexia. If difficulties do arise, they can be explained by comorbid task demands. For example, phonological recoding of stimuli, verbal STM or additional verbal or auditory inhibition demands that dyslexic participants experience difficulty with (Liberman et al., 1982; Palmer, 2000; Reiter et al., 2004). Marzocchi et al. (2009) administered three attention tasks to dyslexic and CA children (7 – 12 years). In the 'Score' task from the TEA-Ch (Manly et al., 1998) participants silently counted strings of nine to 15 identical tones, reporting the number of tones in the brief gap between strings. Marzocchi et al. (2009) also administered the Walk don't Walk (WDW) task from the TEA-Ch (Manly et al., 1998), described in full the method section of Experiment 1. In a third task, an auditory CPT task, participants listened to a long string of phonemes, responding to "o" but refraining otherwise. Misses were recorded. Dyslexic participants performed worse than CAs on the Score and WDW tasks. They performed similarly to CAs on the auditory CPT task.

However, when phonological ability was controlled for, dyslexic participants performed similarly to CAs on the Score task. Indeed, there was a very high correlation between phonological ability and Score task performance for all groups. To keep count in the Score task, children have to employ the phonological loop to retain the number of tones counted and update the total number of tones. Dyslexic children are impaired on tasks requiring the phonological loop (Liberman et al., 1982) and verbal updating (Smith-Spark et al., 2003). Similarly, the WDW task requires additional auditory inhibition skills. The two tones (go and stop) are identical at onset and must be listened to in full to establish their identity. Dyslexic participants struggle with tone discrimination (see Heiervang, Stevenson, & Hugdahl, 2002) and auditory inhibition (Lee Swanson et al., 2006; Wang et al., 2013). For the auditory CPT task, dyslexic participants did not experience difficulty. This is likely due to reduced verbal demands. Whereas the Score task requires verbal STM and verbal updating, the auditory CPT task only requires verbal STM.

Similarly, Vavara, Varuzza, Padovano Sorrentino, Vicari and Menghini (2014) and Menghini et al. (2010) administered the Code Transmission task from the TEA-Ch (Manly et al., 1998) described in full in the method section of Experiment 1. They administered the task to dyslexic and CA participants 8 – 17 years and 12 years respectively. In both studies, the dyslexic group scored lower than the CA group. However, the Code Transmission task involves confounding task demands, including verbal WM and verbal updating. Participants are required to update the number stored whilst listening for the cue. Dyslexic participants are impaired in tasks assessing verbal updating (Smith-Spark et al., 2003). Due to the hierarchical nature of WM it is hard to ascertain whether deficits in these tasks then are due to attention or a result of verbal difficulty in dyslexic groups.

Dyslexic participants may also experience difficulty with letter / word stimuli even when it is presented visually due to a deficit in the automatic recognition of words / digits. Moores and Andrade (2000) administered several tasks to two groups of dyslexic and two groups of CA age matched participants (14, 19 years). Participants first completed the Sustained Attention to Response task (SART), a CPT task. Participants were shown digits sequentially on a screen responding to any number except ‘3’. The aim was to respond as quickly as possible whilst making few errors. Participants also completed a novel ‘squiggle’ SART in which the numbers were replaced with non-nameable shapes and a target shape was selected to be ignored. They also completed a nonverbal go – no go task to assess inhibition. Whilst the dyslexic groups scored lower than the CA groups on the original SART, no group differences were found for the squiggle SART or the nonverbal inhibition task. Group differences in the original SART are not caused by sustained attention difficulties but rather stimulus recognition differences. When required to respond quickly, dyslexic individuals experience a shape recognition automaticity deficit compared to CAs. This suggests that dyslexic individuals have a difficulty in automatically recognising letters and digits (Fawcett & Nicolson, 1994). It is well known that individuals with dyslexia experience a difficulty in RAN tasks in which they have to rapidly name digits. A similar automaticity deficit likely underlies both types of task.

Other studies have found no group differences in CPT tasks using visually presented letters (Kupietz, 1990). Taroyan, Nicolson and Fawcett (2007) found dyslexic (14 – 18 years) and a CA group performed similarly on a CPT task. Participants were required to withhold responses unless “O” was followed by “X” on screen. Arguably the letter stimuli do carry verbal demands that potentially would cause difficulty in dyslexic groups. However a key difference between this task and the CPT task in Moores and Andrade (2000), which used nameable digits, is the pressure to respond quickly and accurately and the type of responding. In Moores and Andrade, (2000), participants continually respond until a certain target appears, at which point they withhold a response. This requires prepotent response inhibition, the active withholding of a response which dyslexic participants have difficulty with (Helland & Asbjørnsen, 2000; Reiter et al., 2004). Taroyan et al. (2007) use a task with positive responding, that is actively making a response only when a target appears on screen. The rest of the time participants are not responding. They do not have to inhibit a response, only respond when the target is present.

Few differences have been found between dyslexic participants and CA groups on tasks involving nonverbal stimuli. Wang et al. (2013) found no difference between a dyslexic group (10 years) and a CA group on a geometric figure task and interesting figure task. In the former, participants saw shapes pass from the left to the right of the screen. The aim was to press the button when targets (not the distractors) passed through a red box in the middle of the screen. False alarms and misses were analysed. Dyslexic participants performed similarly to the CA control group for misses assessing sustained attention. For the interesting figures task, geometric shapes were replaced by pictures of objects (e.g. cat), designed to increase attention. The dyslexic group again performed similarly to the CA control group. Without verbal demands dyslexic participants show a proficiency in sustained attention tasks.

Similarly, Moores et al. (2003) administered nonverbal CPT tasks to two groups of dyslexic and two groups of CA children (14 years, 18 years). In a focus condition, participants responded to target shapes and ignored distractors. In the shift condition, the target alternated between an oval and square. Hits and false alarms were analysed. There were no group differences in hits for the focus condition. A difference in hits was revealed for the shift condition but when first and second half task performances were analysed, dyslexic individuals performed similarly on first and second half suggesting no fall in level of attention throughout the task. This suggests that any group differences are likely caused by shifting demands rather than the sustained focusing of attention for nonverbal stimuli.

2.0.2 D-DLD

Sustained attention correlates with several language skills including both simple and complex sentence comprehension (Montgomery et al., 2009), language production (Duinmeijer et al., 2012) and narrative generation (Blom & Boerma, 2016). It is unsurprising therefore that robust evidence for deficits have been found in both verbal (Spaulding et al., 2008) and nonverbal (Finneran et al., 2009) sustained attention for children with D-DLD. Ebert and Kohnert, (2011) performed a meta-analysis of 33 sustained attention tasks in D-DLD children. The analysis revealed deficits in both verbal and nonverbal sustained attention tasks (even when controlling for comorbid ADHD). Effect sizes were larger for tasks assessing verbal and auditory domains. This suggests that children with D-DLD experience a wider range of sustained attention deficits than dyslexic groups. However, their difficulties are most pronounced in verbal tasks.

As with dyslexia, CPT tasks are often utilised to assess sustained attention and show a pervasive difficulty in participants with D-DLD in both verbal and nonverbal domains. Jongman, Roelofs, Scheper and Meyer (2017) administered an auditory and nonverbal CPT task as well as a picture naming task to D-DLD participants (7-9 years) and CAs. The D-DLD group performed worse that the CA group on all tasks. The D-DLD group performed worse in the auditory task than the visual task but this was not true for the CA group. Performance on both CPT tasks also correlated with picture naming speed for the groups.

Montgomery et al. (2009) and Montgomery (2008) found similar results in a verbal CPT task and a picture-pointing sentence comprehension task. They assessed D-DLD children (6-10 years) compared to a CA age matched group. For the verbal CPT task participants listened to a long list of monosyllabic words, responding to “dog” but otherwise withholding responses. For the sentence comprehension task, participants listened to a sentence before pointing to the most relevant picture. The D-DLD group scored lower than the CA group on the verbal CPT task and complex (not simple) sentence comprehension. Performance on the verbal CPT task correlated with both simple and complex sentence comprehension in the D-DLD but not CA group. These studies suggest that D-DLD groups experience a difficulty in both verbal and nonverbal CPT tasks assessing sustained attention. They evidence the reciprocal role that sustained attention plays in comprehension and naming skills in language and vice-versa. Sustained attention difficulties then could be a fundamental, underlying deficit responsible for language difficulties in D-DLD.

Not all studies have found a difficulty in nonverbal attention, although this may be due to measures used rather than a lack of difference between groups. Noterdaeme et al. (2001) worked with D-DLD children (13 years) and a CA group. They administered CPT tasks, two nonverbal and two verbal. The D-DLD group performed worse than the CA group on both verbal tasks but only one of the nonverbal tasks. However, this may have been due to use of RT data over accuracy. Previous studies (including the inhibition studies seen in chapter four of this thesis) have failed to find differences in RT measures despite clear differences in accuracy data. Finneran et al. (2009) assessed nonverbal sustained attention in D-DLD children (4 – 6 years) compared to a CA group. Participants completed a nonverbal CPT task, responding to circles but ignoring squares. There were no differences between groups for RTs but accuracy measures revealed group differences. Measures used therefore may be particularly important when making conclusions about sustained attention deficits.

Other studies have failed to find non-verbal deficits in D-DLD groups despite using RT and accuracy measures. Spaulding et al. (2008) looked at sustained selective attention in D-DLD children and a CA age matched group (5 years). They included a mixture of verbal, nonverbal and auditory sustained attention tasks. Attentional loads could either be high or low. For the verbal and auditory tasks, the D-DLD group scored lower than the CA group under high attentional loads. There were no group differences for low attentional loads in any mode of stimuli. There was also no difference between groups for the nonverbal tasks. Similar results were found for both accuracy and RT. This study suggests that D-DLD participants experience greater difficulty in verbal than nonverbal tasks. Kapa et al. (2017) also found limited nonverbal difficulties in a D-DLD group compared to a CA group (5 years). They administered verbal and nonverbal CPT tasks to participants. For the verbal task stimuli were short sentences with a target phrase. For the nonverbal task stimuli were animal pictures with a target. They found differences in the verbal but not nonverbal tasks. Both groups scored near maximum for the task and therefore ceiling effects may explain the lack of difference between groups.

Relatively few studies have included language ability level groups compared to D-DLD participants when assessing sustained attention. This is surprising given the strong link between language and sustained attention. Marton et al. (2012) assessed sustained attention in D-DLD children (10 – 14 years) a CA group, as well as a language level matched group (8 – 13 years). Participants completed a variation of the CPT task, withholding responses unless they saw a target sequence. The D-DLD group performed similarly to the CA group and better than the language level group. Contrary to other research using similar tasks, this suggests that for older D-DLD groups, sustained attention is age appropriate.

2.1 Summary

To the best of my knowledge no study has directly compared dyslexia and DLD in terms of their sustained attention ability. The existing evidence suggests that dyslexic individuals only experience a difficulty in sustained attention tasks when they implicate verbal or auditory stimuli

(Marzocchi et al., 2009; Vavara et al., 2014). Dyslexic participants do not seem to experience a difficulty in sustained attention tasks with nonverbal stimuli (Wang et al., 2013). At the same time comorbid (and potentially unavoidable) verbal STM or executive demands (Moores & Andrade, 2000; Moores et al., 2003) also present a difficulty for dyslexic participants. Due to the very nature of the WM system, attention processes necessarily direct focus to and activate EFs necessary for task completion. In turn EFs act on verbal or nonverbal stimuli contained within the temporary stores. The whole process is governed by the CE supervisory system. Different attention tasks place higher and lower demands on EFs and this coupled with verbal stimuli present a particular difficulty for dyslexic participants. Figure 3 shows the interrelationship between these different processes.

Individuals with D-DLD, seem to exhibit a broader deficit in both verbal and nonverbal domains (Ebert & Kohnert, 2011; Finneran et al., 2009; Jongman et al., 2017). Not all studies have found this deficit in nonverbal sustained attention (Spaulding et al., 2008). This may be due in part to measures used (Finneran et al., 2009) or ceiling effects (Kapa et al., 2017). Studies with CA and language matched participants suggest that sustained attention may not be dependent on language ability (Marton et al., 2012).

2.1.1 Hypotheses

The tasks included as sustained attention measures are well developed and common within the literature. They are the CPT tasks 'Code transmission' and also the WDW task from the TEA-Ch (Manly et al., 1998). The Code transmission task is purely verbal in nature with stimuli presented audibly and responses given orally. I would expect dyslexic and D-DLD groups to show difficulty in this task due to the verbal nature of the stimuli. The WDW task on the other hand includes both visual and auditory elements however and so predictions cannot be made based purely on the modality of the task.

In terms of previous research, studies suggest that dyslexic groups experience a difficulty in both the WDW task (Marzocchi et al., 2009) and the Code Transmission task (Menghini et al., 2010;

Vavara et al., 2014). Therefore I predict that the dyslexic group will produce lower scores on both of these tasks compared to the CA group. For D-DLD groups, difficulties have been seen in CPT tasks including the Code Transmission task (Jongman et al., 2017) and tasks similar to the WDW task (Montgomery et al., 2009). Therefore I predict that the D-DLD group will score lower than the CA group on both of these tasks.

Both the Code Transmission and WDW tasks utilise a certain level of updating and inhibitory demands. EF is an area of relative strength for DLD groups (see chapter four). Therefore I predict that the DLD group will score similarly to the CA group and better than both of the literacy impaired groups on the tasks.

Limited research has been undertaken with ability level groups and impaired groups for sustained attention. The one study (Marton et al., 2012) reported failed to find sustained attention difficulties for a group of older D-DLD children with verbal stimuli. This is in stark contrast to other studies which have used similar attention measures (Montgomery et al., 2009). I therefore treat potential interpretations about ability level comparisons in this study with caution. Kapa et al. (2017) found that sustained attention difficulties were more severe than other executive and WM difficulties found in D-DLD groups. Further, Garon et al. (2008), suggest that sustained attention abilities develop early on in childhood, followed by WM, inhibition and then shifting ability. Basic skills such as attention underlie more complex skills such as EF. It could be that D-DLD groups experience a fundamental deficit in sustained attention that underpins the other difficulties experienced in EF, WM and language. If this is the case, the D-DLD group might score lower than both CA and ability level groups, indicating a deficit. I predict therefore that the D-DLD group will score lower than the RA and LA/D-DLD groups on the tasks. Deficits in EF are less documented for dyslexic groups and tend to be restricted to verbal domains. This is likely as a result of deficits in verbal STM stores rather than a deficit in domain general attention processes. I predict that the dyslexic group will show a delay in sustained attention tasks, scoring higher than the RA group but lower than the CA group. Lastly I predict the DLD group will score higher than the LA/DLD group.

3. Method

3.1 Participants

In addition to sample attrition at T2, several participants did not return complete data sets for individual attention tasks due to time constraints[11]. Wherever a participant did not return a score for an individual task, their respective match was also removed from analysis.

3.1.1 Code Transmission participants

For the Code Transmission task, data from a total of 117 unique participants were included at T2. This formed the following groups: 25 dyslexic (25 RA), 18 D-DLD (18 LA/DLD), 10 DLD (10 LA/DLD), 20 CA.

3.1.2 WDW participants

For the WDW task, data from a total of 121 unique participants were included at T2. This formed the following groups: 26 dyslexic (26 RA), 20 D-DLD (20 LA/DLD), 10 DLD (10 LA/DLD), 18 CA.

3.2 Design and procedure

To assess attention, two tasks assessing verbal (Code Transmission) and nonverbal (WDW) sustained attention were selected from the Test of Everyday Attention for Children (TEA-Ch; Manly et al., 1998). The tasks were administered in line with the instruction manual. Both tasks had good test re-test reliability (Code Transmission, 0.82; WDW, 0.73).

3.2.1 Code Transmission

For the Code Transmission task (TEA-Ch, Manly et al., 1998), participants listened to a long stream of numbers lasting approximately 12 minutes. Numbers were comprised of the digits one to

[11] For the Code Transmission task this included one dyslexic participant, three D-DLD participants, and one LA-D-DLD participant. For the WDW task this included one D-DLD participant and one LA-D-DLD participant.

nine and presented orally at a rate of one per second in a female voice. Participants had to listen for two consecutive “fives”. Whenever they heard this cue they were required to orally report to number that directly preceded the cue. These targets varied throughout the stream. In line with the manual, number of correct hits were recorded. This was when participants responded at the correct time and also provided the correct number that proceeded “five, five”. In a deviation from the manual, another score was collect, ‘incorrect hits’. This was when participants identified a target presence by responding at the correct time but confused the identity of the target.

3.2.2 WDW

In the WDW task (TEA-Ch, Manly et al., 1998), participants had to mark an answer sheet when one tone played (a go tone) but refrain from making a mark when another tone played (a stop tone). As soon as the stop tone had been played the trial ended and the participants moved on to the next trial. The tones were identical for the first 208ms but then differed. Participants were unable to tell the two tones apart therefore unless they continued to play close attention. The stop tone included a ‘doh’ sound at the end that differentiated it. Participants had to complete 20 trials. Trials were different lengths. The intervals between tones were identical within a trial but gradually sped up with each trial and the task progressed. Intervals began at 1500ms for trial one and then decreased to 500ms for trial 20. Participants completed two practice trials.

4. Results and summary discussion

Below are the results for the Code Transmission and the WDW tasks. First one way ANOVAs compare CA and impaired groups. T-tests are then used to compare impaired and ability level groups. To control for multiple comparisons, a Bonferroni adjusted alpha level ($p<.0167$) was used for significance.

4.1 Code Transmission

Two scores were derived from the Code Transmission task, accuracy for hits and incorrect hits. Means are displayed in Figure 15 for of these scores for each group.

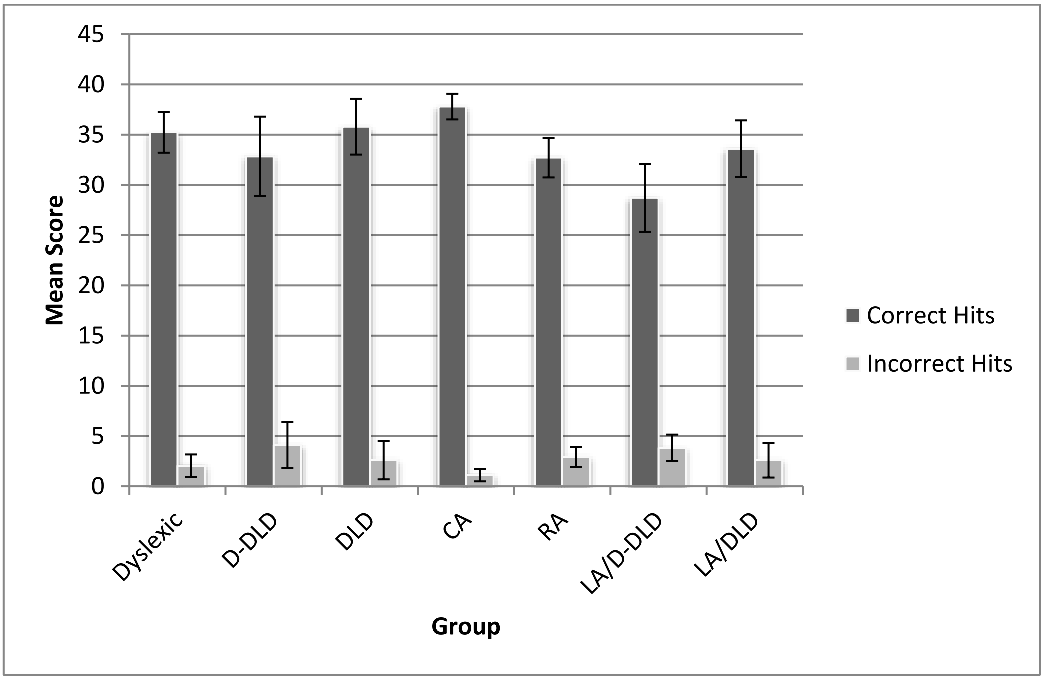


Figure 15: Mean group scores for correct and incorrect hits in the Code Transmission task with confidence intervals (95%) in error bars.

4.1.1 Correct hits

Scores revealed no group differences, *F*(3,69) = 2.62, *p* = .06, r = 0.34 but this tended towards significance. Planned contrasts confirmed no differences between groups when the Bonferroni correction was taken in to account. The difference between the CA and dyslexic, *t*(38.72) = 2.21, *p* =.03, *d* = 0.64, and CA and D-DLD groups, *t*(20.17) = 2.38, *p* =.03, *d* = 0.79, were not significant but tended towards significance. It is possible that a lack of power was responsible for the results obtained. Alternatively, it is possible that this null result reflects ceiling effects with the task being too easy. Participants could score a maximum of 40 on the task. Wang, Zhang, McArdle and Salthouse (2008) caution ceiling effects may impact data when 20% or more of participants are at ceiling. For each of my groups a large proportion scored 39 or above; 45% of the CA group, 30% of the DLD group, 21% of the D-DLD group and 26% of the dyslexic group. With increased difficulty then differences between the CA, dyslexic, and D-DLD groups will likely become significant.

The ability level groups also all performed similarly to their impaired groups: RA vs. dyslexic, *t*(48) = 1.84, *p* =.07, *d* = 0.52, RA vs. D-DLD, *t*(41) = 0.57, *p* = .96, *d* = 0.02, LA/DLD vs. DLD, *t*(18) = 1.26, *p* = .26, *d* = 0.56), LA/D-DLD vs. D-DLD, *t*(34) = 1.61, *p* = .12, *d* = 0.54. It seems that the task is not developmentally sensitive.

4.1.2 Incorrect hits

When screening the data for incorrect hits, an unacceptable level of kurtosis was identified in the sample across all groups combined (skewness = 1.60, kurtosis = 3.15). Therefore a square root + 1 transformation was performed on the data. This reduced the levels of skewness and kurtosis to 0.140 and 1.68 respectively which was acceptable. Analysis for the transformed data is reported. A similar pattern was observed for Incorrect hits as Correct hits. Scores revealed no group differences, *F*(3,69) = 1.96, *p* = .13, r = 0.29. Planned contrasts confirmed this. The ability level groups all performed similarly to their impaired groups: RA vs. dyslexic, *t*(48) = -1.5, *p* =.14, *d* = 0.42, RA vs. D-DLD, *t*(41) = 0.29, *p* = .77, *d* = 0.09, LA/DLD vs. DLD, *t*(18) = -0.35, *p* = .73, *d* = 0.17, LA/D-DLD vs. D-DLD, *t*(26.46) = -0.73, *p* = .47, *d* = 0.24.

4.2 WDW

Raw scores for number of trials passed were analysed for each group.

Figure ***16*** displays the mean scores for each group.

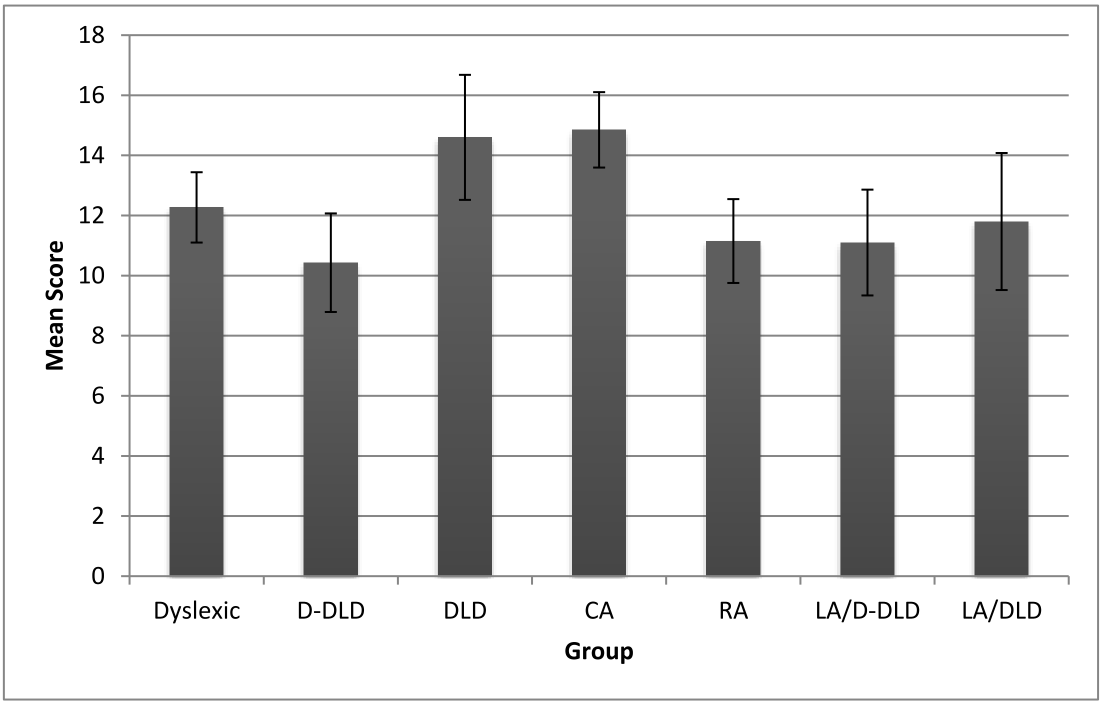


Figure 16: Mean group scores for the WDW task with confidence intervals (95%) in error bars.

Scores confirmed group differences, $F(3,73) = 8.81$, $p < .001$, r = 0.60. Planned contrasts revealed that the CA group scored higher than both the dyslexic group, $t(73) = 2.87$, $p < .01$, $d = 0.96$, and the D-DLD group, $t(73) = 4.68$, $p < .001$, $d = 1.42$ as expected given previous research using sustained attention measures. This confirms that both the dyslexic and D-DLD groups do experience a difficulty in sustaining their attention to tasks. The CA group performed similarly to the DLD group, $t(73) = 0.21$, $p = .83$, $d = 0.09$. The dyslexic group scored similarly to the D-DLD group, $t(73) = 2.08$, $p = .04$, $d = 0.56$, and the DLD group, $t(73) = 2.07$, $p = .04$, $d = 0.80$. The DLD group scored higher than the D-DLD group, $t(73) = 3.59$, $p < .01$, $d = 1.27$.

The ability level groups all performed similarly to their impaired groups: RA vs. dyslexic, $t(50) = 1.26$, $p = .21$, $d = 0.35$, RA vs. D-DLD, $t(44) = -0.44$, $p = .66$, $d = 0.13$, LA/DLD vs. DLD, $t(18) = 2.05$, $p = .06$, $d = 0.91$, LA/D-DLD vs. D-DLD, $t(38) = -0.35$, $p = .73$, $d = 0.11$. This was not expected and I am unsure why this occurred. The task may not have been developmentally sensitive.

5. Experiment 2 – selective attention

As previously mentioned, many of the tasks designed to measure attention, in particular CPT tasks, give multiple measures. According to Wang et al. (2013), false alarms (responding incorrectly to distractors) measures selective attention. It must be noted that false alarm measures are distinct to the incorrect hits measure in Experiment 1. They require participants to respond at the correct time (to targets not distractors). A number of studies discussed in the literature for Experiment 1, in terms of hits / misses are discussed briefly again in the following section, but this time in relation to false alarms. I begin each section by discussing the studies mentioned in relation to sustained attention. I highlight whether measures come from tasks already discussed or new tasks.

5.0.1 Dyslexia

A number of studies described above (in the sustained attention literature for Experiment 1), also measure selective attention. Some of these have not found a difficulty in sustained attention for dyslexic groups. Moores et al. (2003) looked at false alarms in a nonverbal CPT task discussed above. The task had focus (one target) and shift conditions (two targets) adding an increased element of executive difficulty. There were no differences between the dyslexic and CA groups on false alarms in either of the focus conditions. This is in contrast to sustained attention difficulties for the shift conditions. Marzocchi et al. (2009) administered a task measuring selective attention to their groups, the Sky Search task from the TEA-Ch (Manly et al., 1998). In this nonverbal task, participants had to find target space ships among rows of distractors. The dyslexic group performed as well as the CA group. They previously found sustained attention difficulties in the same group for the WDW task. Other sustained attention measures suggested that the groups performed similarly when phonological ability was taken in to account. Both of these studies suggest that nonverbal selective attention is an area of relative strength for dyslexic participants.

However, other studies mentioned have found difficulties in selective attention. Vavara et al. (2014) administered the nonverbal map mission task from the TEA-Ch (Manly et al., 1998), described in full in the methods section of this experiment. They found that the dyslexic group scored lower than the CA group, a results similar to the one they obtained for sustained attention. Menghini et al. (2010) also administered the nonverbal Map Mission task. They also found a deficit for the dyslexic group compared to CAs, similar to results obtained for sustained attention. Wang et al. (2013) also looked at false alarms in two nonverbal tasks. The sustained attention measure revealed limited differences between the groups. The false alarm measures revealed that the CA group scored higher than the dyslexic group. Within the same task then, difficulties were seen for nonverbal selective but not nonverbal sustained attention. This seems to suggest that participants with dyslexia do experience a difficulty in nonverbal selective attention relative to CAs.

It is particularly hard to isolate selective attention difficulties in the verbal domain. Again CPT tasks which present stimuli orally and then measure false alarms go some way to providing a measure of this. The verbal studies mentioned in the literature for sustained attention above do not seem to have taken this measure. Another way in which studies have assessed verbal selective attention is in the use of dichotic listening tasks. Whilst results from these studies can often be hard to interpret (i.e. many variables contribute to performance), they do suggest a deficit in verbal attention for dyslexic groups. Smith and Griffiths (1987) found that dyslexic adults were poor at attending to stimuli played in to the right ear whilst ignoring stimuli played in to the left ear. A CA group did not show this difficulty. Both groups were proficient at attending to stimuli in the left ear. This suggests a failure of unilateral selective attention in the dyslexic group. Similar results were found in a group of university students with dyslexia compared to a CA group (Kershner, 2016). Participants heard pairs of vowels played in to either the left or right ear which they had to repeat aloud. Part way though the task the ear of presentation was switched requiring a shift in attention. The dyslexic group were poor at switching attention to the right ear compared to the CA group but performed similarly for the left ear. Only the dyslexic students with the poorest literacy skills were also impaired at switching attention to the left ear. This suggests that dyslexic participants have a difficulty in tasks that require verbal selective attention.

5.0.2 D-DLD

Again several of the studies mentioned in the sustained attention literature for Experiment 1 looked at both selective and sustained attention simultaneously for D-DLD groups. Many of these studies suggest that D-DLD participants have a difficulty in selective attention. Noterdaeme et al. (2001) also looked at auditory selective attention in their study. They found that the D-DLD group scored lower on tasks assessing selective attention than a CA group. Spaulding et al. (2008) looked at several verbal, auditory and nonverbal measures of sustained ‘selective’ attention. For accuracy they used d’ as a measure which takes in to account both hits and false alarms. This is a measure of both sustained and selective attention in combination. They found D-DLD deficits in auditory and verbal tasks but not nonverbal tasks compared to a CA group.

Finneran et al. (2009) assessed nonverbal attention in a CPT task. Deficits were found in false alarm measures for the D-DLD group compared to the CAs indicative of a selective attention deficit. A similar deficit was found for sustained attention. Similarly Jongman et al. (2017) found deficits in false alarms measures for both verbal and nonverbal selective attention. This was mirrored in their sustained attention measures.

Again very few studies have looked at the contribution of language level matches to studies with D-DLD. Marton et al. (2012) administered a verbal CPT task to a D-DLD, CA and language level group. Whilst this task failed to identify difficulties in sustained attention for the D-DLD group, measures of false alarms did reveal differences in selective attention. The D-DLD group performed worse than the CA group but similarly to the language ability level group. This suggests that D-DLD participants have sustained attention abilities that are appropriate for their language ability.

Lastly some studies (Stevens, Sanders, & Neville, 2006) have looked at dichotic listening in D-DLD groups, suggesting a deficit in selective attention. Victorino and Schwartz (2015) found that D-DLD children (9 – 12 years) were slower at reacting to target words presented in one ear than CA peers for auditory tasks assessing attention. This suggests a deficit in verbal selective attention for D-DLD groups.

5.1 Summary

To the best of my knowledge, no study has directly compared groups with dyslexia and D-DLD on measures of selective attention. Again to this extent the motivation for this experiment was not to compare verbal and nonverbal skills, or develop a new measure, but to directly compare these clinical groups on standardised measures of attention. In terms of previous literature, results are mixed for dyslexic groups. Whilst some studies have failed to find a deficit for nonverbal selective attention (Marzocchi et al., 2009; Moores et al., 2003) others using similar tasks have found a deficit (Menghini et al., 2010; Vavara et al., 2014; Wang et al., 2013). Nonverbal tasks that measure distractor inhibition also utilise selective attention process. These tasks have been found to highlight difficulty in dyslexic participants (Wang et al., 2012, see chapter 4). In terms of verbal selective attention, dichotic listening tasks suggest that dyslexic groups do experience a difficulty compared to CA groups (Kershner, 2016; Smith & Griffiths, 1987).

For D-DLD groups, results point more consistently towards a deficit in selective attention. Difficulties have been found in both verbal (Noterdaeme et al., 2001; Spaulding et al., 2008) and nonverbal (Finneran et al., 2009; Jongman et al., 2017) tasks for D-DLD groups compared to CA groups. These findings also extend to dichotic listening tasks assessing verbal selective attention (Stevens et al., 2006; Victorino & Schwartz, 2015). Research that utilises at ability level groups is sparse. Again, this experiment, to the best of my knowledge is the first to compare dyslexic, D-DLD and ability level groups. D-DLD groups seem to show selective attention ability appropriate for language level (Marton et al., 2012).

5.1.1 Hypotheses

To assess selective attention I have chosen to administer the Map Mission task from the TEA-Ch (Manly et al., 1998). The task is nonverbal in nature, with participants scanning a visual field for a visual target among distractors. It must be noted however that the target was a map symbol representing a restaurant (knife and fork) among other well know map symbols as distractors (i.e. church cross, petrol station pump). These symbols were visual but possess an indicative meaning that is nameable. I believe they will present a difficulty for my dyslexic / D-DLD group therefore. Indeed research suggests that secondary school age dyslexic participants experience a difficulty in this task compared to CA groups (Menghini et al., 2010; Vavara et al., 2014). Therefore I predict that the dyslexic group will score lower than the CA group on the Map Mission task. Difficulty in selective attention seems to be more pronounced for D-DLD groups (Finneran et al., 2009; Jongman et al., 2017; Noterdaeme et al., 2001; Spaulding et al., 2008). Therefore I predict that the D-DLD group will score lower on the Map Mission task than the CA group. I also predict they will score lower than the dyslexic group evidencing a more severe deficit. EF is an area of relative strength for DLD groups (see chapter four). Therefore I predict that the DLD group will score similarly to the CA group and better than both the dyslexic and D-DLD groups.

For ability level groups considering the results seen in Experiment 1 and research with language level groups (Marton et al., 2012), I predict that the impaired groups will perform similarly to ability level groups. This is with the exception of the DLD group who will score higher than the LA/DLD group due to a lack of difficulty and age differences.

6. Method

6.1 Participants

In addition to participants missing from T2 due to attrition, data was missing from two participants for the Map Mission task due to technical issues. This included one dyslexic and one RA participant. Corresponding matches were also removed from analysis. Data from a total of 125 unique participants were included in the analysis. This formed the following groups at T2, 25 dyslexic (25 RA), 22 D-DLD (22 LA/DLD), 10 DLD (10 LA/DLD), 20 CA.

6.2 Design and procedure

For the Map Mission task (TEA-Ch, Manly et al., 1998) participants were presented with an A3 map of a city. The map displayed roads as well as a variety of different symbols depicting restaurants, petrol stations, toilets. The aim of the task was to put a circle around as many as the knife and fork symbols as possible in 60 seconds. Participants were first shown a large depiction of the target symbol. The task administration was in line with the instruction manual. Scores were the number of correctly circled symbols in 60 seconds. The task had a good test re-test reliability of 0.88.

7. Results and summary discussion

Below are the results for the Map Mission task. First one way ANOVAs compare CA and impaired groups. T-tests are then used to compare impaired and ability level groups. The same Bonferroni adjusted alpha level ($p<.0167$) was used for significance as from previous chapters.

Figure ***17*** shows the mean scores for the Map Mission task for each group.

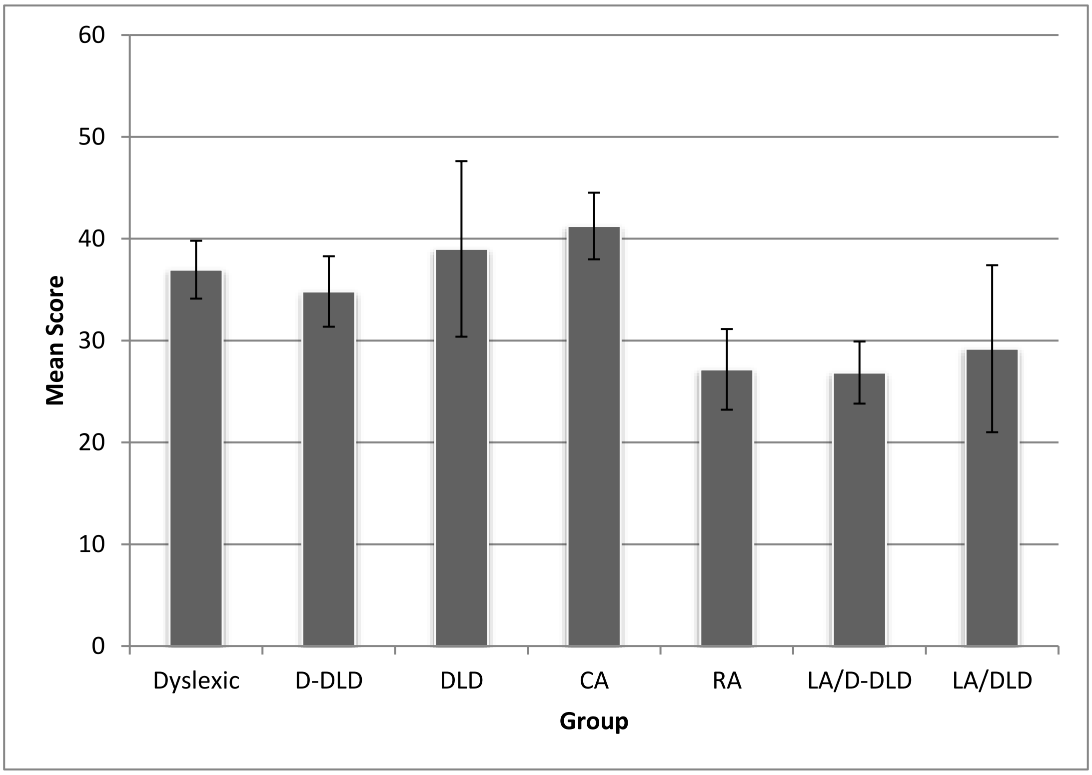


Figure 17: Mean group scores for the Map Mission task with confidence intervals (95%) in error bars.

Scores revealed no group differences, $F(3,74) = 2.43$, $p = .07$, r = 0.32, although this tended towards significance. Planned contrasts confirmed that the CA group scored higher than the D-DLD group as expected, $t(73) = 2.61$, $p < .0167$, $d = 0.87$. Other planned contrasts were not significant however. I expected this for the comparison between the CA and DLD group but not the CA and dyslexic group. I expected the dyslexic group to show difficulty in line with previous literature which has utilised the same Map Mission task. However the literature in regards to selective attention is mixed for dyslexic groups with many studies also not finding a difficulty.

Most of the impaired groups scored higher than their ability level groups: dyslexic vs. RA, $t(46) = 4.09$, $p < .001$, $d = 1.18$, D-DLD vs. RA, $t(44) = 2.99$, $p < .01$, $d = 0.89$, D-DLD vs. LA/D-DLD, $t(42) = 3.59$, $p < .01$, $d = 1.08$. This was with the exception of the DLD and LA/DLD groups who performed similarly, $t(18) = 1.86$, $p = .08$, $d = 0.83$. Again following the null results from Experiment 1, I expected no differences between impaired and ability level groups. However it seems that the selective attention task is developmentally sensitive and reveals group differences.

8. General Discussion

8.1 Summary of results

There were no differences between any of the groups in the Code Transmission task assessing sustained attention with even younger ability level groups performing similarly to the older groups. This was surprising as previous research has found differences in dyslexic groups of a similar age using the same Code Transmission task (Menghini et al., 2010; Vavara et al., 2014). The task involved updating elements and WM, which elicit differences in my groups, (see chapters 3 and 4). This was also surprising as I deliberately administered two measures to try and highlight potential group differences. These included correct hits, known to tap sustained attention and also a novel measure, incorrect hits tapping elements of both selective and sustained attention. Incorrect hits were when participants responded at the correct time but provided the incorrect answer. To this extent a high score would demonstrate an engagement of the CE to allocate attention but a failure of the verbal STM store to provide the correctly encoded information. Results did tend towards heavily significance however, suggesting that the performance of the D-DLD and dyslexic groups were lower than the CA groups.

Looking at the mean scores for the task, see Figure 15, it seems that most of our groups scored near the top (within the 82nd percentile). It could be that the task is too easy to reveal group differences. The fact that even younger groups performed similarly suggests that the task may have been too easy for my sample group with participants experiencing ceiling effects. From now on, when I discuss sustained attention it is in reference to performance on the WDW task which did reveal group differences.

The dyslexic group showed impairment in sustained attention (WDW task) compared to CAs. This was appropriate for literacy level and similar to scores for the D-DLD group. They didn't show impairment in selective attention however, scoring higher than the RA group. I predicted that the dyslexic group would show difficulty as previous literature using the Map mission task had confirmed such (Menghini et al., 2010; Vavara et al., 2014). However other studies assessing selective attention have failed to find difficulties in dyslexic groups (Marzocchi et al., 2009; Moores et al., 2003). The literature surrounding selective attention therefore is mixed. My results however suggest that dyslexic participants do not experience a difficulty compared to CA groups.

The D-DLD group showed difficulty in both sustained (WDW task) and selective attention compared to the CA group. They experienced the greatest difficulty out of all of the groups in both tasks. Kapa et al. (2017) suggest that D-DLD groups experience more difficulty in attention measures than in tasks assessing STM, WM and EF. It could be that difficulties in verbal STM create a cascade of difficulties throughout the WM system. Verbal STM creates difficulty in verbal inhibition and attention. At the same time independent EF difficulties also begin to contribute to problems in attention. This results in almost a double deficit for tasks requiring attention in D-DLD. Performance in the sustained attention task (WDW) was appropriate for both literacy and language level.

Performance in the selective attention task was better than ability level groups but worse than CA groups. This suggests a delay in selective attention for the D-DLD group.

The DLD didn't show difficulty in sustained attention or selective attention compared to the CA group or the ability level group. They showed the least difficulty of all the impaired groups on the tasks. This is again likely due to their proficient CE which is responsible for attention processes.

For the selective attention task overall, larger difficulties were seen between younger ability level groups and older impaired groups. It seems then that selective attention is linked to developmental stage. Sustained attention seems to be more intrinsically linked to literacy and language ability with impaired groups mostly performing similarly to ability level groups.

8.2 Limitations

The tasks utilised in this chapter were not pure measures of sustained attention. The Code Transmission task involves both verbal WM and verbal updating of WM demands. The WDW task involves inhibition demands. Because of this, interpretations can be particularly muddy. I conclude that the literacy impaired groups experience a difficulty in sustained attention due to difficulties on the WDW task. However, the task also requires auditory inhibition which the groups struggle with. Considering that the groups do not show a difference on the other sustained attention measure, it could be argued that comorbid demands are responsible for group differences. Attention is a hard process to capture experimentally, especially without incurring additional EF demands. EF and attentional processes work homogenously and it is likely that no attentional task is entirely free of EF demands. I chose to include these measures as they are well cited in the literature for assessing sustained and selective attention respectively. In future it might be more prudent to adopt a latent variable approach as used in Miyake et al., (2000). However this would require a much larger number of participants within each group which was outside of the scope of this project (Miyake et al., 2000; Wolf, Harrington, Clark, & Miller, 2013). Future studies may want to consider this approach however.

8.3 Conclusions

Groups with literacy difficulty (dyslexia, D-DLD) show deficits in attention measures linked to WM. Groups with comorbid difficulties (D-DLD) show additional problems in attention measures linked to EF. This supports the overlap in memory difficulty proposed for literacy impaired groups. At the same time groups impaired in language only (DLD) seem to possess proficient attention skills which may further help buffer them against developing comorbid literacy difficulty overtime. It is possible that they are able to use intact skills to orient attention to alternative information sources.

I now turn my attention, in the penultimate chapter, to the CE; the system which governs the WM system and is responsible in part for patterns of proficiency and impairment in my groups.

8.4 Thesis Map

Figure ***18*** incorporates the results from the attention measures in to the overall thesis map.

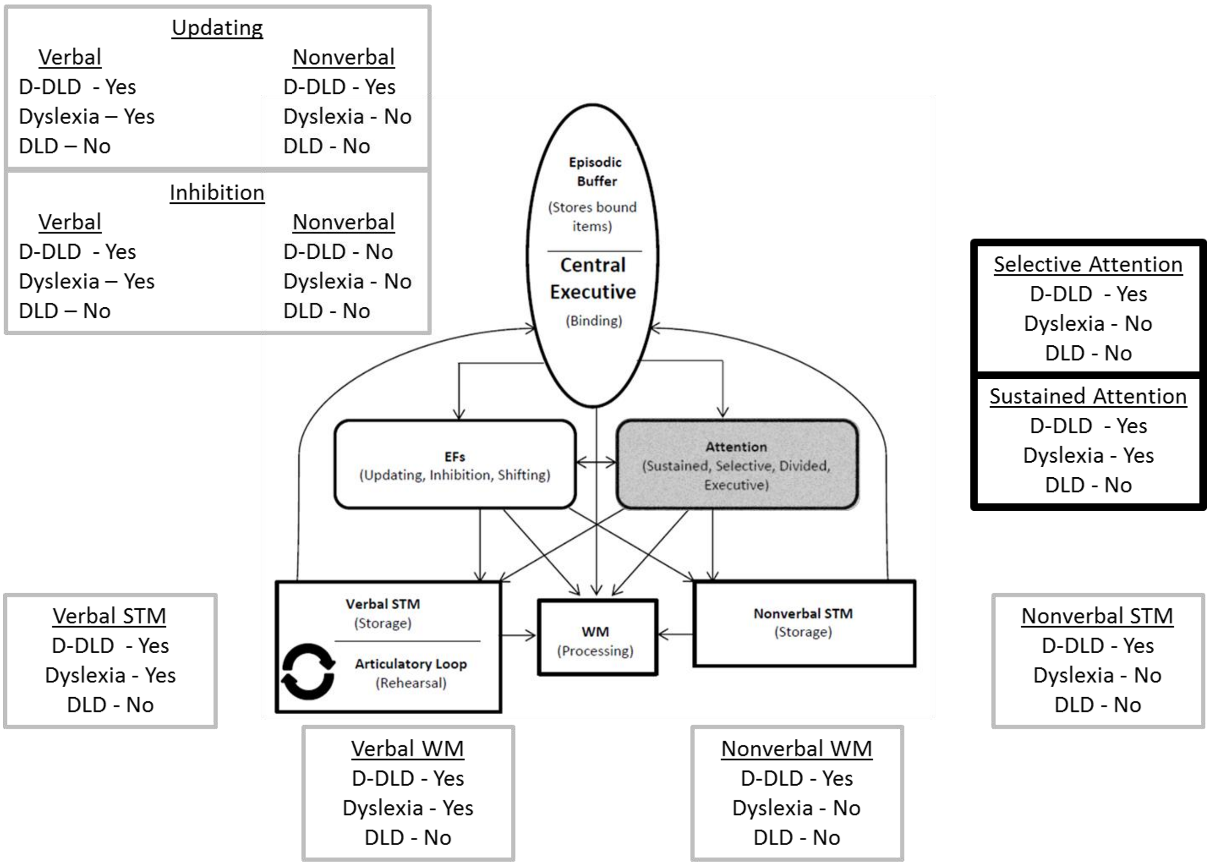


Figure 18: Summary of difficulty (Yes. No) for each group in attention tasks.

Chapter 6 – The central executive

1. General Introduction

In this penultimate chapter I examine the body that supervises the WM system, the CE. This includes all processes that have been discussed up until this point. As previously noted in chapter one, section 6.4, the responsibility of the CE can be split roughly in to two areas, one of attention (switching, focusing, sustaining, employing EFs; Baddeley, 1996) and one of storage (via the episodic buffer; Baddeley et al., 2011). Somewhere betwixt the two, the CE is also responsible for binding together information, relying heavily on attentional resources to do this and then storing the resultant representations (Baddeley, 2012).

In terms of its attentional role, the CE is responsible for selectively focusing and maintaining attention (Baddeley, 2002). It is also responsible for dividing attention and lastly switching attention between tasks. These latter attentional functions are discussed in this chapter. The CE also houses the different EFs. It is responsible for directing them to achieve a goal. In this way, the CE seamlessly directs both attentional and EF processes (which then interact with each other) to control behaviour and complete processing tasks in WM. This complicated relationship is summarised in Figure 3. The arrows on the diagram show the relationships between the different components of the model.

The CE is also responsible for integrating (binding) and storing information from different sources and modalities. Whilst attentional resources in the CE allow mostly for the binding of information, the episodic buffer is responsible for storing these formed representations. The episodic buffer then forms a fractionation of the CE with a more specialised role (Baddeley et al., 2011). Figure 3 shows how information from the short-term stores is combined in the CE and then stored in the episodic buffer.

The CE then is implicated in any task that involves attention, EF, WM (which is enabled by EF and attentional processes) and the binding of information. The CE has always been particularly hard to isolate experimentally (Parkin, 1998). All experimental tasks that require participants to process information will implicate the CE to some degree, this is inevitable. Any task designed to tap the CE specifically will also make use of memory stores, attentional and EF processes. The task designed to assess the CE therefore focused on its two main roles; attention and binding information. The literature concerning both of these roles is now discussed.

2. The CE as an attentional system

The CE as an attentional system performs three functions; focusing attention, dividing attention, and switching between tasks. Focusing attention involves selective and sustained attention discussed in the previous chapter, (see chapter five). The concept of switching can be particularly muddy. Whilst some literature discusses switching in relation to EF, other literature discusses it in relation to attention (Stoet, Markey, & López, 2007; Sylvester et al., 2003). This thesis however considers switching to be more closely linked to EF (Friedman et al., 2006; Lehto et al., 2003; Miyake et al., 2000; Miyake & Friedman, 2012) which has been discussed in chapter three. This chapter rather focuses the CE capacity for dividing attention.

Divided attention tasks are those that ask several demands of a participant simultaneously (Della Sala, Baddeley, Papagno, & Spinnler, 1995). One way experimenters are able to operationalise this ability is via dual task paradigms (Hoffman & Gillam, 2004). In classic dual tasks, participants will have to complete one measure, whilst also completing a second competing task. For example, identifying the direction of an arrow while simultaneously counting backwards in threes. Often measures are taken from both tasks in isolation and then again in a dual task paradigm (Gabay, Schiff, & Vakil, 2012; Lachmann et al., 2009). The difference in performance between single and dual task conditions is thought to reflect the capability of the CE to divide attentional resources adequately.

2.1 Dyslexia

Some of the earliest work on dual tasks in dyslexia investigated the automatisation deficit hypothesis (Nicholson & Fawcett, 1990), suggesting that dyslexic participants have a difficulty in central attention. This suggests that dyslexic participants have a difficulty learning new skills so that they become automatic, that is, performed without conscious effort or demands on the capacity limited cognitive system. Classic studies have focused on dyslexic individuals' ability to balance (i.e. stand on one foot) while completing a secondary competing task. These studies found that, compared to CA controls, dyslexic participants performed poorly on balance tasks when required to complete a secondary phoneme deletion task simultaneously (Nicholson & Fawcett, 1990; Fawcett & Nicolson, 1992; Needle, Fawcett, & Nicolson, 2006; Yap & Leij, 1994). However, many of these tasks involved concurrent tasks assessing cognitive and motor skills (balance, foot tapping; Nicholson & Fawcett, 2000). These tasks arguably measure participant's ability to perform actions automatically rather than their ability to divide attention. Most of the motor tasks used (balance, foot tapping) can be done with ease and little thought. Participants can be successful at these tasks by paying less attention to the motor aspects (which become automatic) and paying more attention to the demanding cognitive task. However, dyslexic groups, but not CA groups, have been found to show difficulty in the automatisation of actions (Nicholson & Fawcett, 1990). The CA groups have an advantage therefore simply because they can better automatise actions. Early dual tasks then don't really provide us with conclusive evidence about the CE.

A better measure of the ability to divide attention comes from dual tasks involving two or more cognitive measures simultaneously, measures which do not become automatic over time. Deficits have been found in concurrent cognitive tasks measuring auditory tone discrimination and letter identification. Lachmann et al. (2009) administered a dual task paradigm to dyslexic participants (9 years) and a CA group. For the first task, participants indicated the orientation of a letter; correct vs. mirrored, or correct vs. rotated. In a second simultaneous task participants identified the pitch of an auditory tone; high or low. In dual task conditions dyslexic participants performed less accurately than the CA group. This suggests that dyslexic groups show difficulty dividing attention between concurrent tasks with visually presented letters and auditory demands. However, we know that dyslexic participants experience difficulty in orthographic processing (letter identification; Bowers & Wolf, 1993; Livingstone, Rosen, Drislane, & Galaburda, 1991) which may have accounted for the results rather than a difficulty in dividing attention.

Differences between CA and dyslexic groups have also been found where one task in the dual task paradigm is purely nonverbal (i.e. the stimulus does not contain letters). Results from previous chapters (3 and 4) suggest that participants with dyslexia do not experience difficulty in purely nonverbal tasks. If dyslexic participants experience a difficulty in nonverbal dual tasks, this then suggests that their difficulty lies in dividing attention. Gabay et al. (2012) worked with dyslexic adults (25 years) and a CA group. Participants completed a nonverbal task concurrently with an auditory task. The dyslexic group were slower to learn the nonverbal task under the dual task condition compared to the CA group. Marzocchi et al. (2009) also found a similar result administering the Sky Search DT task from the TEA-ch (Manly et al., 1998). In this task participants had to circle target spaceships from a nonverbal array whilst also counting tones. Dyslexic participants scored lower than a CA group on the nonverbal search element of the task when in the presence of a second task. These studies suggest that dyslexic groups perform poorly even on nonverbal tasks with the addition of a concurrent task. The demands placed on the CE for concurrent tasks cause more difficulty for dyslexic than CA groups.

When administering dual tasks, most studies collect separate measures for both the primary and secondary task. They often compare performance under single task conditions with dual task conditions to calculate the attentional cost. Very few studies seek to compare scores across tasks. This is problematic because, to perform well, participants do not necessarily have to divide their attention equally across tasks. Participants are not measured on their performance on the second task and so can choose to concentrate largely on one over the other (Wang & Gathercole, 2013). To combat this, Wang and Gathercole (2013) created a composite score encompassing both tasks in their dual task paradigm. Children with dyslexia and a CA group (8-10 years) first performed tasks in isolation and then simultaneously. The tasks were an orally presented digit span task and an arrow task (indicating direction of an arrow on screen). Accuracy for each task was recorded separately as well as the percentage changes in accuracy for each task under dual task conditions. Finally a composite score was calculated. This was the calculated as the percentage change in the digit span tasks plus the percentage change in the arrow task, divided by two (%change digit+%change arrow)/2). The dyslexic group showed a 13% decrease in overall performance whilst the CA group showed a 6% decrease. This suggests dyslexic participants do not divide attention as well as CA groups overall.

Together these studies suggest that dyslexic groups do experience a difficulty in dividing attention between concurrent tasks. Concurrent tasks place demands on the CE which dyslexic groups have a harder time coping with than CA groups. This extends to tasks with both verbal and nonverbal demands. It also extends to concurrent tasks blending motor and cognitive demands. The variety of processes and modalities affected suggest that dyslexic participants have a specific difficulty in dividing attention between tasks that generalise to a variety of different tasks.

2.2 D-DLD

The literature surrounding D-DLD and dual task performance is less developed than that in dyslexia. Literature has referred to D-DLD and the CE more widely though. A systematic review found over 50 papers referring to D-DLD and the CE in general (Henry & Botting, 2017). Of the 10 papers that directly compared a D-DLD group with a CA group on a measure of CE functioning, nine showed a deficit for the D-DLD group. This suggests that D-DLD groups do experience a deficit in the CE. However, many of the tasks utilised within the studies were either WM or EF tasks. Whilst arguably these tasks do tap the CE, unlike dual tasks, they are not considered a specific measure of CE functioning (Hoffman & Gillam, 2004).

A difficulty in dual task performance has been identified for D-DLD participants in both verbal and nonverbal tasks. Hoffman and Gillam (2004) worked with D-DLD children (9 years) and a CA group. They administered a task which had several levels of verbal and nonverbal demands.

Participants first completed tasks in isolation: a digit recall task, recalling lists of numbers presented nonverbally, or location task, recalling a sequence of X's displayed in a grid. In dual task conditions, participants had to identify the colour of numbers verbally or by pointing, before recalling the whole number sequence afterwards. This was repeated with the location task. Stimuli were presented either fast or slow. The D-DLD group showed worse performance for both single and dual tasks (all conditions) than the CA group. They showed an increased deficit for dual task conditions over single task conditions than the CA group. This suggests difficulties ranging from verbal / nonverbal STM tasks, right through to complex verbal and nonverbal dual attention tasks for D-DLD groups.

Very few studies include younger ability level groups when assessing CE in D-DLD. One study that looked at dual task performance suggested that D-DLD groups performed similarly to typically developing groups matched for grammar and vocabulary. Leclercq, Majerus, Prigent and Maillart (2013) assessed D-DLD children (8-13 years), a CA group and a younger ability level group matched for vocabulary and grammar. Participants completed a sentence comprehension task, half of the task under single task conditions and half under dual task conditions. In the dual task condition, participants had to simultaneously identify a colour on screen. Performance was worse for the dual task condition for all groups compared to the single task condition. The decrease in performance was similar for D-DLD and ability level groups who both showed bigger decreases than the CA group. This suggests that D-DLD participants do show a difficulty in divided attention however level of performance is appropriate for language level. It suggests then that a deficit in divided attention and the CE more widely does not form an underlying deficit in D-DLD. Instead it is appropriate given a reduced level of language ability.

Overall D-DLD groups experience a difficulty in divided attention which evidences a difficulty in CE functioning. This extended across tasks implicating both verbal and nonverbal demands. Performance is appropriate for language level suggesting less of an underlying deficit in the CE and more that the CE is functioning appropriately for language age (Montgomery, 2000).

2.3 Comparing across groups

To the best of my knowledge, no study has ever compared both dyslexic and D-DLD groups on dual task performance. From the literature discussed above, it seems dyslexic and D-DLD groups experience very similar deficits in dual tasks, evidencing a difficulty in dividing attention. This suggests that both groups experience difficulty on tasks that implicate the attentional aspects of the CE. However, as noted above, the interpretation of dual task studies can sometimes be problematic. Depending on the nature of the secondary task (i.e. simple motor, tapping, balance), typical participants can sometimes experience an advantage by simply being able to automatise actions. Similarly scores that only take in to account performance on one task (rather than producing a composite score) may not be measuring the ability to divide attention equally over tasks.

3. The CE as a binding and storage system

The second major role that the CE embodies is one of binding information from different sources / modalities and then storing the subsequent representations. This could be orthographic and phonological aspects of text, nonverbal and sensory information, colour and shape information and so on (Baddeley, 2012). Dual tasks do not require participants to combine elements of one or more tasks in to a single response. They therefore do not assess the CE in terms of its binding and storage ability. This is a weakness of previous studies that have used dual tasks to assess CE functioning. The task presented in this chapter rectifies this by combining both attentional and binding elements in a single task.

3.1 Dyslexia

The ability to bind together information from both verbal and visual domains is required in word recognition, spelling and RAN (Hulme et al., 2007). These skills are also implicated in literacy difficulty (Snowling, 2000). It follows therefore that children with literacy difficulties may experience a difficulty in the CE responsible for binding together information.

Studies suggest that participants with dyslexia do experience a difficulty in binding together auditory and nonverbal information. Jones et al. (2013) worked with dyslexic adults and a CA group

(21 years). Participants were first tested on their baseline ability to identify target nonwords and shapes. In the training phase, participants saw visual shapes paired with aurally presented nonwords. In the test phase participants had to indicate whether pairing were the same or different to the training phase. Performance was compared between baseline and test phase. The dyslexic group showed more difficulty in the binding condition relative to baseline condition than the CA group. This study takes in to account the group differences at baseline and found that the dyslexic group showed increased difficulty in binding together information than the CA group.

Other studies have administered similar nonverbal-phonological binding tasks to dyslexic participants (10 years) and a CA group (Albano et al., 2016; Toffalini et al., 2018). These studies also found that a dyslexic group showed greater difficulty in binding nonword and shape information than a CA group. Together these studies suggest that dyslexic participants do experience a difficulty, at least in tasks requiring the binding of verbal information.

Other studies have not found a difference between dyslexic and CA groups in binding tasks when the binding is for nonverbal information only. This suggests that difficulties in dyslexic groups may only arise when they are required to bind together verbal information presented aurally and nonverbal information. For example, Garcia et al. (2014) asked dyslexic children and a CA group (8 – 10 years) to complete a Corsi-blocks task and colour naming task. Participants first completed tasks in isolation, and then in a binding condition. In the binding condition, the squares in the Corsi task sequence appeared as different colours. After the sequence had played out, participants had to tap out the sequence of squares in order of presentation but also name the colour of each square. Participants pointed and named simultaneously. Participants in the dyslexic group scored lower than the CA group for the Corsi-blocks task but similarly for the colour identification task when performed in isolation. In the binding condition there were no differences between groups. The dyslexic group did not perform significantly worse in the binding conditions than the CA group. This suggests that dyslexic participants are relatively proficient in tasks that require the binding of information that is presented nonverbally.

In sum it seems that dyslexic participants do show a difficulty in binding together information but only when the task involves combination of both verbal and nonverbal information. Dyslexic participants do not seem to show difficulty in combining one or more nonverbal elements together.

3.2 Comorbid disorders

To the best of my knowledge, no studies have assessed the binding of verbal and nonverbal information together in groups with D-DLD only. However, one study has looked at binding for both dyslexic and D-DLD groups simultaneously. Schuchardt et al. (2013) administered a dual span task to several groups of participants (9 years), including a CA control group, a dyslexic only group and a D-DLD group. In the dual span task participants saw pictures presented sequentially on a grid. They had to watch the sequence and once it had finished, verbally recode the names of the pictures and say them aloud in order of appearance. At the same time they also had to point to the order and locations of where the pictures had appeared. The dyslexic group performed similarly to the CA and D-DLD group. The D-DLD group scored lower than the CA group. This suggests that for tasks which require participants to combine information from different sources, only participants with additional D-DLD experience difficulty.

This task administered by Schuchardt et al. (2013) is similar to the task administered in this chapter. However, the verbal demands of Schuchardt et al’s. (2013) task may not have been enough to illicit difficulty in the dyslexic group. Pictures are presented visually and participants have to recode them verbally. Dyslexic participants do not experience a difficulty in nonverbal STM or WM but D-DLD groups do (see chapter one). In this task presented in this chapter, the verbal element of the task is presented aurally.

3.3 Comparing across groups

Very few studies look at the binding of information in impaired groups, in particular the binding of verbal and nonverbal information. This seems strange considering the obvious link between literacy and grapheme-phoneme correspondences. Grapheme-phoneme correspondences involves the binding of nonverbal (letter) and verbal (phoneme) information. Studies that have looked at dyslexic groups suggest that difficulties only arise when participants are required to bind verbal information presented aurally and nonverbal information (Albano et al., 2016; Toffalini et al., 2018). Dyslexic participants perform as well as CA controls on tasks requiring the binding of nonverbal task elements (Garcia et al., 2014; Schuchardt et al., 2013). Participants in D-DLD groups experience difficulty in binding tasks even when information is presented nonverbally (Schuchardt et al., 2013), suggesting a wider domain general deficit in binding.

4. The current study

Chapters leading up to this one have found deficits in verbal STM, WM and EF for both dyslexic and D-DLD groups. Additional nonverbal EF difficulties have been found for groups with D-DLD. This is evidence of a ‘double deficit’ (Briscoe & Rankin, 2009) in the D-DLD group for both verbal STM and the domain general EF. Due to the hierarchical nature of WM, deficits in verbal STM could cause difficulty in verbal EF for the dyslexic and D-DLD groups. Whilst this is likely the case for the dyslexic group, it is more likely that the D-DLD group experience an independent, domain general, deficit in the CE which also contributes to their difficulties. This is supported by the fact that this thesis has highlighted nonverbal EF difficulties in the D-DLD group in the absence of nonverbal STM difficulty. By investigating the CE then I aim to investigate further the theory that D-DLD groups experience an independent deficit in the CE system. Results from previous chapters also seem to suggest that DLD participants experience a relative proficiency in EF which may afford alternative routes to literacy. It also follows then that the DLD group will show proficiency in CE measures.

To investigate the CE I will administer a dual span task at T2 (Desoete & De Weerdt, 2013). This is distinct from a dual task in that it requires participants to actively bind information from the two different short-term stores. Few tasks applied to dyslexic and D- DLD populations have included measures assessing binding ability. Participants will complete a combined Corsi-blocks (nonverbal) and digit span (verbal) forwards task. Participants will generate a single combined span score for both elements of the task. I will also extract a trials passed score (see chapter three). To be successful at the task, participants are required to focus on two separate streams of information, one verbal and one non – verbal simultaneously. To the best of my knowledge this is the first time a task has been administered to D-DLD participants which requires the binding of information from two distinct sources; one verbal, one nonverbal.

4.1 Hypotheses

Participants with both dyslexia and D-DLD experience a difficulty in verbal STM tasks that affect performance in higher level cognitive tasks. Both groups have also been seen to show difficulties in tasks assessing the binding of nonverbal and verbal elements (Albano et al., 2016; Schuchardt et al., 2013; Toffalini et al., 2018). Therefore I predict that both the D-DLD and dyslexic group will score lower than the CA group on the combined span and trials scores. I anticipate that the DLD group will perform similarly to the CA group. This is because the DLD group have proficient CE ability which is helping buffer against literacy difficulty. D-DLD groups show deficits in nonverbal tasks in the absence of verbal STM difficulties (see chapter four). I suggest that this is evidence of an additional domain general deficit in the CE for D-DLD groups. D-DLD groups also show a difficulty in dual span tasks which require the binding on nonverbal information (Schuchardt et al., 2013). I predict that due to their double deficit, the D-DLD group will score lower than the dyslexic and DLD groups.

Research suggests that D-DLD groups show CE difficulty which is appropriate for language age (Leclercq et al., 2013; Montgomery, 2000). Therefore I predict that D-DLD groups will perform similarly to language ability level matches. The dyslexic and DLD groups will perform better than their ability level matches due to reduced levels of impairment in CE tasks.

5. Method

The participants, design and procedure for the Corsi-digit dual span task are now outlined.

5.1 Participants

In addition to sample attrition at T2, several participants did not return complete data sets for the Corsi-digits task due to technical issues. Wherever a participant did not return complete Corsi response files and digit recordings then their data was removed from analysis entirely. Their respective match was also removed from analysis. Data from a total of 16 D-DLD (16 LA/D-DLD), 17 dyslexic (17 RA), 8 DLD (8 LA/DLD) and 17 CA participants were analysed at T2.

5.2 Design and procedure

The Corsi-digits task is a novel combination of nonverbal stimuli from the Corsi-blocks task (taken from Kessels et al., 2000) and the BAS-III (Elliot & Smith, 2008) digit span forward task. These separate tasks are described in full in chapter three in their single conditions. In the dual span task, participants viewed a block sequence and upon completion tapped it out in order. At the same time digits were presented aurally for each block to form a sequence of matching length. Again participants were required to recite the digit sequence in order upon completion. To make this a dual span task, participants were required to tap the block sequence at the same time as speaking aloud the digit sequence, one digit for each block. Participants completed a practice block of two trials of two items in length. Participants first saw the sequence play out. They were instructed to tap the blocks at the same time as reciting the digit. If participants detracted from this then they were reminded to tap and speak at the same time. They then completed the full experimental task. Each sequence length was presented twice, the smallest being two items in length and extending to a potential nine items in length. The task was presented on a Tesco HUDL tablet, with a seven inch screen size. The task was built and presented using Opensesame version 2.8.0 with an android back-end. The tablet used to present stimuli only recorded touch responses and not verbal responses.

Due to this, verbal responses were recorded on a voice recorder and coded post hoc. Ceiling level was applied when a participant made an error (either nonverbal or verbal) on both items of a given span length.

Two main measures were extracted from the task, the combined span score and the combined trials score. This was calculated in a similar way to span and trials passed measures in chapter three assessing short-term and WM. Combined span scores were the maximum length at which participants answered at least one trial fully correct (i.e. both verbal and nonverbal responses were correct). The combined trials score was the total number of trials (within combined span scores) that were fully correct for both voice and touch responses. Similarly to the measures used in chapter three, participants could achieve similar span length scores but very different trials passed scores. For example, to achieve a span score of six, participants only needed to answer one trial per block correctly (resulting in a trials passed score of six also). Another participant may achieve a similar span score of six but also pass every trial in every block, achieving a trials passed score of 12. It was reasoned that the latter shows an increased ability to employ EF processes, namely inhibition and updating (see chapter three). Therefore total trials and span scores were assessed separately.

Finally a digit trials only score was extracted as well as a Corsi trials only score. These were the total number of correct digit trials (regardless of Corsi response) within the combined span score and vice versa. The stop rule was coded to activate when a participant failed two out of two Corsi responses (as the tablet only recorded touch responses). Participants needed to score correctly on both digit and Corsi elements of a trial to pass and so it was reasoned that choosing the stop rule based on Corsi responses alone would suffice. [12]

[12] I cannot calculate maximum digit span scores separately. It is possible for example for a participant to fail the task based on Corsi scores alone but still be providing digit responses that are correct. This also means that I are unable to compare performance in single task conditions in chapter three with the dual span task in this

6. Results and summary discussion

The results for the Corsi-blocks task are now presented. I present full findings for the combined span scores and then highlight any differences in combined trials scores. I present the results in same format as previous measures (an ANOVA comparing impaired and CA groups, t-tests comparing impaired and ability level groups) with the same Bonferroni correction level ($p < 0167$). Figure 19 shows group means for combined span, combined trials, and digit only trials and Corsi only trials.

chapter. Also participants completed the single task conditions at T1, a year previously and the dual task condition at T2. It is however possible to calculate how many (within combined span scores) trials were correct for both digit and Corsi tasks separately. I can then compare group performances on this.

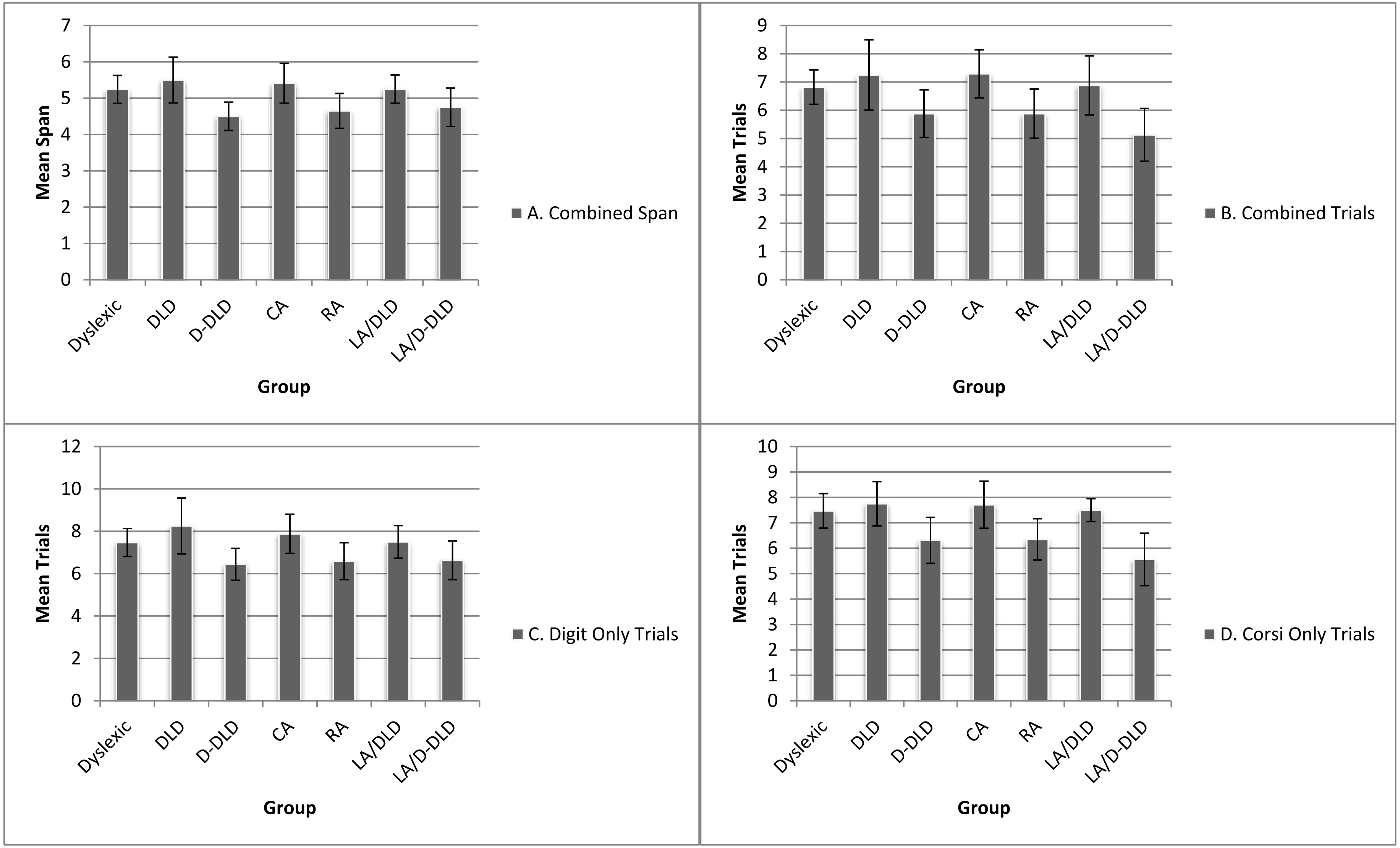


Figure 19: Group means with confidence intervals (95%) in error bars for combined span and trials scores and Corsi and digit only trials.

6.1 Combined span score

A between-subjects ANOVA with the independent variable group (D-DLD, DLD, dyslexic, CA) and the dependent variable combined span score confirmed group differences, $F(3,54) = 4.13$, $p < .0167$, r = 0.48. Planned contrasts (Bonferroni corrected criterion of $p < .0167$) confirmed that the CA group scored higher than the D-DLD group as expected, $t(54) = 3.07$, $p < .01$, $d = 1$. The CA group scored similarly to the other impaired groups: dyslexic, $t(54) = 0.60$, $p = .55$, $d = 0.19$, DLD ($t(54) = -0.24$, $p = .81$, $d = 0.10$. This was expected for the DLD group but not the dyslexic group considering previous literature. Unlike previous dual tasks in the literature, the current task is not facilitated by inhibition (both streams must be attended) and processes do not become automatic. Instead the task relies more heavily on equally dividing attention and the ability to bind information together. These skills arguably form a much purer measure of the CE. The dyslexic group do not seem to be impaired on these skills specifically. Both the dyslexic, $t(54) = 2.48$, $p < .0167$, $d = 1$, and DLD ($t(54) = 2.71$, $p < .01$, $d = 1.34$, groups scored higher than the D-DLD group. Dyslexic and DLD group scored similarly, $t(54) = 0.73$, $p = .47$, $d = 0.34$. As expected, the D-DLD group scored lower than both the dyslexic and DLD groups who performed similarly.

Independent samples t-tests confirmed that the impaired groups all performed similarly to their respective ability level groups: dyslexic vs. RA, $t(32) = 2.03$, $p = .05$, $d = 0.76$, D-DLD vs. RA, $t(31) = -0.50$, $p = .62$, $d = 0.12$, D-DLD vs. LA/D-DLD, $t(30) = -0.81$, $p = .43$, $d = 0.34$, DLD vs. LA/DLD, $t(14) = 0.80$, $p = .44$, $d = 0.40$[13]. Contrary to predictions, the impaired groups all performed similarly to their ability level groups, see Figure 19.

[13] The combined trials score provided the same pattern of results as the combined span score with the exception that, the dyslexic and D-DLD group performed similarly, $t(54) = 1.83$, $p = .07$, $d = 0.68$, and the DLD group did not differ from the D-DLD group, $t(54) = 2.14$, $p = .04$, $d = 0.89$, though effect sizes indicated this may be due to a lack of power.

6.2 Comparing Corsi and digit trials

A mixed ANOVA with the independent variable group (D-DLD, DLD, dyslexic, CA) and dependent variable trial type (Corsi, digit) was employed to assess the interaction between digit and Corsi responses for combined spans by group. There was no main effect of response type indicating digit and Corsi responses were correct a similar proportion of times within passed blocks, $F(1,54) = 1.62$, $p = .21$, r = .03. There was a main effect of group, $F(3,54) = 0.35$, $p = .79$, r = .02 suggesting a difference in groups between number of correct responses. However, there was no interaction between group and response type, $F(3,54) = 1.62$, $p = .21$, r = .03, suggesting that no one group showed an advantage for the recall of digit or Corsi responses within passed blocks. Each group passed a similar number of digit and Corsi trials within combined span scores. However effect sizes are extremely low suggesting a lack of power to detect group differences in this analysis.

7. General Discussion

7.1 Summary of results

The CE measure in this chapter is arguably a much purer measure of CE than has been previously measured in dual tasks. It assesses divided attention and binding, two processes controlled by the CE. Traditionally in dual tasks, performance is compared between tasks performed in isolation and under dual conditions (Gabay et al., 2012). In the dual task condition, to be successful, participants can largely ignore one stream, using inhibition, EF or automatization processes. Differences between single and dual conditions will still be compared but this seems to give an advantage to CA participants who can effectively employ EFs and use automatisation processes (Nicholson & Fawcett, 1990; Fawcett & Nicolson, 1992; Needle et al., 2006; Yap & Leij, 1994). In the current task however, participants are required to divide their attention equally between two streams of information (Schuchardt et al., 2013; Wang & Gathercole, 2013). The combined span score means that participants must divide their attention equally and bind information together. These skills arguably form a much purer measure of the CE.

For both the combined span and combined trials measure, the D-DLD group show a difficulty compared to the CA group as expected (Schuchardt et al., 2013). As expected, this is worse than both the dyslexic and DLD groups for the combined span score which suggests they have the largest difficulty. I hypothesised that children with D-DLD experience a double deficit in both verbal STM and also CE functioning (Briscoe & Rankin, 2009). I therefore expected them to have the lowest performance of all groups on the CE task that taps both of these processes. Performance was similar for D-DLD and literacy and language level groups. This suggests that difficulty in the CE is appropriate for ability for the D-DLD group. Effect sizes however point to a lack of power for comparisons with the D-DLD group and ability level groups rather than a genuine lack of difference between groups. This is also true for other comparisons between impaired and ability level groups.

For the combined span and combined trials measure, the dyslexic group scored similarly to the CA group suggesting a proficiency in CE ability. This is contrary to other research which suggests that dyslexic groups do show a difficulty in the binding of verbal and nonverbal information (Albano et al., 2016; Toffalini et al., 2018) and a difficulty in dividing attention (Lachmann et al., 2009). As previously noted, many dual tasks in the existing literature do not produce composite measures. Participants can do well by employing inhibition and automatisation processes. Dyslexic participants experience difficulty in attention measures requiring inhibition (Reiter et al., 2004) and also the automaticity of tasks (Needle et al., 2006; Yap & Leij, 1994). They therefore may show deficits in dual tasks which make use of these processes. The current task instead is a measure of divided attention and binding which is very much controlled by the CE (Baddeley, 2012). The dyslexic group do not experience a difficulty in the CE, hence their lack of impairment in this task.

Previous studies that have found a deficit for dyslexic participants have used nonwords as stimuli rather than numbers. An alternative explanation then could be that numbers are easier to remember as they are familiar and this is why no differences between the CA and dyslexic group are revealed. However, low-frequency nonwords are easier to recall in discrimination tasks (saying whether an item appeared in a previous list of not) than real words as they do not cause interference (Gardiner & Java, 1990). A more likely explanation then is that the dyslexic group do not show a difficulty in CE tasks. This supports my theory that dyslexic groups do have intact CE and EF processes.

The DLD group showed a similar profile to the CA group. This gives support to the theory that DLD groups show a relative proficiency in CE functioning. No differences were found for any groups in terms of the type of trial passed, i.e. digit or Corsi. However after observing effect sizes, this is likely due to a lack of power.

7.2 Limitations

The CE task employed in this chapter has several potential limitations. The first is namely a lack of power. Each block of the task only contained two trials. This makes it difficult to make comparisons between performances on the Corsi or digit tasks individually. Further it contributes to the potential explanation of why limited differences were found between the impaired and ability level groups. If this task was repeated it might be more fruitful to administer five trials in each block, similar to the digit span task from the BAS - III (Elliot & Smith, 2011) to highlight group differences. Having said this, the task did confirm differences between the D-DLD and CA groups as expected when using the combined span measure.

I appreciate that the current task is a good measure of overall CE functioning. Participants have to complete two tasks simultaneously and then bind information from each in to a single response. However it could be criticised that the task only measures binding and not divided attention. Traditionally in divided attention tasks participants will complete each task in isolation and then simultaneously. Performance is assessed for each task when done in isolation as well as each task when performed simultaneously. The difference between performances in each condition reveals the effect of dividing CE attention. Whilst my task is likely dividing the attention of participants between the two tasks, the cost of this cannot be calculated. To assess the contribution of dividing attention, I would have to compare performance on single task conditions with dual task conditions. I cannot do this as the automatic stop rule on the tablet was based on the Corsi task alone (i.e. participants did not necessarily reach maximum digit span responses) and single and dual task conditions were performed at separate time points.

7.3 Conclusions

This penultimate chapter confirms that the D-DLD group do indeed have an independent difficulty in the CE that is not explained by the individual performance on Corsi or digit trials (i.e. STM ability). It also confirms that the DLD group show a relative proficiency in CE tasks which may help buffer against the development of additional literacy difficulties. The dyslexic group also do not show a difficulty in CE functioning, suggesting that both literacy difficulties and verbal EF difficulties arise from a baseline difficulty in verbal STM.

7.4 Thesis Map

Figure 20 incorporates the CE measures in to the overall thesis map.

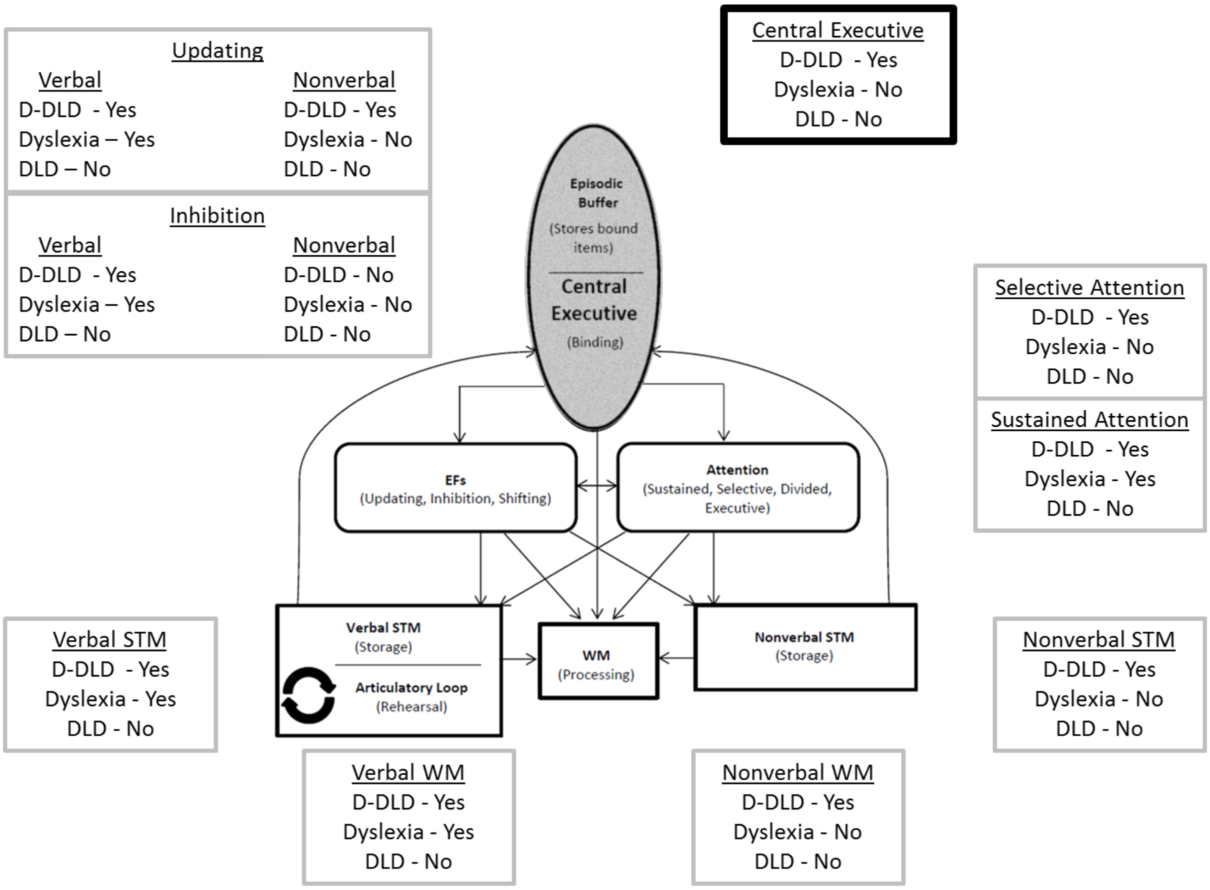


Figure 20: Summary of difficulty (Yes. No) for each group in the CE task.

Chapter 7 – General discussion

1. General introduction

This thesis has examined the profiles of children with dyslexia, D-DLD, and DLD only, comparing performance to both CA and ability level groups. It has looked at profiles of literacy, language, phonology and processing speed, administered in the background measures chapter. It has also looked at performance on several experimental studies designed to examine every level of Baddeley's (2000) WM model including: verbal and nonverbal STM and WM and EF (inhibition and updating), sustained and selective attention processes, and culminating in a task designed to tap the overarching control system, the CE. These tasks together have revealed unique profiles of difficulty in each of the impaired (dyslexic, D-DLD, DLD) groups. The profiles of each of these groups will now be discussed individually for both background and experimental measures. Finally, the implications for a model which profiles the overlap between dyslexia, D-DLD and DLD will be discussed.

2. Profile of literacy impaired groups (dyslexic and D-DLD vs. CA, literacy level group)

2.1 Background measures

Both the dyslexic and D-DLD groups showed a difficulty compared to the CA group in every area of literacy tested, including SWE (sight word efficiency, at T1 and T2), spelling and reading comprehension (see Table 7). Both the dyslexic and D-DLD groups scored similarly to the RA group for SWE (at T1 and T2) as this was a matching measure. Therefore the same RA ability level matches were used for T1 and T2. The D-DLD and dyslexic group also performed similarly to each other for SWE and both groups improved from T1 to T2. For spelling, the two literacy impaired groups performed similarly. However, the D-DLD group performed worse than the dyslexic group in reading comprehension. This suggests that the D-DLD and dyslexic group show a similar profile for word level processes (word reading and spelling).

The D-DLD group have an additional difficulty (or more severe difficulty) in reading comprehension. This is consistent with the simple view of reading (Gough & Tunmer, 1986). This suggests there are three routes to literacy difficulty, a problem with decoding (dyslexia), a problem with comprehension (hyperlexia), or a problem in both decoding and comprehension. This is consistent with previous research that suggests children with D-DLD experience reading comprehension difficulty compared to CAs and language level matches (Skarakis-Doyle & Dempsey, 2008). Difficulties in reading comprehension are more severe than difficulties in decoding for D-DLD groups (Bishop & Adams, 1990).

For phonology, the D-DLD and dyslexic group showed difficulty compared to the CA group on all tasks including PDE (phonological decoding efficiency, at T1 and T2), alliteration fluency and spoonerisms (PA). They performed similarly to each other and lower than the RA group on the PDE task (the only phonology task to include an ability level match). Whilst the dyslexic group improved from T1 to T2 on PDE, the D-DLD group did not (see Table 7). The literacy impaired groups show a deficit in phonology compared to both CA and RA groups, suggesting a deficit that is likely responsible for their literacy difficulty (Snowling, 1998; Snowling, 2001; Bishop & Snowling, 2004). It is interesting that phonology isn't improving as rapidly in D-DLD groups as it is in dyslexic groups. This could be due to differences in intervention or effectiveness of intervention. Whilst the dyslexic and D-DLD groups perform similarly now, it is possible that if performance was continually monitored in these groups, that the gap would widen, with the D-DLD group falling further behind (Snowling et al., 2000).

For language, the D-DLD showed difficulty in all tasks compared to the CA group, including listening comprehension (expressive and receptive vocabulary, and sentence comprehension), formulated sentences (expressive syntax) and semantic fluency. This was expected given that listening comprehension and language difficulty in general were factors used for defining the D-DLD group. For all of the language measures for the D-DLD group, performance was appropriate for literacy for comparisons that included RA matches; formulated sentences and listening comprehension (see Table 7).

The dyslexic group generally did not show difficulties in language. The dyslexic group scored higher than RA and D-DLD groups for listening comprehension and formulated sentences. They only showed a difficulty compared to CAs in semantic fluency (performing similarly to the D-DLD group) which I did not expect as it was a language measure. However, this result is consistent with some previous literature (Levin, 1990; Snowling et al., 1997). Snowling et al. (1997) found that a dyslexic group scored lower on a measure of semantic fluency. Differences between the dyslexic and CA groups were reduced when vocabulary differences were controlled for, with group differences becoming marginal. The CA and dyslexic group perform similarly on the expressive and receptive vocabulary measure however (listening comprehension). Snowling et al. (1997) used similar categories for the semantic fluency task, 'names of food' and 'names of animals'. They found that the dyslexic group were comparable to CAs for food items but not animals. I this thesis however, scores were combined for these different categories in line with the manual (PhAB – Frederickson et al., 1997). Although in the future it might be possible to see if the dyslexic participants showed a similar pattern of results. It could be that dyslexic participants have a difficulty in categories that are less tangible like animals, as opposed to categories concerning very common everyday objects such as 'food', 'items in the home / school'. Dyslexic participants don't experience a difficulty with the episodic buffer element of the CE (see chapter six) which arguably links attention, WM and episodic memory for everyday items and experiences. In short, dyslexic participants may not struggle naming items that they have regularly encountered in their everyday experiences due to fluid CE processes.

For the other processing skills measured, the D-DLD group showed difficulty compared to the CA group in all measures including RAN, NVIQ and processing speed. The dyslexic group showed difficulty in RAN, NVIQ (tending towards significance) but not processing speed compared to the CA group (see Table 7). The D-DLD and dyslexic groups scored similarly to each other on these measures suggesting any differences on experimental measures between these groups cannot be attributed to differences in processing skills. Both the D-DLD and dyslexic group scored higher than the RA group for processing speed but lower for NVIQ. This suggests that the D-DLD and dyslexic groups show a deficit in NVIQ relative to both CAs and RAs. It was expected that the D-DLD group would show difficulty in NVIQ. Research has suggested that typical NVIQ be removed as diagnostic criteria for groups with language difficulty (Bishop, 2017; Fey, Long, Cleave, Watkins, & Rice, 1994).

It wasn’t expected that the dyslexic group would show difficulty in NVIQ tasks. However, previous research suggests that dyslexic groups show ‘Matthew Effects’ over time, with NVIQ becoming increasingly poor (Ferrer et al., 2010). A similar effect has also been observed in D-DLD children, with a particular drop in NVIQ between the ages of eight and 14 (Botting, 2005). This thesis involves older children, 11 – 15. Whilst NVIQ may be typical in younger children and at time of diagnosis, by adolescence this may have fallen behind peers. Lastly Siegel (1992) found that poor readers with both good and bad NVIQ performed similarly on measures of memory and phonology. NVIQ then does not seem to cause large differences between different reading impaired groups.

2.2 Experimental measures

2.2.1 STM and WM

In chapter three, it was found that both the dyslexic and D-DLD groups show difficulties in verbal STM and WM compared to the CA group. Both literacy impaired groups scored lower than their RA groups for verbal STM but not verbal WM (in which they performed similarly). For both verbal STM and WM, the dyslexic and D-DLD groups performed similarly. This suggests that they both have a severe underlying deficit in verbal STM that likely contributes to the difficulties experienced in literacy and verbal WM. For the dyslexic group, verbal WM difficulties are the result of verbal STM difficulties only, see

Table *8*.

Table 8: Summary of impairment in dyslexic, D-DLD and DLD groups for experimental tasks.

Group	Chapter 3				Chapter 4				Chapter 5		Chapter 6
	Verbal STM	Verbal WM	Nonverbal STM	Nonverbal WM	Verbal Updating	Verbal Inhibition	Nonverbal Updating	Nonverbal Inhibition	Sustained Attention	Selective Attention	Central Executive
Dyslexic	Deficit	Delay(A)	No Deficit	No Deficit	Delay(A)	Delay(A)	No Deficit	No Deficit	Delay(A)[14]	No Deficit	No Deficit
DLD	No Deficit	No Deficit	No Deficit	No Deficit	No Deficit	No Deficit	No Deficit	No Deficit	No Deficit	No Deficit	No Deficit
D-DLD	Deficit[15]	Delay(A)	Delay(A)[16]	Delay(A)[17]	Delay(A)	Delay(A)	Delay(A)	No Deficit	Delay(A)[18]	Delay	Delay(A)

Note. Deficit means < than CAs and ability matched groups. Delay means < than CAs > than ability matches. Delay (A) means < than CAs but equal to ability matches.

[14] For WDW task only.

[15] Compared to RAs only, appropriate for language age.

[16] For trials passed only.

[17] For trials passed only.

[18] For WDW task only.

The D-DLD group experience a difficulty in nonverbal STM and WM tasks, but the dyslexic group do not. Performance was similar between the literacy impaired groups and the RA group. Deficits seen for the D-DLD group were only revealed for trials passed measures. There is not sufficient evidence in my results to conclude that the D-DLD group have a specific deficit in the nonverbal STM store therefore, see

Table *8*. Instead they experience a difficulty in the domain general CE, which controls EF (Baddeley, 2012). EFs are known to be implicated in nonverbal STM and WM tasks that lack their own rehearsal processes (Crowder & Morton, 1969; Penney, 1989).

Other studies have also failed to find a difficulty in nonverbal STM and WM tasks for D-DLD participants (Briscoe & Rankin, 2009; Helland & Asbjørnsen, 2003; Lukács et al., 2016). Marton (2008) argues that D-DLD groups only experience a difficulty in nonverbal STM tasks when EF demands are high. In a meta-analysis of 21 studies assessing nonverbal STM and WM, Vugs et al. (2013) only found a moderate effect size for nonverbal STM (0.49). The effect size for nonverbal WM was larger (0.63). EF is implicated in WM tasks to a higher degree than STM tasks (Nee et al., 2012). Larger effect sizes for nonverbal WM over STM tasks therefore could due to the increased EF demands, with the D-DLD groups experiencing a difficulty in domain general EF.

The trials passed measure in the STM experiment in this thesis requires a greater degree of EF (see chapter three, section 4.1) than the block span measure. It is able to highlight differences between the D-DLD and CA groups that the block span measure does not. It supports the theory that D-DLD groups have an independent deficit in domain general EFs / CE as they only show difficulty on the measure which requires increased EF.

To this extent the D-DLD group experience a double deficit in verbal STM and the domain general CE, as postulated by the double jeopardy hypothesis (Briscoe & Rankin, 2009). Not only do they experience verbal STM difficulties which cause a difficulty in verbal WM, they also experience

EF difficulties that contribute to difficulty in verbal WM. At the same time, difficulty in EF causes a difficulty in nonverbal tasks that are complex and also nonverbal WM tasks.

2.2.2 EF measures

Results seen for updating and inhibition in chapter four supports the pattern of results observed in verbal STM and WM in chapter three. Children with dyslexia and D-DLD share a difficulty in verbal updating and verbal inhibition that is of a similar severity in both disorders. However, only the D-DLD group show additional difficulty in nonverbal EF. This is supported by previous literature that suggests both groups share a pervasive difficulty in verbal EF tasks, but that nonverbal EF difficulties are limited in dyslexia (Smith-Spark et al., 2003; Smith-Spark & Fisk, 2007; Spaulding, 2010). D-DLD groups do show a difficulty in nonverbal EF (Henry et al., 2012). Both the dyslexic and D-DLD groups perform similarly to the RA group for verbal updating and inhibition in conditions sensitive to individual differences, suggesting ability is appropriate given literacy level.

Participants in the D-DLD group show a difficulty in nonverbal updating but not inhibition, compared to the CA group. The D-DLD group performed similarly to the RA group suggesting that their performance is appropriate for literacy level. The dyslexic group do not show a nonverbal EF difficulty compared to the CA group. This suggests that my D-DLD group experience difficulty in nonverbal EF (caused by a difficulty in the CE; Baddeley, 2012) in addition to their verbal STM difficulties.

However, the dyslexic group also do not differ from the D-DLD group on nonverbal tasks. If the dyslexic group perform similarly to the CA group and better than the RA group (but don’t differ from the D-DLD group), it suggests the nonverbal EF difficulty in D-DLD is minimal. This supports the idea that nonverbal difficulties in D-DLD are not being caused by nonverbal STM problems in addition to a domain general CE difficulty. Instead D-DLD groups experience a difficulty in the domain general CE which on occasion (if the task is demanding enough) will cause difficulty in nonverbal STM and EF tasks. This nonverbal difficulty is not severe and is not as prevalent as their verbal difficulties (which likely can be attributed to verbal STM plus CE difficulty). See

Table *8*.

2.2.3 Attention

The dyslexic and D-DLD groups both showed a difficulty in sustained attention compared to the CA group (for the WDW task but not code transmission, in chapter 5). They performed similarly to each other and to the literacy group suggesting performance that was appropriate for reading ability level. This result is not surprising given the link between successful reading and the ability to sustain attention to text over time and further the links between literacy difficulty and ADHD (Lam & Beale, 1991; Stern & Shalev, 2013). In particular reading comprehension requires a certain level of sustained attention to engage with the text and extract meaning. Previous research has also suggested that dyslexic participants have a difficulty in sustained attention for WDW tasks (Marzocchi et al., 2009). Marzocchi et al. (2009) found that parents and teachers of dyslexic children often reported distractibility and difficulty with attention in the classroom. This was in the absence however of symptoms of impulsivity and hyperactivity often associated with ADHD. Attentional problems in dyslexia then may be quite specific and restricted to the ability to maintain focus on a task especially in the face of distractor information. The WDW task asks participants to respond to targets but inhibit a response for a distractor. Dyslexic participants experience difficulty in tasks that ask them to inhibit distractors (Brosnan et al., 2002; Chiappe et al., 2000; Reiter et al., 2004). Attentional difficulties in dyslexia then may be limited to distractibility.

Only the D-DLD and not the dyslexic group showed a difficulty in selective attention compared to the CA group (see Chapter 5). The dyslexic group did score similarly to the D-DLD group suggesting slightly impaired performance. The D-DLD group seem to have wider difficulties in attention though than the dyslexic group. The dyslexic and D-DLD groups scored higher than the RA group. This suggests that the D-DLD group experience a delay in selective attention. The CE is responsible for attentional skills (Baddeley, 2012) and any deficits that the D-DLD group experience in the CE likely delays the development of attentional skills (Baddeley, 1996). At the same time EF is developmentally sensitive, with older groups mostly outperforming younger groups (Davidson, Amso, Anderson, & Diamond, 2006), see

Table *8*.

2.2.4 The CE

The D-DLD participants showed a difficulty in the CE task whereas the dyslexic group did not (see chapter 6). The D-DLD group scored lower than the dyslexic group and both literacy impaired groups performed similarly to the RA group.

The CE task in this thesis requires participants to divide their attention equally between two streams of information and bind information together from the two streams. This represents two of the key roles performed by the CE, binding and dividing attention (Baddeley, 1996; Baddeley et al., 2011). The D-DLD group also showed difficulty compared to the CA group on measures that assessed sustained and selective attention (for which the CE is also responsible; Baddeley, 2012). To this extent then, the D-DLD group showed difficulty on all processes the CE is responsible for. The dyslexic group on the other hand showed difficulty only for sustained attention.

Binding difficulties in the D-DLD group are evidence of an independent deficit in the CE rather than a problem in EFs that the CE also controls. It is established that binding tasks do not demand EF resources (Baddeley, Hitch, & Allen, 2009). This suggests my D-DLD group experience a robust deficit in the domain general CE, reflective of a domain general double deficit (Briscoe & Rankin, 2009; Pickering & Gathercole, 2004), see

Table *8*.

2.3 Brief summary of difficulties in literacy impaired groups

The D-DLD and dyslexic groups show qualitatively different patterns of impairment. The D-DLD group show difficulty in word level and text level literacy, phonology, language, EF and the CE and verbal STM. The dyslexic group show a smaller range of difficulties in word level literacy, phonology and verbal STM.

3. Profile of language impaired groups (D-DLD and DLD vs. CA, language level groups)

3.1 Background measures

The D-DLD group showed difficulty on all measures of literacy compared to the CA group whilst the DLD group showed difficulty in reading comprehension and spelling. The DLD group scored similarly to the D-DLD group for reading comprehension only. This is consistent with previous research which has found DLD children who experience language and reading comprehension difficulty in the absence of decoding difficulty (Nation et al., 2004). The DLD group scored higher than the D-DLD group for spelling and SWE and higher than the LA/DLD group for SWE (see Table 7). This suggests that DLD groups experience difficulties in comprehension, together with a very mild difficulty in word level literacy (spelling only). The DLD group do not show the same profile of literacy impairment as the D-DLD group. It is likely that proficient EF and lack of verbal STM difficulty has buffered against the DLD group developing additional literacy difficulty.

The D-DLD group scored lower than the LA/D-DLD group for SWE again highlighting a deficit in SWE compared to language matched groups. Interestingly the DLD group did not improve in SWE between T1 and T2, in contrast to the D-DLD (and dyslexic) groups who did. This highlights a key issue which I have discussed in section 7 below.

For phonology, whilst the D-DLD group showed difficulty in all measures compared to the CA group, the DLD group only showed difficulty in PA. The DLD group scored similarly to the D-DLD group for PA and alliteration fluency, but higher for PDE decoding (see Table 7). This is consistent with previous research that has found DLD only groups do experience difficulty in PA (Briscoe, Bishop, & Norbury, 2001). In terms of their phonological profile, a proficiency in PDE could also help the DLD compensate against developing literacy difficulty. Previous research suggests that D-DLD groups experience a wide difficulty in phonological tasks (Bishop & Snowling, 2004; Joanisse & Seidenberg, 1998). The D-DLD group scored lower than the LA/D-DLD group for PDE, but the DLD group performed similarly. Interestingly the DLD group did not improve in PDE either over time and neither did the D-DLD group. It suggests again that the D-DLD group experience a deficit in PDE (linked to literacy deficit) which is harder to remediate than it is in dyslexic groups.

Both the D-DLD and DLD groups showed a difficulty compared to the CA group in language measures. The one exception was that the DLD group did not show a difficulty in semantic fluency compared to the CA group but the D-DLD group did (they did however perform similarly to the D-DLD group; see Table 7). This was unexpected; however the DLD group experience a proficiency in the CE and related EFs. Fluency has been conceptualised as a measure of both language but also EF, requiring processes such as inhibition and cognitive flexibility (Reiter et al., 2004). If the DLD group do have an advantage in EF skills then it follows that they may also be relatively proficient in language tasks that rely heavily on them. The D-DLD group performed similarly to the DLD group for listening comprehension (note that this task was used for matching to language ability level matches). The same pattern was seen for formulated sentences at T2, with the DLD and D-DLD group performing similarly to each other and similarly to language level matches. Therefore the same ability level matches were used at T1 and T2. Both groups experience a robust deficit in expressive and receptive language.

For processing measures, whilst the D-DLD group showed a difficulty in all tasks (NVIQ, RAN, processing speed), the DLD group only showed a difficulty in NVIQ. They performed similarly to the D-DLD for NVIQ but better than them for RAN and processing speed (see Table 7). This fits with research that suggests that children with language only difficulty avoid developing additional literacy difficulty if they have intact RAN skills and PDE skills (Bishop et al., 2009; Vandewalle et al., 2012). Interestingly, the group of children (10 years) with language only difficulty discussed in Bishop et al. (2009) experienced language difficulty as severe as a comorbid group (D-DLD). They also experienced reading comprehension difficulty. Finally they also experienced early phonological difficulty that was similar to the comorbid group. This profile is strikingly similar to the profile seen in the DLD group in this thesis. Bishop et al. (2009) suggest that language difficulty does not necessarily lead to poor decoding if RAN ability is intact.

In terms of ability level matches, the DLD and D-DLD group both showed a difficulty relative to CAs and their language level groups for NVIQ. This again suggests an underlying deficit in NVIQ for both groups. Both groups performed higher than their language level groups for processing speed.

3.2 Experimental measures

3.2.1 STM and WM

The D-DLD group show a difficulty in verbal STM and WM compared to CAs but the DLD group do not. The DLD group do perform similarly to the D-DLD group for verbal STM and WM suggesting they show lower performance on these tasks to an extent. However this assertion is made tentatively. It could be that very subtle difficulties in verbal STM and WM for the DLD group are linked to difficulties in spelling and phonology observed in the group. The language impaired groups performed similarly to their language level matches. Conti-Ramsden and Durkin (2007) suggest that if children with language difficulties have phonological STM deficits, then they will also experience a literacy difficulty. If they don't then they will experience pure language difficulties. This seems to be the case for the two language impaired groups in this thesis. The DLD only group show good verbal STM and only very mild word level literacy difficulty (spelling) and difficulty in comprehension. The D-DLD group on the other hand show difficulty in verbal STM and a much wider range of difficulties in word level reading including decoding and spelling and a more severe comprehension difficulty.

The D-DLD group showed difficulty on trials only scores for nonverbal STM and WM whereas the DLD group showed no impairment relative to the CA group. The language impaired groups performed similarly to each other and similarly to ability level groups. Nonverbal STM and WM seem to be an area of relative strength for the DLD group and highlights their proficiency in tasks, that require EF, see

Table *8*.

3.2.2 EF measures

The DLD group did not show a difficulty in any of the verbal or nonverbal EF measures as compared to the CA group. This is in contrast to the D-DLD group who showed difficulty in verbal and nonverbal updating and verbal inhibition. Again this pattern largely fits with that seen for verbal and nonverbal STM / WM in which the DLD group also did not show difficulty. The DLD group did perform similarly to the D-DLD group for verbal updating and inhibition, suggesting lower ability to some extent (similar to verbal STM). Again tentatively it could be that very subtle difficulties in verbal updating and inhibition for the DLD group are a reflection of mild verbal STM difficulties and difficulties in phonology / spelling.

The DLD group scored higher than the D-DLD group for nonverbal updating but not inhibition (although the task failed to detect any group differences). The DLD group scored higher than their language level match for nonverbal updating but the D-DLD group performed similarly to theirs. This again highlights a proficiency in nonverbal EF for the DLD group. This is further evidence towards a proficient domain general CE system in DLD that is likely compensating against additional literacy difficulty.

The DLD group also scored higher than the CA group for verbal target identification in the updating task (verbal 0-back). This condition requires verbal WM skills to keep an auditory target in mind and make online comparisons. The DLD group seem to have an exceptional ability in this which may also compensate their literacy development, see

Table *8*.

3.2.3 Attention

Of both language impaired groups, only the D-DLD group showed a difficulty for sustained and selective attention. The DLD group scored higher than the D-DLD group for selective but not sustained attention. On the whole, attention seems to be an area of relative strength for the DLD group, which is likely related to their proficiency in the CE system. A proficiency in sustained attention also probably helps them better engage with text and helps prevent the development of full literacy difficulty. Sustained attention ability was appropriate for language level in the DLD and D-DLD group. The DLD group performed similarly to the LA/DLD group. The D-DLD group scored lower than the CA group but better than the LA/D-DLD group, suggesting they experience a delay in selective attention. Difficulties in the CE for the D-DLD group likely cause a delay in the development of selective attention ability in D-DLD, see

Table *8*.

3.2.4 The CE

Only the D-DLD group show difficulty in the CE task. Performance on the CE task was proficient for the DLD group, with the DLD group out-performing the D-DLD group. Both groups scored similarly to their language ability level groups. Again the DLD group do not show difficulty in the CE task, sustained or selective attention tasks, suggesting they have an intact CE system overall. This proficiency in the CE system likely helps compensate against additional literacy difficulty. According to the 'interactive-compensatory model' (Stanovich, 1980; Stanovich, West, & Freeman, 1981), literacy involves a combination of different types of information (e.g. orthographic, semantic). Proficiency in one area can compensate for difficulty in another. In line with this theory, it is likely that the DLD groups are making use of alternative routes to literacy. They are afforded this ability due to intact PDE, RAN and also CE and attentional processes. In particular, intact CE processes allow them to switch fluidly between different processes and combine information from different sources. They are buffered in the first instance against the development of literacy deficits by intact CE processes, see

Table *8*.

3.3 Summary of difficulties in impaired groups

The D-DLD group clearly show the widest range of difficulties of all of the groups examined in this thesis including word level and text level literacy, phonology and language. They also experience difficulty in EF (and the CE) and verbal STM.

For experimental measures, the D-DLD group show the greatest difficulty in verbal STM. Difficulties in nonverbal STM and WM are only apparent when EF demands are high and nonverbal EF difficulties are not as severe as verbal EF difficulties. The nonverbal difficulties seen in the D-DLD group are likely caused by a domain general difficulty in the CE (controlling EF) cascading down the WM system, rather than a nonverbal STM difficulty propagating upwards. Nonverbal difficulties in D-DLD seem to evidence a delay in skills.

D-DLD groups show a deficit in verbal STM in relation to CA and ability level groups. This deficit is likely causally linked to their literacy difficulty, forming a precursor to it (see Gallagher, Frith, & Snowling, 2000). CE, EF and WM skills seem to be literacy and language age appropriate, whereas difficulties in attention evidence a delay. Both the DLD and D-DLD groups show difficulty in language but only the D-DLD group shows difficulty in EF and the CE. These skills therefore are separable.

Literacy and language difficulties are also separable. D-DLD groups score lower than CA and RA groups for verbal STM suggesting a deficit which is linked to their literacy impairment. Performance on verbal STM is comparable to language level matches however in D-DLD groups.

The dyslexic group show difficulty in word level literacy, phonology and verbal STM predominantly. They experience a similar underlying deficit as the D-DLD group in verbal STM. Difficulties also arise for verbal (but not nonverbal) WM, EF and sustained attention appropriate for reading ability. This is likely evidence of a specific verbal STM difficulty in dyslexia that carries through to tasks requiring verbal EF and verbal WM. Sustained attention difficulty is related to literacy ability.

The DLD group experience a much narrower range of difficulty with mild effects on spelling, PA and reading comprehension which are ability level appropriate, and large effects on language. They were unimpaired in EF, processing speed and STM skills. Superior EF, WM and CE performance has likely helped buffer against literacy difficulty.

5. Implications for model

Various models have conceptualised the overlap between dyslexia, DLD and comorbid difficulties in different ways (Bishop & Snowling, 2004; Catts et al., 2005; Pennington, 2006; Ramus et al., 2013).

Bishop and Snowling's (2004) model would predict that the dyslexic, D-DLD and DLD groups would differ only in terms of language skills or language-related skills, rather than broader EF or STM skills. A deficit in verbal STM could be associated with phonological language skills, but it would be only the presence or absence of this skill that would differentiate between the DLD and D-DLD groups in this conceptualisation. The DLD and D-DLD groups in this thesis however can be differentiated based on their EF / CE skills also. Hence, the findings of this thesis are not a good fit with this model. Bishop and Snowling (2004) define a group with poor language but good phonological skills (PCs). The DLD group in this thesis cannot be conceptualised as PCs as they have a difficulty in spelling and PA. The phonological difficulties in the DLD group do not fit with the profile of good phonology seen in PCs (see Nation, 2005). It is true that the DLD group is small and therefore variability within the group my affect results. However the profile of the DLD group fits strongly with other research with purely language disordered groups. For example Snowling et al. (2019) found a DLD group with spelling difficulty, and large deficits in language and phonology. Lastly, PCs also tend to experience difficulty in verbal WM (not STM) which the DLD group in this thesis do not (Nation, Adams, Bowyer-Crane, & Snowling, 1999). Therefore, it is likely that PCs form a group that, like dyslexia and DLD, are distinct from D-DLD. Instead they share overlapping features with D-DLD coincidentally, see Figure 21.

I disagree that early oral language difficulties are solely responsible for the literacy difficulty seen in D-DLD groups. If they were, literacy difficulties would be an inevitable consequence of language difficulties and DLD only groups would not exist. However, this thesis has shown a distinct pattern of impairment for a group with DLD only and this fits with Catts et al.'s (2005) conceptualisation.

The component model suggests that language and literacy processes are separable which fits with the results of this thesis. They suggest that DLD and dyslexia are separable but can co-occur. Children with poor phonological and non-phonological language skills are classed as having 'SLI plus dyslexia' rather than 'classic SLI' in Bishop and Snowling's (2004) model. In the component model participants with poor language are classed as 'SLI only' (researchers would now term DLD only) and these children can present with either good or poor phonology. I agree that language and literacy difficulties can co-occur, but not that we should classify children showing language and literacy difficulties as having co-occurring DLD and dyslexia. According to the results of this thesis, DLD groups do not experience a difficulty in verbal STM, EF or literacy. Dyslexic groups do experience a difficulty in verbal STM that is likely linked to their difficulty in literacy. Any groups experiencing a verbal STM difficulty would likely experience literacy difficulty. Similarly, Catts et al. (2005)'s conceptualisation of a 'SLI plus dyslexia' group (DLD plus dyslexia) is not the same as the D-DLD group examined in this thesis. According to my results, a group with DLD plus dyslexia would not experience a difficulty in EF/CE skills but my D-DLD group clearly do.

The results of this thesis therefore probably best fit with multi-component models (Pennington, 2006). Ramus et al. (2013) suggest that in addition to phonological and non-phonological skills, a third variable accounted significantly for the difference between groups, phonological representations. They concluded that explicit phonological skills (i.e. RAN) which require verbal STM, WM and attention might be more important for literacy proficiency. In line with this, my DLD group do not show difficulty in RAN tasks, verbal STM, WM or attention, which likely separates them from D-DLD groups with language and literacy difficulty (Bishop et al., 2009; Vandewalle et al., 2012).

Similarly, Pennington (2006) suggests that complex behavioural disorders such as dyslexia, DLD and D-DLD are multifactorial in their etiology. Multiple risk and protective factors come together to determine the probability of developing a disorder. It is clear that certain risk factors such as verbal STM and protective factors such as proficient EF / RAN / make the groups more or less likely to develop literacy difficulty. Pennington (2006) suggests that the cause of disorders cannot be reduced to one factor and that instead several are necessary. Therefore it is likely that comorbidity will occur between disorders as they share common factors. Again this fits with the conceptualisation that D-DLD and dyslexia and D-DLD and DLD do share overlapping features, see Figure 21. However I believe that they remain distinct disorders. Groups with shared literacy difficulty for example, (D-DLD and dyslexia) are separated by differences in proficient EF (for dyslexia).

5.1 Defining a new model

In line with the results of this thesis, I believe that the DLD group represent a qualitatively different pattern of impairment to the D-DLD group, they are distinct disorders. This group have compensatory skills in CE / EF and limited verbal STM difficulties which together have stopped them from developing a full literacy difficulty. Evidence comes from performance in tasks such as the verbal updating task in which the DLD group outperformed the CA group at baseline, see Figure 21. They share a severe difficulty in language with the D-DLD group and mild spelling and PA difficulty.

Groups with dyslexia only or poor comprehension also form distinct disorders that are independent of D-DLD. The group with dyslexia share common difficulties with the D-DLD group in word level literacy, phonology and verbal STM.

Although not included in this study, I hypothesise that groups with poor comprehension only share common difficulties with the D-DLD group in language, verbal WM, and possibly EF / CE.

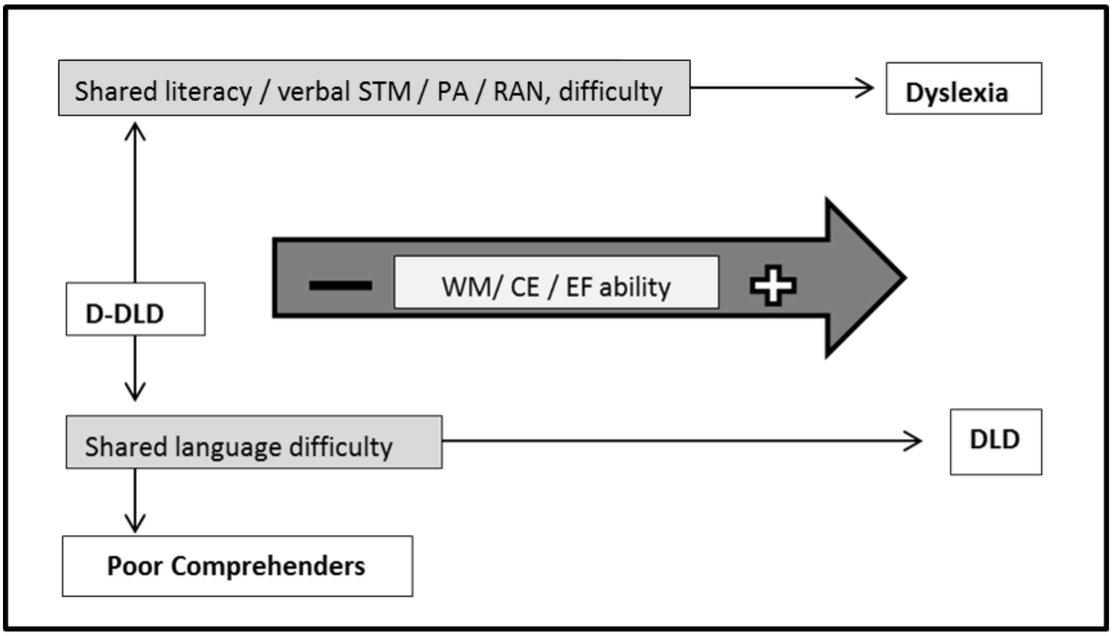


Figure 21: A conceptualisation for the overlap between groups with literacy and language difficulty.

6. Implications for practice and intervention

Difficulties in dyslexia seem to centre on the verbal domain including verbal STM, WM and verbal EF processes. A fundamental verbal STM deficit likely drives the difficulty seen in higher order processes such as verbal updating. Nonverbal skills however, both memory and EF seem to be largely intact and provide an area of relative strength for dyslexic participants. Classroom interventions then could focus on visual memory aids. Mind mapping software might be useful to ameliorate difficulties in verbal WM. Children would be able to create visual representations of complex ideas presented orally. The dyslexic group also showed difficulty in attention but only for tasks that required a focus over time that was resistant to distractors. Dyslexic children may have a particular difficulty with distractibility in the classroom (Marzocchi et al., 2009), particularly when distracting information is auditory. It might be particularly important to ensure that dyslexic children are able to learn and focus in an environment that is free from distraction.

The DLD group did not improve in SWE or PDE from T1 to T2 but the literacy impaired groups (dyslexic, D-DLD) did. The DLD group were not receiving help in school for literacy development. From the background measures it is evident that this group does experience mild difficulty in reading comprehension, spelling and PA. It could be that without intervention, these skills are at risk of plateauing and not improving over time. Conversely comprehension difficulties could result in a lack of engagement in reading for this DLD group. Lack of engagement overtime could then result in a lack of improvement in decoding overtime. Literacy difficulties could then increase in this group. It is essential therefore that practitioners and teachers continue to monitor the literacy and phonology development of children with DLD so that difficulties do not increase.

Interventions for DLD then might want to focus on engagement and motivation to read to ensure a greater exposure to text. They also might want to centre on their proficient EF skills such as self-regulated strategy development which uses EF skills such as planning (Harris, Graham, & Mason, 2003). This is also true for dyslexic groups whose difficulties seem to stem from verbal STM deficits specifically. Therefore nonverbal routes and domain general EF processes are largely unaffected and could be utilised in interventions.

For D-DLD, intervention may not be as straight forward. This group experiences difficulty in both the verbal STM store and also domain general EF and CE. They don't experience difficulty in the simple storage of nonverbal information as long as it is not taxing on the EF / WM system. However, this is difficult as the nonverbal STM necessarily uses EF skills to preserve information for tasks of certain level of difficulty. It may be necessary therefore to consider improving EF and WM skills as for example by employing WM and EF interventions early on. Evidence surrounding the effectiveness of these interventions is mixed at best (Melby-Lervåg & Hulme, 2013). Studies suggest that WM training is not transferable to other skills and only produce short term effects. Interventions for WM and EF seem to be most reliable in groups of pre-school children (Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009). It might be that the key to administering help to D-DLD groups is early diagnosis and intervention. Children who present with early verbal STM and EF difficulty should definitely flag as those at risk of developing comorbid literacy and language difficulty.

7. Conclusions and final remarks

This thesis has provided a comparison of D-DLD, DLD and dyslexic groups in terms of verbal and nonverbal memory, EF, attention and CE processes. It has discussed the profile of these groups in relation to CA and ability level matches at every level of Baddeley's (2000) WM model. This has provided a clear pattern of strengths and weaknesses in each group and helped conceptualise the relationship between the groups.

Certain questions still remain, predominantly, to what extent do proficient CE processes or a lack of verbal STM difficulty account for the absence of literacy difficulty in DLD groups. Are these processes mutually responsible? In the future a larger study with a greater number of DLD participants may help resolve this.

Ultimately, however, this project was less about establishing resolutely the underlying causes of impairment in the groups. Instead it was more about profiling the strengths and weaknesses in each group. No study before had previously compared D-DLD, DLD, dyslexic, CA and ability level groups on every level of the WM model. This thesis therefore provides strong evidence for the pattern of impairments in each group suggesting they are qualitatively different.

Importantly it also provides an insight in to what interventions may be most practical for each of my groups. It has been clear to me throughout the thesis that more care is needed in the screening of children for comorbid difficulties. A large proportion of the children included in my thesis were referred for specific difficulties (either literacy or language alone) receiving only specific intervention. Yet many of these children actually displayed comorbid difficulties after screening measures were applied. It is necessary then that practitioners and teachers are mindful of the high rates of comorbid impairment when applying literacy and language intervention.

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