COGNITIVE CONTROL IN DYSLEXIA: INVESTIGATING THE COMPETITION RESOLUTION IN VERBAL AND NON-VERBAL TASKS

BY

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ABSTRACT

Developmental Dyslexia is a characterised with difficulties in literacy acquisition, despite normal intelligence and sufficient educational exposure. The heterogeneous profile of developmental dyslexia includes not only reading related deficits, but also cognitive processing deficits that extend beyond the language domain. In this thesis, I investigated how adults with dyslexia (AwD) resolve competition in verbal and non-verbal tasks. In the first study, the results indicated that AwD experience increased lexical competition. In particular, they exhibited poorer accuracy in the more competitive conditions of the verbal tasks and also increased rates of semantically related errors. I further explored if the increased lexical competition in AwD was part of domain-general control deficit by administrating non-verbal competition tasks. I found group differences only in some of the non-verbal tasks, with AwD experiencing slower response times in the competitive conditions. However, the non-verbal task performance was not related to the lexical tasks, which suggest against AwD deficit in general cognitive control. I also found that the suppression deficit in the non-verbal tasks were secondary to their language difficulty, which is most likely due to low-level processing deficits. Therefore, the main contribution to knowledge of this thesis is the obtaining of empirical evidences for the existence of domain specific competition deficits in AwD.

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CHAPTER 1

INTRODUCTION

Literacy, a human cultural invention, has been recently developed when viewed on an evolutionary scale. The first writing systems were invented around six-thousand years ago (Powell & Schmandt-Besserat, 2007). Compared to other, earlier evolved skills such as speaking, which evolved at around six million years, this short time is not enough for reading to evolve into separate brain structure. As a consequence, reading is seen as a skill that "borrows" processes from other cognitive structures, like visual and cognitive control structures. Reading and reading disorders should therefore be investigated from a broad cognitive angle. This thesis did this in order to better understand AwD deficits and to potentially contribute to future intervention practices.

1.1 Research Question

The principle aim of this thesis is to investigate one particular type of general cognitive mechanisms, namely suppression mechanisms involved in competition resolution, and it asks whether these mechanisms might be impaired in AwD. Developmental dyslexia, henceforth referred to as dyslexia, is a common neurodevelopmental condition with a prevalence of around 7-10% of the general population that is characterised as a literacy deficit, despite explicit teaching and adequate reading instructions, and average or above-average intelligence (Peterson & Pennington, 2015). Several causes have been proposed to explain the nature of dyslexia such as the Phonological Deficit theory (e.g., Snowling, 1981) or poor learning of the grapheme to phoneme mappings (Blau et al., 2010). However, children with dyslexia (CwD) and AwD difficulties have been found not only in language-related skills, but are also present in combination with cognitive deficits such as temporal (Miles, 1993) and spatial (Stein & Walsh, 1997) sequencing deficits, and multi-modal integration deficits (Francisco, Jesse, Groen, & Mcqueen, 2017; Hairston, Burdette, Flowers, Wood, & Wallace, 2005; Kast, Bezzola, Jäncke, & Meyer, 2011). The broader nature and the relationships between the different facets of dyslexia are not well understood. Thus, investigating general cognitive mechanisms and their relationship with dyslexia could play an important role in the development of more effective interventions. The present thesis specifically investigated suppression mechanisms involved in the resolution of competitive situations and their potential role in dyslexia. In the following literature review, I will first explain the theories of developmental dyslexia as well as the previously reported language and non-language related deficits. Subsequently, I will describe the type of cognitive control relevant for the question at hand (i.e. competition resolution and its relation to inhibition and suppression mechanisms). To conclude, the chapter will define the scope and the different chapters of the thesis.

1.2 Developmental Dyslexia

Developmental dyslexia manifests itself as a literacy difficulty with difficulties in reading and spelling (Lyon & Shaywitz, 2003), in spite of average or above-average intelligence and adequate reading instruction. While these language-related deficits define dyslexia, there are several non-language difficulties previously reported in the dyslexia population, for instance, poorer focus of attention (e.g., Moores, Tsouknida, & Romani, 2015), difficulties with temporal (Miles, 1993) and spatial sequencing (Stein & Walsh, 1997), and deficits in integrating multi-modal information (e.g., Francisco et al., 2017). These non-literacy deficits form a broader dyslexia syndrome (Reid, 2014), with inconsistent appearance/various expressions across the dyslexia population. In what follows, I will present an introduction to the theories that explain the aetiology of dyslexia and the possibility that additional cognitive control mechanisms, such as suppression, might have an influence on AwD’s reading performance.

1.2.1 Phonological deficit theory

Several theories have tried to explain the aetiology of dyslexia (Blau et al., 2010; Castles & Coltheart, 1996; Snowling, 1981). One explanation for the nature of dyslexia is the phonological deficit theory (Snowling, 1981, 2001). According to this theory, individuals with dyslexia have poor phonological representations and struggle to segment, manipulate, store and retrieve phonemes, together with difficulty to connect sounds (i.e. phonemes) to letters (i.e. graphemes). In turn, this impairment leads to a poor accumulation of the orthographic lexicon, leading to difficulties in reading acquisition (Ramus et al., 2003; Snowling, 1981; Snowling, Bishop, & Stothard, 2000). Evidence to support the phonological deficit hypothesis stems from the findings that people with dyslexia perform worse than a control group in a number of phonological measures such as non-word repetition (Snowling, 1981), phonemic fluency (Frith, Landerl, & Frith, 1995) and phonemic awareness(Morris et al., 1998). However, not all participants with dyslexia have a poor phonological representation (Castles & Coltheart, 2004). Therefore, the phonological deficit hypothesis seems to account very well for individuals with phonological dyslexia, but it seems not sufficient to explain the profiles of those individuals with dyslexia without phonological impairments (Castles & Coltheart, 2004).

One such sub-group of dyslexia is that of people with surface dyslexia. These individuals have normal phonological processing, but struggle to read irregularly spelled words (e.g. *yacht*) (Castles & Coltheart, 1996). For these words, standard grapheme-to phoneme rules cannot be applied because this would lead to the incorrect pronunciation. Therefore, the correct pronunciation strongly depends on whole-word orthographic reading. Some authors have argued that the phonology deficit theory can account for the deficits in surface dyslexia. According to Share (1995), the orthographic lexicon is highly dependent on the phonological decoding skills in the early stages of reading. However, empirical evidence challenges this view, arguing that orthographic processing and phonological processing are at least partly independent, with orthographic processing ability being a predictor for early reading skills independent of phonological processing ability (Cunningham, Perry, & Stanovich, 2001; Stanovich, Siegel, Gottardo, Chiappe, & Sidhu, 1997).

The independence of orthographic and phonological processing is also supported by the Dual-Route Cascade Model of visual word recognition (DRC;Castles & Coltheart, 1993, 1996; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). This model includes two different routes for reading printed words; one sub-lexical route that involves grapheme to phoneme conversion rules and a lexical route that accesses the word as a whole. Castles and Coltheart (1993) predicted that deficits in the sub-lexical route would explain poor non-word reading, as found in phonology dyslexia, while difficulty using the lexical route would explain deficits with reading irregular or exception words as in surface dyslexia.

1.2.2 The orthographic learning account

The independence of orthographic and phonological processing is also shared by the orthographic learning theory. This account has more recently been proposed as an explanation for reading difficulties(e.g., Aravena, Snellings, Tijms, & van der Molen, 2013; Blau et al., 2010). According to this account, reading difficulties in dyslexia are not due to underlying phonological deficits, but result from poor learning of the grapheme to phoneme mappings, which leads to the inability to develop fluent reading (Aravena et al., 2013; Blau et al., 2010; Blomert, 2011; see Peterson & Pennington, 2015 for a discussion). However, as Peterson and Pennington (2015) pointed out, the main limitation of this account is that grapheme-phoneme mappings depend on successful phonological development. In addition, testing letter to sound mappings in isolation of testing phonology is problematic. Nevertheless, the implication of grapheme-phoneme correspondence has been established as an important factor in the development of fluent reading (Blomert, 2011).

1.2.3 Perceptual non-language theories

Studies on non-linguistic deficits in dyslexia have focussed primarily on sensory deficits, for instance, the Visual Magnocellular Deficit Theory (Hansen, Stein, Orde, Winter, & Talcott, 2001; Lovegrove, Bowling, Badcock, & Blackwood, 1980; Stein, 2001; Stein & Walsh, 1997) and the Auditory Deficit Theory (Tallal, Miller, & Fitch, 1993). The Visual Magnocellular Theory proposes a low-level visual processing deficit in the dyslexia population that is characterized by impairment in the magnocellular visual system. The magnocellular system is involved in the processing of fast temporal visual information (c.f. saccades in reading; Stein, 2001; Stein & Walsh, 1997). Evidence that supports this theory stems from studies that show people with dyslexia, in contrast to typical participants, possess unsteady binocular fixation (Stein, 2001) and reduced contrast and motion sensitivity (Cornelissen, 1993; Lovegrove et al., 1982). The unsteady binocular fixation is particularly important for the perceptual stability of the letters during reading, while the motion sensitivity has been linked to following the correct order of letters and words when reading (Stein, 2001). These low-level visual processing mechanisms have also been linked to language skills. For example, Talcott et al., (2002) found that visual motion sensitivity is a good predictor for children's phonological and orthographical skills.

The Auditory Deficit Theory (Tallal et al., 1993) postulates that poor phonological representations in dyslexia result from auditory processing deficits. Support for this theory stems from the findings that people with dyslexia have poorer temporal order perception than controls (Tallal et al., 1993) and poorer fluency discrimination (Ahissar, Protopapas, Reid, & Merzenich, 2000). These deficits are characterised with poor sequencing of phonological sounds a result of less sensitive modulation of sound frequency and amplitude (McAnally & Stein, 1996; for a review see Stein, 2001). These deficits have been linked to a specific type of neurons, namely auditory magnocellular neurons (Stein, 2018). Witton et al., (1998) reported a relationship between the sensitivity to auditory and visual modulations in children and adults with and without dyslexia. The authors concluded that similar genetic and environmental factors operate in both populations.

Although perceptual theories of dyslexia do not contradict the phonological deficit as the cause of reading impairment in dyslexia, they argue that visual and auditory perceptual difficulties lead to a phonological deficit (Stein, 2001, 2018). However, perceptual theories can only explain deficits in specific dyslexia subgroups (i.e. those characterised with additional visual and auditory impairments; see also Ramus et al., 2003, for a lack of visual deficits in people with dyslexia).

1.2.4 Multiple-deficit accounts

To address the heterogeneous profile of dyslexia, the multiple-deficit account has been proposed. This account proposed that the etiology of complex behavioural disorders, like dyslexia and other developmental disorders, usually co-morbid to dyslexia is multifactorial and involves the interaction of multiple risk and protective factors, which can be either genetic or environmental (Pennington, 2006). This account relates cognitive processing abilities (e.g. naming speed) with dyslexia and argues that these abilities determine the development of dyslexia (Bishop, 2006; Bishop, McDonald, Bird, & Hayiou-Thomas, 2009; Menghini et al., 2010; Pennington, 2006; Peterson & Pennington, 2015; Snowling et al., 2000; Snowling, Gallagher, & Frith, 2003). For example, in longitudinal studies, in which children in families at risk of dyslexia were monitored from their early pre-school years up until school, it was found that not all children who are at risk develop dyslexia (Snowling et al., 2003). Similarly, not all children who show phonological deficits at the pre-school age develop the dyslexia disorder (e.g.,Bishop et al., 2009). The multi-factorial account suggests that no single etiological factor is sufficient for a disorder, and few may be necessary (Pennington, 2006). The main cognitive skills found to be strong predictor for developing dyslexia are rapid serial naming speed; verbal short-term memory and vocabulary (see, Norton & Wolf, 2012 for a review on rapid naming). Children with multiple cognitive difficulties were the most likely to develop dyslexia and were more likely to suffer from a severe type of dyslexia (Bishop & Rutter, 2009; Pennington, 2006).

1.3 Cognitive control mechanism in Developmental dyslexia

One question that remains is whether individuals with dyslexia might have deficits in a more general cognitive component. Based on the findings of non-language deficits in dyslexia and in line with the multiple deficit account, there seem to be indications of such general mechanisms, especially cognitive control mechanisms.

Cognitive control is defined as successful goal-related behaviour by adjusting response selection and execution accordingly (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001). This control mechanism is required in situations where there is a discrepancy between an automatic process and goal related behaviour. This creates situations of competition (Posner & Snyder, 1975; Schneider & Shiffrin, 1977). The interference created by the automatic processes requires time to be overcome resulting in overall slower cognitive processes (Posner & Snyder, 1975; Ridderinkhof, 2002b; Schneider & Shiffrin, 1977). Cognitive control is also tightly linked to another cognitive construct known as executive function. In the cognitive psychology literature, cognitive control and executive function are generally treated as synonyms because of the indistinguishable processes involved in the two (see review by Cohen, 2017). In this chapter, I will use the executive functions and cognitive control terms interchangeable.

As established in the previous sub-section, children who are at higher risk of dyslexia are those characterised with multiple cognitive deficits. Better understanding of the exact cognitive control deficits might result in developing better interventions for improving the reading performance in dyslexia. To do so, I first need to first understand which control functions might be impaired.

In the literature, executive functions are often used as an umbrella term including various higher-order cognitive processes, but there is no generally agreed model. For instance, Miyake et al., (2000) distinguished between three basic components of executive functions: inhibition, working memory and shifting. They argue that these functions, while being related, are separable. Later studies suggested that inhibition could not be distinguished from a common executive function factor that represents what is common to all executive function tasks (e.g.,Friedman et al., 2008; Hall & Fong, 2015; Miyake & Friedman, 2012; Valian, 2015). According to others, the common executive factor is seen as the ability to maintain and manage goals that guide task relevant processing (see Friedman & Miyake, 2017 for a review). Overall, the differentiation of these two views is a matter of interpretation. Diamond, (2013) proposed a model in which the term executive functions encompassed not only the core processes of working memory, inhibition and shifting, but also higher-order processes such as planning, problem solving, and decision making that built on the core processes.

Given the lack of agreement on how many and which executive functions there are, the research into executive functions in dyslexia have studied various subsets of functions. For example, Helland and Asbjørnsen (2000) argued that attention is a basic feature of executive function and thus measured focus of attention and shifting attention, finding that CwD performed poorer on both components. Brosnan et al., (2002) studied inhibition, verbal working memory, planning, sequencing and organization of memory. They reported CwD and AwD deficits only in inhibition and verbal working memory. In addition to these studies, there are numerous other studies that have reported executive function deficits in individuals with dyslexia (Altemeier, Abbott, & Berninger, 2008; Arnett et al., 2017; Booth, Boyle, & Kelly, 2014; Brosnan et al., 2002; Doyle, Smeaton, Roche, & Boran, 2018; Helland & Asbjørnsen, 2003; Jeffries & Everatt, 2004; Levinson, Hershey, Farah, & Horowitz-Kraus, 2018; Marzocchi et al., 2008; Deny Menghini, Sorrentino, Varuzza, Varvara, & Vicari, 2014; Moura, Simões, & Pereira, 2015a; Poljac et al., 2010; Reiter, Tucha, & Lange, 2005; Shanahan et al., 2006; Varvara, Varuzza, Sorrentino, Vicari, & Menghini, 2014; but see Bexkens, Van Den Wildenberg, & Tijms, 2015; Smith-Spark & Fisk, 2007; Smith-Spark, Henry, Messer, Edvardsdottir, & Ziecik, 2016;Wang & Yang, 2015 for no executive functions impairment). For the present thesis, I decided to focus on the one function that had been proposed to be involved in all executive functions tasks (Friedman et al., 2008) and that therefore might be central to cognitive control in both typically reading controls and individuals with dyslexia, namely inhibition.

1.4 Inhibition in Cognitive control

In psychology, inhibition is often related to the ability to resolve competition of interfering thoughts and/or unwanted behaviour. This inhibition is also referred to as suppression. Suppression mechanisms play a crucial role in attention, behaviour, thoughts and emotions (Dempster, 2011; Garavan, Ross, & Stein, 1999). They are needed for the ability to supress irrelevant stimuli or interfering impulses and instead to execute the relevant process for the task at hand (Diamond, 2013).

The literature presents conflicting findings regarding inhibition deficits in dyslexia. While some studies report group differences between the individuals with dyslexia and controls (Booth et al., 2014; Brosnan et al., 2002; Willcutt et al., 2001; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005; for a review see Doyle et al., 2018), other studies show no such differences (Bexkens et al., 2015; Reiter et al., 2005; Schmid, Labuhn, & Hasselhorn, 2011). One explanation for these mixed findings could be that inhibition maturates in late adolescence (Leon-Carrion, García-Orza, & Pérez-Santamaría, 2004) and might therefore not show group differences in younger populations. For instance, Bexkens et al., (2015) measured response inhibition and selective inhibition in CwD and controls. While they found a correlation between cognitive inhibition and rapid automatic naming task (RAN), they did not find any performance differences between the two participant groups. But their participants were on average 10 years old.

Another reason for the inconsistencies in the literature might be that no task is a pure measure of one executive function. Inhibition tasks usually include cognitive functions such as attention and shifting. Most of the previous studies that measured inhibition used one task (e.g. tapping only into response inhibition), which has been argued not to be enough for detecting all aspects of inhibition (Hasher & Zacks, 1988). The present thesis therefore tested various aspects of inhibition and with various tasks. In what follows, I will outline different types of inhibition and then summarise the specific deficits concerning inhibition in people with dyslexia.

1.4.1 Components of inhibition

In the executive function literature, the term inhibition encompasses a number of functions that work closely together (Dempster, 2011; Nigg, 2000). In recent studies, response inhibition, sometimes defined as a top-down inhibition, has been proposed to consist of two components: *selective response inhibition* (Forstmann, Jahfari, et al., 2008; Forstmann, Van Den Wildenberg, & Ridderinkhof, 2008), applied to lower activation of a strong competitors, and *global response inhibition,* used for stopping execution of an ongoing response (Logan & Cowan, 1984). These constructs have been referred to as interference control and motor inhibition in Nigg's (2000) study.

Selective response inhibition, also referred as *selective inhibition*, operates on a cognitive processing level, where it is applied to lower activation of a strong competitor to a target response (Ridderinkhof, 2002a). According to the activation-suppression hypothesis proposed by Ridderinkhof (2002a) this effect is observed in conflict interference paradigms like The Eriksen Flanker task (Eriksen & Eriksen, 1974), where in one of the conditions visual distractors generate competing responses to the selection of a target. However, I should also note the role of spatial attention in flanker task. According to Yantis and Johnston (1990) model, flanker effect results from an attentional leakage to distractors, which is reduced when spatial attention is focussed on the target. Therefore, poor focus of spatial attention could subsequently result in higher activation of the distractors, leading to increased flanker effect. Previous studies have reported poorer performance by CwD (Bednarek et al., 2004; Buchholz & Davies, 2005; Facoetti & Molteni, 2000; Facoetti, Paganoni, & Lorusso, 2000) and AwD(Goldfarb & Shaul, 2013; Mahé, Doignon-Camus, Dufour, & Bonnefond, 2014) with this task, suggesting for a possible deficit with selective inhibition and/or poor focus of attention, depending on the model. In this thesis, the question about potential deficits in selective inhibition and its involvement in dyslexia reading deficits is one of the main foci of Chapter 3.

Global inhibition, also referred to as *response inhibition*, involves stopping the execution of an ongoing response (Barkley, 1997). This type of inhibition is also referred to as cancellation and it is considered as one type of motor inhibition function (Sinopoli, Schachar, & Dennis, 2011). For example, this inhibition is tested by the stop-signal paradigm where participants respond to features of stimuli, but when presented with a signal called the stop-signal they have to discontinue/cancel their response (Logan & Cowan, 1984). The crucial element defining cancelation from other types of motor inhibition functions, like restraining the response execution for example, is that there is variable delay in which the signal appears. Thus, the go-response time is active and has to be cancelled every time a signal is presented. In contrast, in tasks like go-no-go the signal appears at the same time as the go-response using the restraining type of the inhibition function where the response is withhold before it is initiated (Sinopoli et al., 2011). In order to use a terminology consistent with the literature I am adopting the term response inhibition to refer to the suppression processes in the Stop-signal task.

In the dyslexia literature, studies have reported poorer performance of CwD compared to controls when response inhibition is measured with the Stop-signal task (De Jong et al., 2009; Purvis & Tannock, 2000; Van der Schoot & de Sergeant, 2000; Van der Schoot, Licht, Horsley, & Sergeant, 2002; Willcutt et al., 2005). In Chapter 4, I aimed to address and further extend these response inhibition findings by testing highly functioning AwD and controls.

Even though selective and response inhibition are considered separate components, there is a commonality between them, namely resolving the increased competition between two processes/stimuli. This commonality means that some studies consider inhibition to be one general process (Botvinick et al., 2001). This argument is in line with the proponents of the idea that inhibition underlie all executive functions tasks (e.g., Valian, 2015) more specifically, that most executive function tasks involve participants to suppress interfering responses or distractors to produce goal-relevant behaviour (Zacks & Hasher, 1994).

Competition arises when the activation of the target or desired action and its competitors is similar. In order to select the target, the competition needs to be resolved. This can be done in two ways: by applying inhibition to the distractors or by applying more activation to the target. Essentially, the effect of the two is the same, namely a relatively higher activation level of the target. The clear distinction between these two processes is almost impossible and the current study does not aim to discriminate between them. For the purpose of this thesis, I will use inhibition/suppression as a term applied in competitive situations, but do not rule out that competition is resolved by increasing activation.

1.4.2 Selection by competition in language tasks

1.4.2.1 Competition in word reading.

Competition does not only arise in non-verbal tasks like the Flanker task or Stop-signal task, but also in linguistic tasks, more specifically in reading and language production. For instance, several models include inhibitory links for resolving the competition of words during word recognition. According to the Interactive-Activation model of word recognition (IAM;McClelland & Rumelhart, 1981), inhibition occurs between words. Similarly, the Dual Route Cascaded Model (DRC;Coltheart et al., 2001) includes inhibitory links between various levels of representations. In the DRC model, activated information travels from one layer to another until production. Each of the different layers i.e., letters, phonology and orthography contains within-level competition generated by different unit activation (e.g., phoneme /ou/ inhibits the required /o/ in *comb*).To select the required information within each level, competition is resolved through lateral inhibition (Coltheart et al., 2001).

The question therefore arises if it is possible that a deficit in competition resolution at any of these levels might contribute to the deficits shown in dyslexia. The involvement of inhibition has previously been linked to word recognition by proposing that unrelated phonological codes of a letter need to be inhibited in order to retrieve the correct phonological code (Altemeier et al., 2008). A deficit in such inhibition would be in line with the orthographic account of dyslexia in that the increased competition of phonological sounds could result in poor letter-sound mappings. Studies examining correlations between inhibition and word recognition have indeed suggested a strong connection between poor reading skills and inhibition (Savage, Cornish, Manly, & Hollis, 2006; Wang & Yang, 2015). However, since dyslexia is characterised with poor phonological representations, it is difficult to differentiate increased competition from general phonological deficits (i.e. weaker phonological activation).

1.4.2.2 Lexical competition.

Competition between word names can also arise when a word is selected for production. Selection by competition is incorporated in some speech production models, e.g. the WEAVER ++ (Levelt, Roelofs, & Meyer, 1999). According to this model, on the basis of general spreading activation in the lexicon, the target word concepts (i.e *fur* and *tale*) increases the activation levels of the target word name refer to as lemma (i.e *cat*) as well as of its semantically related representations in the lexicon (i.e. *dog*). In other words, it is generally assumed that conflict arises from the competition between the target lemma and the strong competitors. Lexical competition is normally investigated with paradigms like the cumulative picture naming task or the blocked cyclic picture naming task (Belke & Stielow, 2013; Damian, Vigliocco, & Levelt, 2001). Both tasks manipulate the semantic relatedness of previously named pictures on the naming of a target picture. Having named semantically related pictures means highly activated competitors, which generates increased competition in the lexicon. Therefore, naming objects after naming semantically related competitors is slower compared to naming objects after semantically unrelated objects.

However, the assumption that lexical selection is a competitive process is contentious. The non-competitive view suggests instead that the most activated lexical unit is selected irrespective of the activation level of the co-activated units (see Oppenheim, Dell, & Schwartz, 2010). The slowing down is explained by means of an implicit learning mechanism that changes connections between conceptual and lexical units based on the speaker's experience. In cases where the activation of semantically related items is too high so that a winner cannot be selected, it has been suggested that additional boosting mechanisms increase the activation level of all units until one item is stands out and can be selected (Navarrete, Del Prato, Peressotti, & Mahon, 2014; Oppenheim et al., 2010). According to Nozari, Freund, Breining, Rapp and Gordon (2016), this boosting mechanism could be part of a general cognitive mechanism. While the proposed speech production models differ with regards to the exact mechanisms behind lexical access and word retrieval, the models generally agree that there is a competitive mechanism at a lexical selection level (Caramazza & Miozzo, 1997; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997a; Howard, Nickels, Coltheart, & Cole-Virtue, 2006; Levelt et al., 1999; Rapp & Goldrick, 2000).

Some authors have suggested that lexical-semantic competition is resolved via inhibition of the co-activated competitors, also called lateral inhibition (Feldman & Ballard, 1982; Harley, 1990, 1993; McClelland & Rumelhart, 1981). The involvement of lateral inhibition in resolving lexical competition is implemented in some speech production models (Dell et al., 1997a; Howard et al., 2006; McClelland & Rumelhart, 1981), but not in other competitive models like WEAVER++ (Levelt et al., 1999). In the WEAVER++ model (Levelt et al., 1999; Roelofs, 2018), for instance, a lexical unit is selected when its activation exceeds the activation of its semantic competitors (according to the "luce ratio" as defined by Roelofs, 1997). Previous studies with patient populations with impaired inhibition abilities (e.g., Schizophrenia (Fuentes & Santiago, 1999; Titone & Levy, 2004) and Parkinson disease (Watters & Patel, 2002)) have suggested a deficit in lateral inhibition as the likely mechanism behind an increase of semantic errors in naming tasks. Others, like Shao, Roelofs, Martin, and Meyer (2015) have proposed the involvement of selective inhibition mechanism in lexical selection rather than lateral inhibition. Selective inhibition is applied to reduce the activation of the strong competitors thus resolving the conflict and allowing selection of the target word (Shao et al., 2015).

General cognitive mechanism have also been suggested to be operating on different processing levels in some interactive-stage models of word production (Dell, Nozari, & Oppenheim, 2014; Nozari et al., 2016). Nozari, Dell, and Schwartz (2011) proposed the involvement of cognitive control in two stages; the first stage is the resolving of competition during semantic-lexical and lexical-phonological retrieval. The second stage is the output production level where phonological codes are segmented before production.

1.5 The Present study

1.5.1 Why focusing on highly functioning AwD?

The experimental chapters of this thesis will attempt to address the inhibition functions in dyslexia by focusing on highly functioning AwD, with this sample being of a particular importance for the experimental question. Firstly, as I have already mentioned in the previous sub-section inhibition is the last higher-order function to develop with maturation in the early adulthood (Leon-Carrion et al., 2004). Thus, by testing children population it is not clear if dyslexia deficits are a result of developmental lag that disappears in adulthood or an insufficient inhibition that continue even after the maturation of the system. Secondly, as discussed by previous studies in some instances formal diagnosis of dyslexia is not given until later in life (for review see Snowling, 2005). Given the strong biological evidence for the origins of dyslexia, it is important to profile the inhibition function of an adult population with a diagnosis of dyslexia to identify the possible core deficits. Thirdly, AwD would be a homogenous group as they have all continued into higher education.

1.5.2 Subtypes of dyslexia

As I mentioned in the beginning of the chapter individuals with dyslexia are characterized with both literacy and non-literacy deficits, with inconsistent appearance and various expressions across the dyslexia population (Reid, 2014). These various expressions form different reading styles in the individuals with dyslexia, shaping specific dyslexia subtypes (e.g. magnocellular deficits is one example of such subtype). Having said that, I should stressed that investigating the specific subtypes of dyslexia is beyond the scope of the current thesis. I am mainly interested in cognitive control deficits underlying the population with dyslexia in general, not isolated to a specific subtype. However, the study design allows for linking the experimental tasks performance with the assessments for dyslexia where if apparent a potential subtype of dyslexia might emerge. In addition, the experimental tasks in Chapter 3 are investigating specific selective attentional processes previously linked to magnocellular deficits in individuals with dyslexia (see Visual search task). If group differences are evident in these tasks, this could suggest for a population with dyslexia characterised with magnocellular deficits.

1.5.3 Thesis aim

The aim of this thesis is to explore how AwD resolve competitive situations in different verbal and non-verbal experimental tasks. These competitive situations arise when there is a discrepancy between an automatic process and goal related behaviour. According to the literature, control processes are required in order to successfully resolve the competition (Botvinick et al., 2001). In the executive function literature, these control processes also known as inhibition and encompasses a number of functions that work closely together (Dempster, 2011; Nigg, 2000). As I already mentioned the inhibition functions include, but are not limited to lateral inhibition, top-down or selective inhibition and response inhibition. In each chapter, I will outline and investigate these different functions in population with dyslexia. With the main question asking, if AwD have difficulties with resolving competition and if yes, is it a result of domain-general suppression or language specific deficit?

In the Chapter 2 of the present thesis, I was interested in the question whether highly functioning AwD show increased competition within the lexicon. The concept of increased lexical competition in individuals with dyslexia has not been fully explored. But it has been found that CwD produce an increased number of semantically related errors when naming pictures (Nation, Marshall, & Snowling, 2001). While this finding has been accounted to the dyslexia phonological deficits, it is also in line with the hypothesis of increased lexical competition. I will address this question with two tasks measuring lexical competition. If AwD experience increased competition either due to less inhibition applied to semantic competitors (as proposed by Howard et al., 2006 model) or increased activation of the competitors (as proposed by Levelt et al., 1999) this would result in a higher chance of erroneously selecting competitors over the target name, due to the higher activation of the competitor word nodes.

In Chapter 3, I explored if AwD have deficits in resolving competition in non-verbal tasks. I answered this question by using tasks where distractors needed to be suppressed in order for the interference to be resolved. Similarly, in Chapter 4 I used a task where dominant response needed to be suppressed. I also used the same participants in Chapters 3 and 4 as in Chapter 2 to answer the question if the potential increased competition in AwD is a result of an underlying deficit in general cognitive or task specific mechanisms. In Chapter 5, I investigated if AwD have early visual processing deficit in suppressing distractors.

Collectively, the results of the studies reported in this dissertation provide insight on how AwD resolve competitive situations and if the performance in the experimental tasks relate to their language deficits.

CHAPTER 2

What about Lexical competition? Exploring the locus of lexical retrieval deficits in adults with Developmental Dyslexia

2.1 Abstract

Dyslexia deficits are not limited to word reading, but also extend to slower and less accurate picture naming. Such picture naming deficits were mainly linked to the prevalent phonological deficits in individuals with dyslexia. However, lexical retrieval difficulties could also arise because of increased competition within the lexicon. The present study tested if AwD are more affected by competitive semantic context using blocked cyclic picture naming paradigm. To test the generalization of the competitive process I also administered auditory sentence completion task. For blocked cyclic task, the results showed that all participants suffered from semantic interference in their response times and accuracy. For the sentence, completion test both groups performed better on the completing sentences compared to the sentences where unrelated words were required. In both tasks, AwD had more competitive lexicon when compared to the controls. This was evident with increased error rates in the competitive condition compared to the easy condition. Moreover, there was a significant relationship between the semantic errors made in both tasks in all participants, confirming the hypothesis of generalization of the competitive process. Future, studies need to establish the mechanisms behind the increased competition in the AwD's lexicon.

2.2 Introduction

Previous research suggests that individuals with dyslexia experience deficits not restricted to word reading, spelling and phonological encoding, but also include deficits in naming pictured objects (e.g., for results in children see Katz, 1986; Swan & Goswami, 1997; for a review see Nation, 2005; in adults see Raman, 2011). These naming deficits persist even when individuals with dyslexia are matched to control participants in terms of reading age and when they perform equally to controls on a vocabulary test, at least in case of children (Nation, 2005). Producing the name for a picture involves identification of the picture (Johnson, Paivio, & Clark, 2005), its semantic representations and phonological representations. As a result, deficits in any of these processes could lead to poor picture naming.

Previous studies using picture naming reported slower response latencies and a large proportion of phonological errors in CwD when compared to age matched controls (e.g., Swan & Goswami, 1997). Nation, Marshall, and Snowling (2001) found that CwD were less accurate in naming pictures compared to control children, and their pattern of errors was different. CwD made mainly lexical competition errors, producing words semantically related to the target words and these errors were not influenced by the visual similarity with the target. In comparison, control participants' errors were names of objects visually and semantically related to the targets. In addition to their semantic errors, CwD also made phonologically similar to the target word errors (e.g., "*microscope*" pronounced instead of "*stethoscope*"). The authors concluded that CwD's naming errors were in line with the phonological deficit hypothesis. However, the two types of errors experienced by the CwD could be an indication of increased competition in two different levels, one at semantic level and one at the phonological level. At the semantic level, control children need to have visual similarity (i.e., similarity form the picture) for semantic similarity to cause errors. This was not true for the CwD, which were disrupted by the semantic similarity also when pictures were visually distinct. These results are indicating of a higher intrinsic level of competition in the dyslexia semantic and possibly phonological system. The view that semantic and phonological errors could be as a result of increased competition at semantic and phonological levels is in line with some lexical production models (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997b; Rapp & Goldrick, 2000).

Increased competition in semantic and phonological levels in picture naming is not the only evidence for a potential lexical retrieval deficit in the dyslexia population. Other evidence stems from the 'Tip of the Tongue' phenomenon, lexical-semantic processing tasks (Jones, Branigan, Hatzidaki, & Obregón, 2010a; Torkildsen, Syversen, Simonsen, Moen, & Lindgren, 2007) and semantic fluency tasks (Korhonen, 1995; Levin, 1990; Menghini et al., 2010; Moura, Simões, & Pereira, 2015; Reiter, Tucha, & Lange, 2005; Snowling, Nation, Moxham, Gallagher, & Frith, 1997; Varvara, Varuzza, Sorrentino, Vicari, & Menghini, 2014;but see Frith & Frith, 1995; Landerl, Fussenegger, Moll, & Willburger, 2009; Plaza & Guitton, 1997 for an opposing results). 'Tip of the tongue' (TOT) refers to a weakness in name retrieval. When a person experiences TOT, he/she is temporarily unable to produce a well-known word. This temporary impairment is often assumed to happen due to deficits in phonological retrieval (Caramazza & Miozzo, 1997). This account of the TOT fits with the' phonological deficits reported in dyslexia. However, TOT could also be caused by a more accessible but incorrect substitute word that spontaneously comes to mind and interferes with the retrieval of the target word (Logan & Balota, 2003). I should also point out that the two interpretation of the TOT are not mutually exclusive. In combination with the picture naming deficits, this points to deficits in the dyslexia population that extend beyond phonological problems, namely to possible deficits of lexical-semantic activation and/or selection.

This assumption of lexical-semantic deficits is supported by evidence from a lexical-semantic priming experiment by Torkildsen et al., (2007) who compared the performance of children with a family risk of dyslexia with that of age matched controls. Children were exposed to three conditions of picture–word pairs; congruent pairs (e.g., a picture of a “dog” followed by the auditory presentation of “dog”), incongruent-semantic pairs (e.g., the same picture followed by “cat”) and unrelated (e.g., the same picture followed by ”car”). The authors looked at the between group differences by measuring electrophysiological responses. More specifically, they looked at a negative ERP component peaking around 400ms after stimulus onset, the N400. This component has been shown to reflect the processing of semantic information, with higher amplitudes for more challenging than less challenging semantic processing (Kutas & Hillyard, 1980). Control children who showed an expected increase in negativity for unrelated compared to related pairs, while CwD did not show this effect. In addition, CwD experienced the largest negativity in the congruent condition, unlike the controls. This semantic processing deficit was confirmed with a subsequent unimodal auditory experiment where possible cross-modal integration deficits were ruled out. The authors found that the deficits in children at-risk for dyslexia not only affected their lower-level phonological abilities (measured with earlier ERP components), but also extended to their higher order linguistic skills such as lexical and semantic processing.

Further evidence stems from a semantic category study by Jones et al., (2010). They tested highly functioning AwD to classify pictures according to their attribution to a specific category (e.g., living/non-living) or to name them. While the AwD were found to be primarily slower in the naming task, which required the retrieval of lexical-phonological code, they also showed deficits in the object-categorization task, where only visual processing as well as access of semantic properties of the target word were required without access to the word's phonological codes. The authors suggest that AwD naming deficits point to non-phonological problems that result in retrieval delay of semantic and phonological information. Specific deficit with resolving lexical-competition in individuals with dyslexia is a plausible explanation for these findings. More specifically, the sensory-functional hypothesis suggests that the categorization of natural categories (as required in the above experiment) requires semantic knowledge. This can lead to a more competitive lexicon and thus requires more time to accept or reject a specific category (Patterson, Nestor, & Rogers, 2007).

Furthermore, individuals with dyslexia have been found to perform worse in the semantic fluency task, also known as category fluency task. In this task participants are asked to produce as many words from the same semantic category (e.g. animals or furniture) within a certain amount of time (e.g. 60 seconds). The task requires cognitive mechanisms, such as inhibition of the already pronounced word, working memory, and self-monitoring and cognitive flexibility (Schwartz, Baldo, Graves, & Brugger, 2003).Individuals with dyslexia have been found to produce fewer words compared to controls within the time limit, suggesting a deficit in the cognitive mechanisms required for lexical retrieval. It should be noted that this paradigm does not differentiated between the different mechanisms involved (i.e. suppression of already named word; working memory). Thus, it is not clear where the dyslexia deficits stem from. Furthermore, the typical analysis of only correct responses limits the information that could be extracted. It would, for instance be interesting to see whether perseveration errors are the main source of errors. This would point to a deficit of suppressing highly activated lexical representations. Some authors have argued that low performance of individuals with dyslexia in category fluency task might be due to an executive functioning deficit (Reiter et al., 2005). Nevertheless, it should be noted that category fluency is also language processing task that involves lexical retrieval processes(Whiteside et al., 2016).

Tasks like the category fluency task, the TOT paradigm and picture naming all involve lexical retrieval supporting the notion of a possible deficit in lexical-semantic processing. However, only the picture-naming task involves stimuli encoding, suggesting for the possibility that the individuals with dyslexia perform poorly on these tasks because they have difficulties in encoding the stimuli, as opposed to difficulties in generating a response as the less-likely option. Therefore the cause of the lexical retrieval deficit might be increased lexical competition according to the speech production models(e.g., Levelt, Roelofs, & Meyer, 1999). Lexical competition could be linked to all tasks. For the category fluency task, when a category is activated it will subsequently increase the activation of the word nodes related to it. This increased activation within the category will create higher competition. Therefore to perform the task participants must suppress not only irrelevant co-activated responses but also to avoid repetitions of the already produced names (Henry & Crawford, 2017; Hirshorn & Thompson-Schill, 2006). Similarly, high competition has been suggested to be involved in the TOT paradigm/phenomenon that arises due to partial recovered information about the target word (Logan & Balota, 2003). The idea is that this partial information is not sufficient to recover the word, but it is sufficient to activate similar words, which can give rise to lexical competition(Maril, Wagner, & Schacter, 2001). Similarly, lexical competition[1] has been argued to be involved in naming pictures, namely by co-activated representations semantically related to the target word (Belke & Stielow, 2013).

[1] Note that in this thesis I approach a more competitive lexicon as less difference between the target word and the background noise. There are several underlying causes that could act as a source of this competition; it can be due to less active target, increase noise due to strongly co-activated items or can be due to less suppression within the lexicon.

2.2.1 The present study

The aim of the present study was to explore whether AwD have lexical-semantic retrieval deficits with regards to the resolution of lexical competition. More specifically I was interested in lexical retrieval performance during heightened demand of lexical-semantic competition. Lexical competition in word retrieval has been investigated in the general population with experimental paradigms where participants have to name pictures in competitive versus non-competitive contexts. Two such tasks are the Colour Stroop task (Stroop, 1935) and the blocked cyclic picture naming task (Belke, 2013; Belke, Meyer, & Damian, 2005). In the Colour Stroop task participants are asked to name the colour of a written word, where in some cases the word and the colour match (i.e. the word GREEN in green ink, congruent condition), while in other cases they do not (i.e. the word GREEN in blue ink, incongruent condition). The incongruent condition leads to slower response times than the congruent condition. The difference between the two conditions is called the Stroop effect. Individuals with dyslexia have been found to have an enhanced Stroop effect compared to a control group (Faccioli, Peru, Rubini, & Tassinari, 2008; Helland & Asbjørnsen, 2003; Kapoula et al., 2010; Protopapas, Archonti, & Skaloumbakas, 2007; Proulx & Elmasry, 2015; Reiter et al., 2005; Schoot & de Sergeant, 2003). It has been hypothesized by Roelofs, (2003) that the Stroop effect is a result of the conflict between the activated lexical representation of the word and that of its colour (i.e., word GREEN in red). However, another account of the Stroop effect suggests the effect to be caused by participants needing to inhibit (i.e. suppress) the dominant response (i.e. reading the word), in order to name the colour (MacLeod, 1991). The conflict therefore might rather lie between different task responses than different lexical representations. Furthermore, others (e.g., Posner & Raichle, 1994) have claimed that the Stroop effect involves conflict control at a visual processing level. Given that is not clear whether the Stroop effect is caused by response inhibition (suppression of the habituated response), by lexical competition or by visual processing mechanisms, it is difficult to tell what the cause of the enhanced Stroop effect in individuals with dyslexia is.

A more appropriate paradigm to study competition during lexical retrieval seems to be the blocked cyclic picture naming task (Belke, 2013; Belke, Meyer, et al., 2005). In this task participants are asked to name pictures that are either blocked into pictures from the same semantic category (e.g., different kind of animals = homogeneous condition) or into pictures from different categories (e.g., one animal, one piece of furniture, one clothes item and one tool = heterogeneous condition). Response times in the homogeneous condition are usually longer than response times in the heterogeneous condition and the difference between the two conditions is called the “semantic interference effect” (e.g., Belke, Meyer, et al., 2005). While it is agreed that due to changes in the semantic-lexical system in the homogeneous condition, behavioural consequences arise at lexical selection level, the exact mechanism of how this comes about is debated. Most researchers assume that the increased effect in the homogeneous block is caused by repeated access to the same semantic category resulting in increased accumulation of activation in a small set of lexical-sematic representations that compete for selection (Belke, Brysbaert, Meyer, & Ghyselinck, 2005; Damian, Vigliocco, & Levelt, 2001). But, not all models consider competition at lexical-semantic level, for example, Oppenheim et al., (2010) argue in their “Dark side” incremental learning model that the effect originates at the strength of the links between concepts and lexical representations. According to their view the strength of the links is determined by repetition priming and interference, both of which have a role in the weight distribution, by either strengthening or weakening the links.

To date, there are no dyslexia studies measuring lexical-semantic retrieval using the blocked cyclic naming paradigm. But it is a perfect candidate to test lexical-semantic encoding processes in individuals with dyslexia.

In addition to the blocked cyclic naming task, I used another task that requires selection and suppression of strong lexical competitors, namely the Hayling task (Burgess & Shallice, 1996). This task was initially designed to test inhibition abilities in patients with frontal lobe lesions (Burgess & Shallice, 1996) and since then it is widely used in other patient populations such as Mild Cognitive Impairment (Bélanger & Belleville, 2009), Alzheimer (e.g., Belleville, Rouleau, & Van der Linden, 2006), Parkinson disease patients (e.g., Obeso et al., 2011) as well as in normal aging (e.g., Cervera-Crespo & González-Alvarez, 2017) and child development (e.g., Jacobsen, de Mello, Kochhann, & Fonseca, 2017). In the Hayling task, participants are asked to complete sentences with missing final words. Each sentence has a highly probable ending (e.g., *dog* for "The cat was chased by the *...dog".*). Participants are asked to complete a sentence with a related word (automatic condition; e.g. "The captain wanted to stay with the sinking *ship".*) or an unrelated word (inhibition condition; e.g. "The captain wanted to stay with the sinking *avocado".*). The performance in the automatic condition is linked to the ability to use lexical-semantic knowledge and response initiation, because of the sentence context that strongly primes its completion and thus limits response possibilities. In order to select an unrelated word in the inhibition condition, the related word and all its semantic competitors, all primed by the sentence, need to be successfully suppressed (Bélanger & Belleville, 2009). This clear processes dissociation between the two conditions is further supported by studies using neuro-imaging techniques where distinct cerebral regions were found to be involved in response initiation and response suppression (e.g., de Zubicaray, Zelaya, Andrew, Williams, &

Bullmore, 2000). Thus, the initial task design focusses on the clear distinction between response initiation and suppression of the proponent response.

To conclude, the advantage of the Hayling task over other lexical retrieval paradigms such as the Stroop task comes from the clear distinction between the response generation and response suppression component. In addition it is not restricted to the visual domain, in which some individuals with dyslexia have early processing deficits (Stein & Walsh, 1997). Therefore, it is the perfect candidate to test if AwD are having lexical-semantic retrieval deficits. It needs to be kept in mind, though, that while the Hayling task measures suppression, it also places demands on the generation and selection of alternative responses from a large array of competing alternatives (see discussion in de Zubicaray et al., 2000). In other words, the suppression condition does not just require the suppression of a habitual response, but also the internal generation of a novel response from a wide array of possibilities. If generation of novel responses is the problematic area for AwD then they will have mainly no-responses compared to the other type of errors and this pattern of errors will be different from that of the control participants.

In the present study, I tested AwD and typically reading controls on both the blocked cyclic picture-naming paradigm and the Hayling task. For the blocked cyclic naming task, I expect the following results: Given previous findings on picture naming, AwD might name the pictures more slowly than controls overall. But given that participants name the same pictures repeatedly, this difference might disappear. If AwD had a lexical-semantic retrieval deficit with regards to resolving increased lexical-semantic competition, I would expect that they show a larger semantic interference effect compared to the controls in terms of response times, errors, or both. In terms of errors, they would produce more semantically related errors than controls, especially in the homogeneous condition. In terms of the Hayling task, I expected the following: If AwD have a deficit supressing active and therefore competing lexical representations, then this will be evident in their slower response times and/or in more error responses in the inhibition condition when compared to controls. However, in order to differentiate between the different mechanisms involved in the task I need to have a closer look at the type of errors participants make. There are two possible processing mechanisms involved in successful performance in the Hayling task: task-related response suppression and context related lexical suppression. If a participant, responds with a prepotent response in the inhibition condition and/or if they repeat their response from the inhibition condition in the automatic condition, then this points to a failure of task related response suppression. If a participant responds with a word that completes the sentence context, but it is not the prepotent response, then this could be as a result of increased lexical competition between the co-activated from the sentence context items.

Both paradigms involve lexical competition. If AwD have a deficit in lexical competition resolution, then I would expect the same pattern of results in both experimental tasks and a positive correlation of performance in both tasks. In addition, if I find deficits in lexical competition for the dyslexia group, I would investigate this further by looking at how the semantic deficits relate to the severity of the dyslexia, by looking at correlations between the tasks measures and the language assessments.

2.3 Methods

2.3.1 Participants

Thirty-seven AwD and forty controls participated in the study. All participants were recruited through study-specific recruitment posters displayed around the University of Birmingham campus and through the School of Psychology research participant scheme. For the analyses, I included only data from native monolingual English speakers with normal or corrected-to-normal vision, who completed all tests, and who fit the inclusion criteria for the study based on the neuropsychological assessment performance. Based on these criteria two participants (one from each group) were excluded due to being bilingual and one participant from the control group because they failed to complete the second session of the experiment. The majority of the AwD participants that took part in the experiment suffered from both reading and phonology segmentation and retention difficulties. Assessments for dyslexia included a set of verbal and non-verbal tasks and were used for the inclusion criteria. Participants were categorised as having dyslexia if:

- they had formal dyslexia assessment,
- had no history of psychological and/or neurological problems,
- they scored at least 2 SDs below the mean of the control group on at least two tests of a series of dyslexia measures (e.g. word/non-word reading, phonological processing subtests, reading measures; for details of tests see below).
- They scored no-less than -2SDs or more from the control mean on both the non-verbal IQ measure (formed of Perceptual Reasoning and Processing speed scales of Wechsler Adult Intelligence Scale-Fourth edition (Wechsler, 2008) and Visaul spatial working memory test - Corsi-block test (PEBL software; Mueller, 2011).

Similar inclusion criteria were applied for the control participants. They were expected to have:

- no history of psychological and/or neurological problems
- scored no-less than -2SDs or more from the group mean on both: the non-verbal IQ measure and Visual spatial working memory test,
- did not score more than 2 SDs below the mean of the group on more than one test of the dyslexia measures.

Using the criteria four participants from the control group were excluded from the analyses due to scoring more than 2 SDs below the mean of the control group on at least two of the language sub-tests. Since I the neuropsychology tests I used are a diagnostic tools for assessing developmental dyslexia excluding control participants who have similar to AwD performance minimising the possibility of including participants with learning difficulties who are not holding formal diagnosis. The same stringent criterion for the dyslexia group resulted in nine participants formerly diagnosed as having dyslexia being excluded from the analyses, for having only one or none language subtests being 2 SDs below the control mean. This resulted in 27 AwD (mean age 20.4, SD = 2.3, 6 male) and 34 control (mean age 19.1, SD = 1, 6 male) participants being included in the analyses.[2] Participants were either paid £20 compensation or given course credits. All participants gave written consent for their data to be used in the analysis.

Participants completed the experiment individually in a quiet testing room at the University of Birmingham over two sessions carried out on two different days, no more than seven days apart. In session one, they were assessed on the following dyslexia tests and in the following order: Gray Silent Reading Test, the Comprehensive Test of Phonological Processing, Wechsler Adult Intelligent Scale (WAIS-IV), the Test of Word Reading Efficiency, the Irregular Word Reading Efficiency test and the Corsi-block tapping test (see details of tests below). In session two participants completed all of the verbal experimental tasks: Cyclic blocking task and Hayling task. Each testing session lasted between 1.5 and 2 hours. All verbal tasks were tape-recorded for later analysis.

[2] The male: female ratio is somewhat different from the more typical 3:1 ratio that you might expect in a sample of people with dyslexia. This is most likely because many of the participants used were psychology students who in the UK are predominantly female.

2.3.1.1 Dyslexia defining characteristics assessment tasks.

2.3.1.1.1 General cognitive ability.

2.3.1.1.1.1 Non-verbal IQ - WAIS-IV.

For measuring the non-verbal IQ, two scales, *The Perceptual Reasoning Index Scale* and *The Processing Speed Index Scale,* from *the Wechsler Adult Intelligent Scale-fourth edition* (WAIS-IV) (Wechsler, 2008) were used. From the *Perceptual Reasoning Index,* I used *Block Design (*reproduction of abstract designs, using cubes made of red and white parts*), Matrix Reasoning* (requires selecting one option that correctly completes incomplete matrices or series*),* and *Visual Puzzles (*requires selecting three response options that, when combined, reconstruct a previously seen puzzle*).* For the *Processing Speed Index,* I administered the two core subtests *Symbol Search (*requires deciding whether one of two varying target symbols appears within a row of distracters.*)* and *digit symbol (*requires the translation of as many symbols as possible into numbers in a unit of limited time). The standardised scores for the subtests were used to calculate a performance IQ score for each participant, which representing their IQ measure.

2.3.1.1.1.2 Non-verbal working memory - Corsi-block tapping test.

Spatial short term working memory was measured with a computerised version of the Corsi-block tapping test (PEBL software; Mueller, 2011).In this task participants observe sequences of blocks lighting up on the computer screen. Their task is to repeat the sequence back in order until two consecutive errors were made. The measure entered into the analyses was the Memory span calculated as follow (start length + total correct)/trials per lengths.

2.3.1.1.2 Literacy.

2.3.1.1.2.1 Reading comprehension.

The Gray Silent Reading Test (GSRT; Wiederholt & Blalock, 2000) was administrated in order to measure participants reading comprehension. Participants were asked to quietly read up to 13 brief stories (in their own pace) of increasing complexity (in their own pace) and answer five multiple-choice questions for each story. The test raw scores were used for the group comparison analysis (all participants were older than 17years which was the ceiling reading age on the task; also the case for all language tests).

2.3.1.1.2.2 Phonological processing.

The Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) was used to assess phonological awareness, phonological memory and rapid naming. Phonological awareness was assessed with the subtest *Elision* and *Phoneme reversal*. For the *Elision* test participants are asked to omit a sound from a word, thus forming a new word (e.g. “Say *tan* without saying /*t*/” would lead to the production of the word ‘an’). The *Phoneme reversal* test measures the ability to say phonemes in reversed order to form a real word (e.g., ”Say *ni*, now say *ni* backwards” would lead to the production of the word ‘in’). Phonological memory was tested with the *Memory for digits* and the *Non-word repetition subtests*. Where, participants were asked to repeat a sequence of digits or non-word stimuli in serial order. *Rapid Letter naming* asked participants to name two sets each consists of thirty-six letters arranged in four rows, as fast as possible.

2.3.1.1.2.3 Single word and non-word reading.

Word and non-word reading fluency was assessed via *The Test of Word Reading Efficiency-Second Edition* (TOWRE-2) (Torgesen, Rashotte, & Wagner, 1999). This test requires reading high frequency words or nonwords as quickly and as accurately as possible within the time limit. The *TOWRE* score was the number of words pronounced correctly. In addition, irregular word reading was assessed with *TIWRE Irregular Word Reading Efficiency* test (Reynolds & Kamphaus, 2007). The *TIWRE* score was the number of correctly pronounced words read by the participant in their own pace (the test is untimed).

Table 2-1 provides an overview of the participants' demographic data and their performance on the dyslexia assessment tasks (non-verbal IQ, visual-spatial memory, various orthographic skills (reading comprehension, word and non-word reading) and sub lexical phonology (phonological short-term memory; phonological awareness). For the non-verbal IQ measure the standardised test score of the two subscales were averaged for each participant. This final score was used as an overall IQ measure[3]. For all of the other assessment tasks participants were compared using their raw score.

Table 2-1 Mean (SD) age and scores on standardised tests of literacy and general cognitive abilities in both dyslexia and control groups.

		AwD				CONTROLS				COMPARISON	
		Min.	**Max.**	**Mean**	**SD**	**Min.**	**Max.**	**Mean**	**SD**	**Test significance**	**Value**
Gender	Male:female			6:21				6:28		$\chi2$= .19	*.449*
Age	Years	18	31	20.4	2.9	18	22	19.1	1.0	F= 6.0	.017
Non-verbal tasks											

[3] I should note that this overall IQ score was not recognised non-verbal IQ measure. But the scores of the two scales were.

WAIS Non-verbal IQ	Scaled score	86.5	125.5	102.5	10.1	89.5	128.5	107.4	9.6	F= 3.75	.06
Spatial memory (corsi-blocks)	N of correct	4	7.5	5.4	0.9	4.5	7.5	5.8	0.8	F= 2.64	.110
Reading											
Reading Comprehension	N correct	35	64	52.4	8.3	36	63	55.2	6.5	F= 2.17	.146
Reading Comprehension	Time (sec.)	300	2340	998	473	240	1620	965	336	F=.1	.755
Towre-word reading	N correct	66	102	84.2	8.4	88	108	97.1	4.7	F= 58.0	$\leq$ .001
Towre-nonword reading	N correct	27	60	43.2	8.7	37	66	58.6	6.2	F= 65.3	$\leq$ .001
Tiwre-word reading	N correct	38	49	44.3	3.0	41	50	46.6	2.2	F= 11.8	$\leq$ .001
Phonological STM											
Memory digits	N correct	10	21	14.4	3.2	10	21	17.2	2.7	F= 14.7	$\leq$ .001
Non-word repetition	N correct	9	17	12.6	2.4	10	19	15.4	1.9	F= 26.3	$\leq$ .001
Phonological awareness											
Elision	N correct	7	19	16.2	3.5	15	20	18.6	1.1	F= 14.5	$\leq$ .001
Phoneme reversal	N correct	5	15	9.2	2.1	8	17	11.9	2.7	F= 18.35	$\leq$ .001
Naming speed											
Rapid Letter Naming	Time (sec.)	21	44	32.7	5.7	16	30	23.7	3.1	F= 54.6	$\leq$ .001

The two participant groups differed significantly in terms of age, with AwD being on average slightly more than 1 year older. The difference mainly stemmed from two participants with dyslexia who were much older than the remaining participants. However, since I do not anticipate any major development between the ages 19 and 20 and since AwD were matched with the controls in terms of educational level and IQ, the two participants with dyslexia were kept in the analysis. As expected, the AwD group did not differ from the control group in terms of educational level, gender, non-verbal IQ (WAIS-IV), and non-verbal spatial memory (Corsi-block test). However, it is important to highlight that the *p* value for the non-verbal IQ measured with WAIS-IV test showed a trend towards significance. This difference stemmed from the Processing speed subtests where AwD had significantly lower scores that than the controls *(p=.002).* However, the two groups did not differ in the Perceptual reasoning sub-scale (*p=.645*). These results are in line with previous dyslexia studies where processing speed deficits were reported (e.g.,Moura, Simões, & Pereira, 2014; Park & Lombardino, 2013). Despite these results I consider the sample of dyslexics to have normal IQ, as indicated by the Perceptual reasoning subtest (see also Smith-Spark & Fisk, 2007 for similar conclusion). The two groups did not differ either on the text reading comprehension tests. This might be surprising, but it this is in line with what has been found previously for university students with dyslexia (Finucci, Whitehouse, Isaacs, & Childs, 1984). As expected, AwD showed severe impairments on the word and non-word reading, naming speed, verbal short-term memory and sub-lexical phonology measures compared to the control group. This pattern of impairments is in line with what has been reported in the literature and also with the formal diagnosis of developmental dyslexia.

2.3.2 Experimental tasks

In session two, participants completed the inhibition tasks. The order of the tasks was fixed for all participants, with the Semantic Blocking Task first, followed by the Simon Task, the Hayling Task, the Flanker Task, the Preview Search task and the Stop Signal Task. In this section, I report results for the Semantic Blocking Task and Hayling Task. The other task results were reported in Chapter 3 and Chapter 4. In all tasks, participants were instructed to sit approximately 65 cm from the computer monitor. Before each task both written and oral instructions were given.

2.3.2.1 Verbal inhibition tasks.

2.3.2.1.1 Semantic-blocking task.

2.3.2.1.1.1 Stimuli and Design.

The procedure used in this study was adapted from Damian et al., (2001) Semantic Blocking Paradigm. The stimuli consisted of sixteen-line drawings representing daily objects from four different semantic categories: animals (Snake, Duck, Mouse and Fish), clothing (Tie, Coat, Boot and Skirt), tools (Brush, Saw, Rake and Drill) and furniture (Lamp, Chair, Desk and Bed). The stimuli were taken from previous studies (Belke, Meyer, et al., 2005; Damian et al., 2001). The pictures were digitized as line drawings to a size of approximately 8 x 8cm the visual angle was 13.18 degrees from the viewing distance of 65 cm. In each set, pictures were controlled for visual similarity and phonological overlap. Pictures from each semantic category formed four homogeneous stimuli set. There were also four heterogeneous stimuli sets, constructed by selecting one picture from each of the four homogeneous sets. This resulted in four semantically homogeneous stimuli sets and four heterogeneous stimuli sets. There were eight blocks in the experiment, one for each stimulus set. In each block, a stimulus set was repeated eight times. This resulted in 128 trials per condition. The lists were counterbalanced in experimental blocks according to the Greco-Latin square design.

2.3.2.1.1.2 Procedure.

Each trial started with a fixation cross presented in the centre of the screen for 800 ms, followed by a 100-ms blank interval and the presentation of the target picture presented for 250 ms. Participants were instructed to name aloud the picture as fast and as accurately as they could. The maximum response time allowed was 2000 ms from the onset of the picture. Responses were audio-recorded, and response times were measured with a SV-1 Voice Key-Cedrus (: http://www.cedrus.com/sv1/).

2.3.2.1.2 Hayling test.

The difference between the original Hayling task and its adapted version is in the presentation of the blocks. A blocked design is used in the original task, where automatic and inhibition sentences were seen in two separate blocks. In the adapted version of the task unblocked design is used, where both sentence types are seen in the same block. The unblocked design minimizes the use of strategies to boost the performance and also it is more similar to Stroop interference task (Burgess & Shallice, 1996), which other studies have found to cause difficulties for the individuals with dyslexia. The current task consists of 30 sentences each seen twice, once in the Automatic condition and once in the Inhibition condition, resulting in 60 stimuli in total. Stimuli were presented in two blocks. The first block included 30 sentences, half of which were part of the automatic condition and the other half part of the inhibition condition. The second block included the same sentences, but in the reversed condition. The block order was counterbalanced between participants.

2.3.2.1.2.1 Stimuli.

The stimuli used in the task were unfinished sentences selected from Bloom and Fischler's (1980) pool of 329 sentences with final words having high predictability from the sentence context (cloze p>.60) (e.g "The captain wanted to stay with the sinking_", where the sentences should be complete with the word “ship”). In order to investigate if the sentence structure has a highly predictable final word in British English, I selected 34 sentences with high prediction rates (cloze $p > .60$). I presented them to a group of 10 monolingual native British students and asked them to complete the sentences with the most appropriate word. The analysis showed that participants were in complete agreement about the target words that completed each sentence. But note that in three of the sentences some of the participants gave also a possible *British* ending (e.g “You can’t buy anything for a pound/penny” instead of “cent”), which were different from the Bloom and Fischler (1980) predicted words. I considered both of these responses as correct. The sentences were recorded in a soundproof booth by a native British English speaker. They were recorded as complete sentences in order to sound natural. The last word of each sentence was then cut off to produce the stimulus.

2.3.2.1.2.2 Procedure.

Participants listened to the sentences one by one. After each sentence, a cue appeared on the screen. Depending on the cue shape, they had to either complete the sentence with the most appropriate word (i.e., automatic condition) or with a totally unrelated word (i.e., inhibition condition). The cue shapes were 4.25 x 4.25 inches. A blue circle was presented for the automatic condition and a red octagon for the inhibition condition. The size and shapes are based on Bélanger and Belleville's (2009) experiment. Each trial started with a fixation cross in the centre of the screen, which was presented for 1500ms and remained on the screen during the auditory presentation of the sentence. Fifty milliseconds after the last uttered word, the condition-associated cue was visually presented. The cue remained on the screen until the participant’s verbal response triggered the voice key or until the end of the maximum response period of 5000ms (see also Bélanger & Belleville, 2009). Participants were instructed to listen carefully to each sentence and to respond as quickly as they could. Both reaction times (RT) and response errors were measured.

2.3.3 Data analysis

2.3.3.1 Accuracy and Response times.

For both tasks, response times were analysed with linear mixed effect models employing the lmer function of the lme4 package (Bates, Maechler, & Bolker, 2013) using R version 3.3.1 (R Development Core Team, 2009). Accuracy measures were analysed using logistic regression (generalized linear mixed models with a binomial link function).

To obtain p-values[4] and degree of freedoms the "Satterthwaite" approximation was used with the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2016). The advantage of this statistical approach is that it takes into account random effects and random slopes for items and subjects. Random effects structures were determined by model comparison, starting with a model including all factors and a fully specified random effect structure, i.e. random intercepts and random slopes. The random effect for subjects was step-wise reduced while the random effect of items and the fixed effect structure were held constant. The best fitting model for each random effect or random slope was determined on the basis of the Akiake's Information Criterion (AIC) (Sakamoto, Ishiguro, & Kitagawa, 1986). The random effect of items was determined in the same way, keeping the random effect of subjects constant and using a fully specified fixed-effects model.

[4] Throughout the thesis, p-values below .05 would be considered as significant and values between .05 and .08 would be categorised as trends to significance and considered as being meaningful.

To determine the best model fit for the fixed effect structure, the fully specified fixed-effects model was further step-wise reduced and models were compared using a maximum likelihood ratio tests (Bates et al., 2013). The reduction always started by removing the higher order interactions and then the least important main effect. This approach was used for all tasks except for the Stop-signal task, where a different analysis method was required by the experimental paradigm.

2.4 Results

For response time analyses, only accurate responses were included. In addition, all responses deviating from the means of the individual measurements by more than 2.5 SDs or responses below 200 ms were considered outliers and were removed from the analyses. The percentage of errors and outliers are reported with each task. Due to technical problems with the voice key, the data of one participant from the control group had to be excluded from the analysis (the results of the language assessment analysis remain the same when the participant was removed).

2.4.1 Blocked Cyclic Picture Naming task

Since previous studies had demonstrated that the blocking effect in the blocked cyclic naming task starts to emerge from the second cycle of a presentation block (Belke, Meyer, et al., 2005), the first cycle of each block was excluded from the analysis. In addition, this also minimise possible effect that phonology would have on the performance, since participants will have initially accessed names in the first cycle. This was true for both Accuracy and RT analysis.

2.4.1.1 Accuracy.

Mean accuracy rates in both heterogeneous and homogeneous conditions for both AwD and control participants are displayed in Figure 2-1. The participants’ utterances were categorised as correct or incorrect. All trials were participants failed to pronounce the correct picture name were classed as an errors. The types of errors participants made were hesitations (e.g. “uhh” or “aa”), competitor errors (self-corrections (partial repetitions) and whole word names of other pictures within the same experimental block), stutters, and incorrect object names (e.g. using ‘jacket’ instead of ‘coat’). Table 2-2 shows the dependent variable accuracy in the heterogeneous and homogeneous conditions for the group with dyslexia and controls.

Table 2-2 Means and standard deviations of the accuracy in each condition of the blocked cyclic naming task.

Accuracy	*Heterogeneous condition*	*Homogeneous condition*
Control group	1 (0.07)	0.99 ms (0.09)
AwD group	0.99 (0.08)	0.98 (0.14)

In accordance with previous research, I found a significant main effect of Condition ($\chi2$=21.50; df= 1; p < .001), with participants responding more accurately in the heterogeneous condition than in the homogeneous condition. In addition, the effect of Group was significant ($\chi2$=7.56; df= 1;p= .005), with AwD being less accurate than controls. Importantly, there was a significant interaction between Group and Condition ($\chi2$=3.91 df= 1; p= .048). I therefore investigated the effect of Group in the homogeneous and heterogeneous conditions separately. I found no significant group difference in the heterogeneous condition ($\chi2$=0.11; df= 1; p=.739), but a significant difference in the homogeneous condition ($\chi2$=11.03; df= 1; p < .001), with AwD making more errors than controls. This can be seen in Figure 2-1.

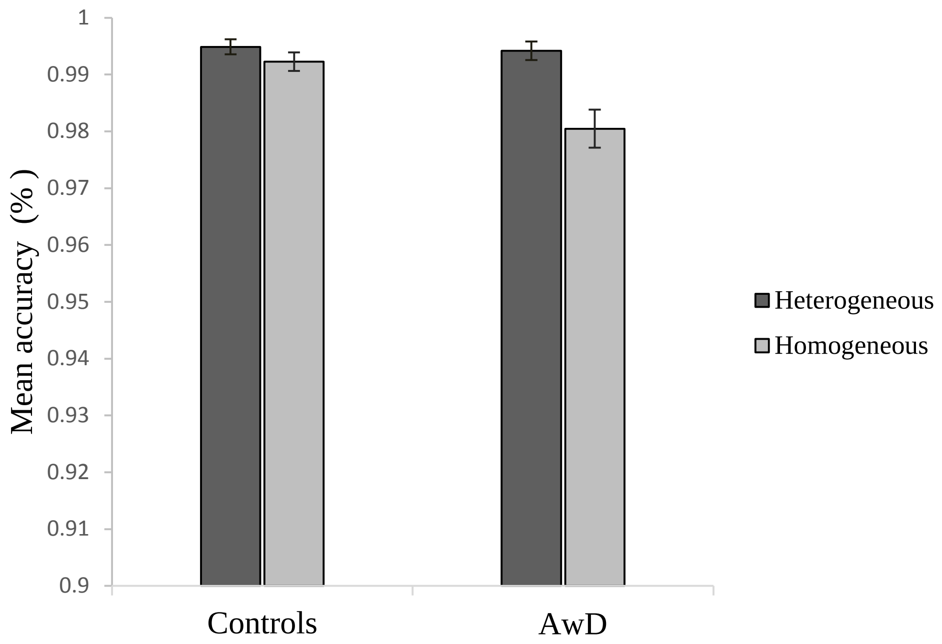

Figure 2-1 Mean accuracy rates of AwD and control participants in the homogeneous and heterogeneous conditions in the blocked cyclic picture- naming task. Error bars represent standard errors.

Competitor errors can be a sign of suppression failure of highly activated competitor words (Belke, 2013; Howard, Nickels, Coltheart, & Cole-Virtue, 2006; see also Oppenheim et al., 2010 for a non-competitive account). I therefore investigated whether competitor errors were more frequent in participants with dyslexia than in controls. Participants made very few errors in the heterogeneous condition overall (N= 30) and even fewer competitor errors (N=22). Given the small number of errors in this condition, I did not analyse these further. In the homogeneous condition, participants made mostly competitor errors (70%; with higher numbers in AwD (N=40) compared to Controls (N=18) compared to other types of errors. While these errors were also rare, they were frequent enough to analyse. I performed a logistic regression to test for a group difference. I fitted a full model with Accuracy (competitor errors vs all other responses) as the Dependent Variable (DV) and Group (Control versus AwD) as a fixed factor. The random structure included random intercepts for subjects and items. I found significant effect of Group ($\chi 2$=10.47; df= 1; p = .001), with AwD making more competitor errors compared to controls in the homogeneous condition. The proportion of the competitor errors could be seen in Figure 2-2.

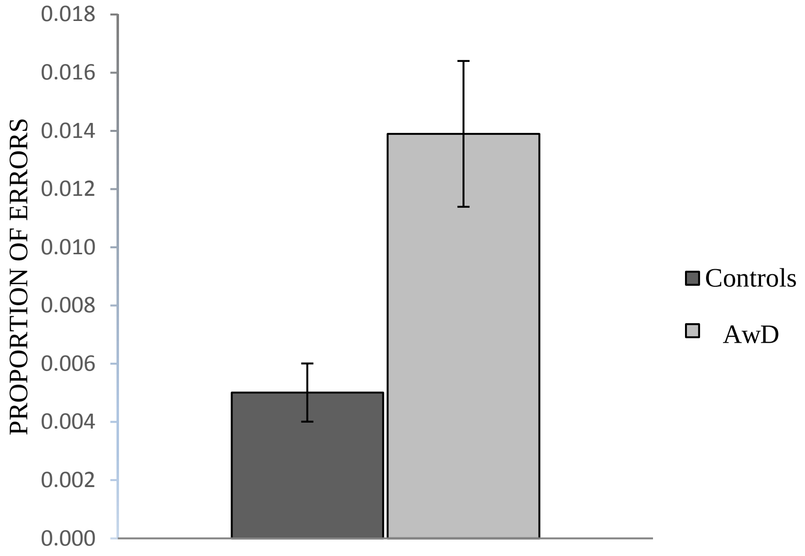

Figure 2-2 Proportion of competitor errors compared to all other responses made by controls and AwD in the homogeneous condition. Error bars represent standard errors.

In order to rule out phonological deficits as the underlying cause of the larger proportion of lexical-semantic errors in AwD, I plotted the sum of hesitations, stutters and competitor errors across the eight cycles in Figure 2-3 (incongruent object names were not included, because the processes underlying those could not be explained by phonological deficits). Based on previous studies of aphasic patients with reported deficits in phonology decoding (e.g., Schnur, Schwartz, Brecher, & Hodgson, 2006), the expected pattern of results for a phonological deficit would be to find more errors at the start of a block and a gradual decrease of errors across the cycles due to picture repetitions. Figure 2-3 shows that this is clearly not the case. Instead, AwD experienced more lexical competition errors in the homogeneous condition compared to the controls in almost all cycles. This pattern of results is in line with a deficit in resolving increased lexical-semantic competition in the homogeneous condition (e.g., Belke, 2017). Moreover, it appears that AwD experienced more lexical competition or were less able to suppress lexical competitors compared to controls.

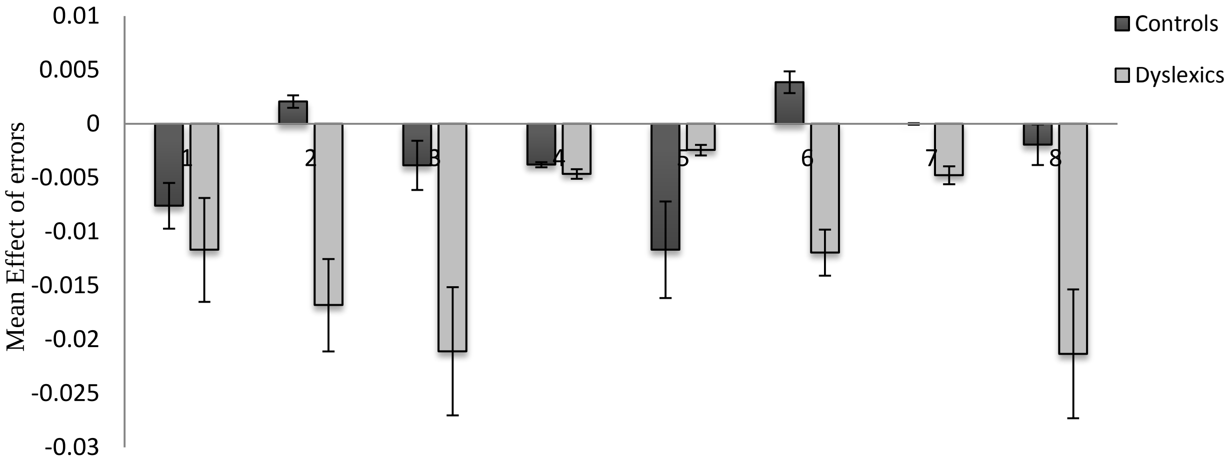

Figure 2-3 Error rates across cycles in both participant groups. Error bars represent standard errors.

2.4.1.2 Response times.

I fitted a mixed effect model with Response Time as the Dependent Variable, Group (Control versus AwD) and Condition (homogeneous versus heterogeneous) and their interaction as fixed factors. The best fitting random structure included random intercepts for subjects and items, as well as by-item random slopes for the effect of condition. Table 2-3 shows the dependent variable RTs in the heterogeneous and homogeneous conditions for the group with dyslexia and controls.

Table 2-3 Means and standard deviation of the RTs in both heterogeneous and homogeneous conditions for each group separately.

Response times	*Heterogeneous condition*	*Homogeneous condition*
Control group	600 ms (49)	631 ms (56)
AwD group	627 ms (70)	655 ms (81)

Response times more than 2.5 SDs from participant means and below 200ms were considered outliers and eliminated. These accounted for 2.7% of the total responses (N=12,860). The final number of data points after removing the outliers and the incorrect responses was 12,432. The results are displayed in Figure 2-4. I found no significant Group by Condition interaction ($\chi2$=0.46; df= 1; p=.497) and no Group effect ($\chi2$=2.57; df= 1; p= .109). Only the effect of Condition was significant ($\chi2$= 9.22; df = 1; p= .002), with the Homogeneous Condition leading to longer response times than the Heterogeneous Condition. The competitive semantic context slowed down both groups equally.

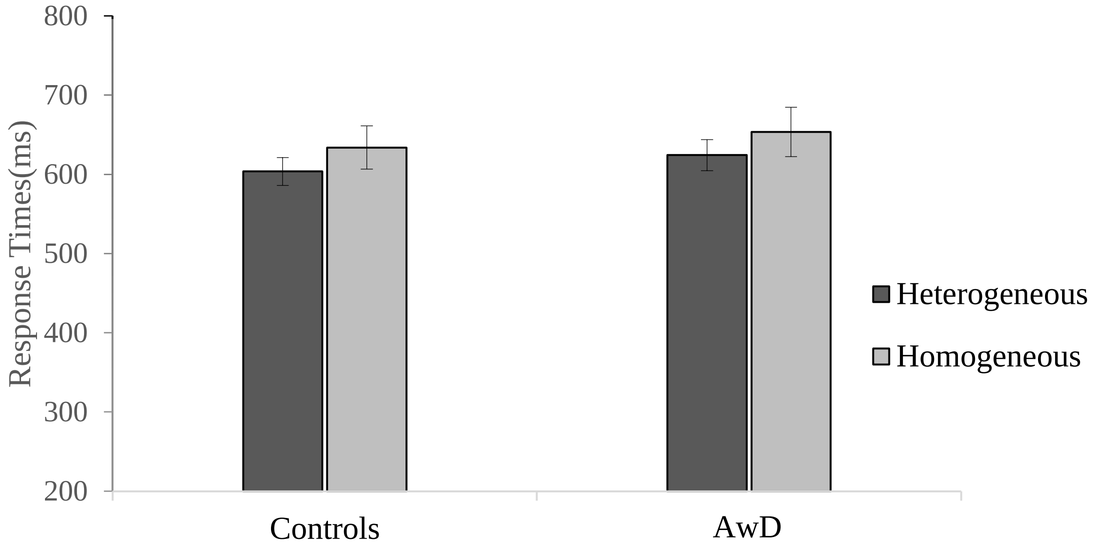

Figure 2-4 Mean response times for controls and AwD in Homogeneous and Heterogeneous blocks in the blocked cyclic naming task. Error bars represent 95% confidence intervals.

2.4.2 Hayling task

I analysed the Hayling task by investigating error patterns and response times in the automatic and inhibition conditions separately. Looking at the two condition separately was an essential step considering the clear process dissociation between the response initiation and suppression of the proponent response in the two conditions (e.g., de Zubicaray, Zelaya, Andrew, Williams, & Bullmore, 2000). Response times were analysed using linear mixed models and errors with mixed model logistic regression. I removed one participant from the dyslexia group because they used a strategy in the inhibition condition (i.e. naming only body parts as a response) that led to unusually accurate and fast responses.

2.4.2.1 Accuracy.

Incorrect responses in the Hayling task accounted for 8.2% of the data overall (7.7% incorrect responses in the inhibition condition and 0.5% incorrect responses in the automatic condition).

2.4.2.1.1 Automatic condition.

In the automatic condition, all words that correctly completed the sentence were counted as correct responses. All other responses counted as errors. The number of errors made in the automatic condition was too small for a meaningful analysis (*9* errors or *0.5%* of the total responses). We, therefore, did not perform a group comparison.

2.4.2.1.2 Inhibition condition.

Following Burgess and Shallice (1996), errors in the inhibition condition were categorised into four categories: inhibition failures, partial (inhibition) failures, perseveration errors and missing responses. Inhibition failures were word responses that used the expected sentence endings instead of unrelated words (e.g. saying "*ship*" in "*The captain wanted to stay with the sinking…").* Perseveration errors were responses that were repetitions of earlier responses in the task. Missing responses were failures to produce a response in the time limit of 5 seconds. Partial failures were erroneously produced words that did fit the context of the sentence but were not the expected word. Partial failures were semantically related to or antonyms of expected words (i.e. "*submarine" in "The captain wanted to stay with the sinking...*"). Table 2-4 shows the dependent variables (i.e. accuracy) in the inhibition condition for the group with dyslexia and the control group.

Table 2-4 Means and standard deviations for each of the dependant variables in the accuracy analyses.

Analysis	Inhibition condition
Control group	
Overall accuracy	0.87 (0.07)
Inhibition failures	0.99 (0.02)
Partial failures	0.98 (0.03)
AwD group	
Overall accuracy	0.79 (0.13)
Inhibition failures	0.97 (0.05)
Partial failures	0.94 (0.06)

2.4.2.1.2.1 Error-type analysis.

In order to test overall accuracy in the inhibition condition I fitted a *glmer* model with accuracy (all type of errors vs correct responses) as dependent variable, and Group (Control vs AwD) as fixed factor[5]. The best random structure included random Intercepts for Subjects and Items. I found a significant main effect of Group ($\chi 2=9.72$; df= 1; p = .002). AwD were less accurate than controls (see Figure 2-5).

[5] I also investigated whether the fact that a sentence was responded to for the first or the second time made a difference to the number of errors or response times in the two participant groups. I did not find any interaction between Presentation order and Group in any of the analyses.

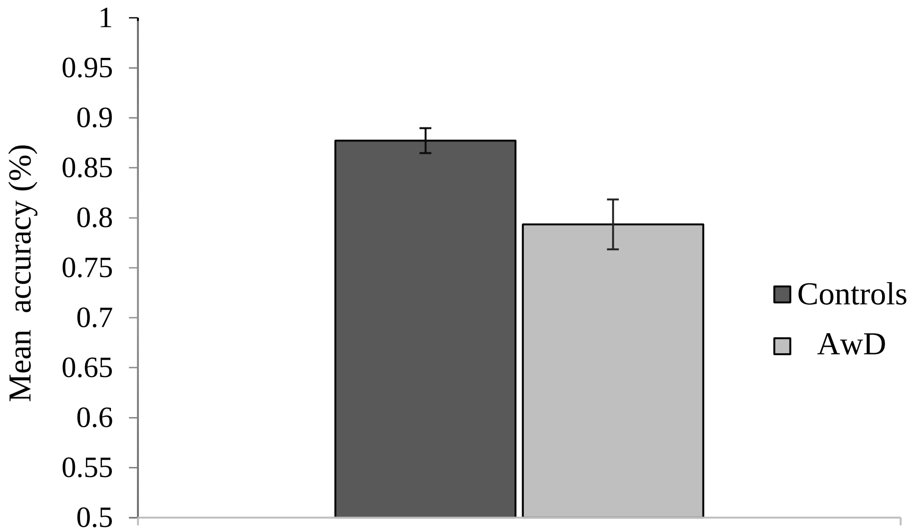

Figure 2-5 Mean accuracy for the inhibition condition. Error bars represent standard errors.

Inhibition-failure errors.

To investigate if the AwD decreased accuracy in the inhibition condition was due to a difficulty supressing a prepotent response (i.e. a response that created an appropriate sentence ending instead of an unrelated word); I fitted a new model with inhibition failures (versus all other responses) as the dependent variable and Group as fixed factor. The best random structure included only random intercepts for Subjects. I found no significant main effect of Group ($\chi 2$=2.25; df=1; p =.134). AwD did not significantly differ from the controls in suppressing proponent responses (see Figure 2-6).

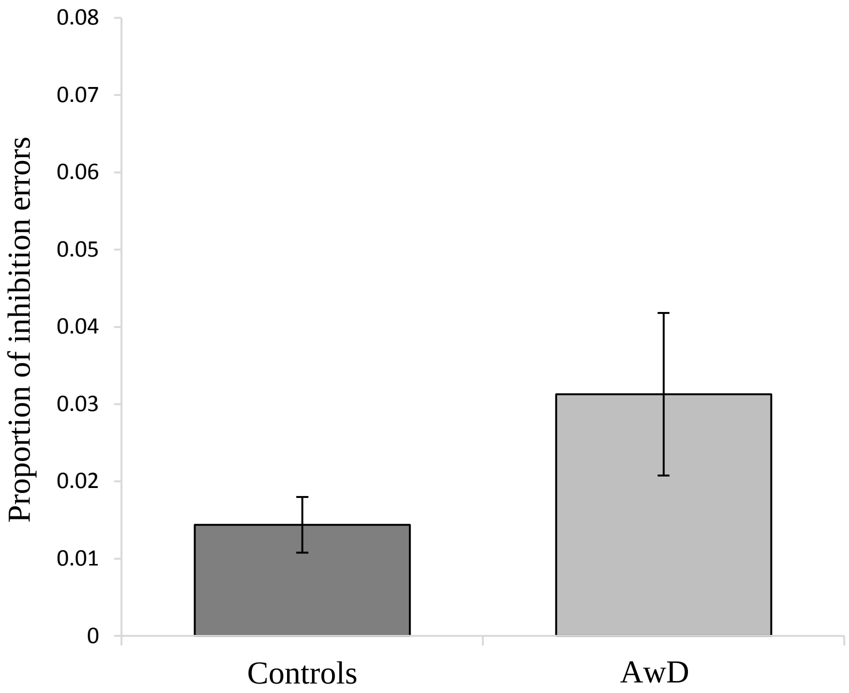

Figure 2-6 Proportions of the inhibition failure errors for both participant groups. Error bars represent standard errors

2.4.2.1.2.2 Partial-errors.

To investigate if AwD experienced more partial failure errors, I fitted a model with semantically related words completing the context of the sentence versus all other responses, including inhibition failures, as the dependent variable. Group was a fixed factor. The best random structure included random intercepts for Subjects and Items. I found a significant main effect of Group ($\chi 2$=6.71; df=1; p =.009), with AwD producing more partial failures than controls (see Figure 2-7).

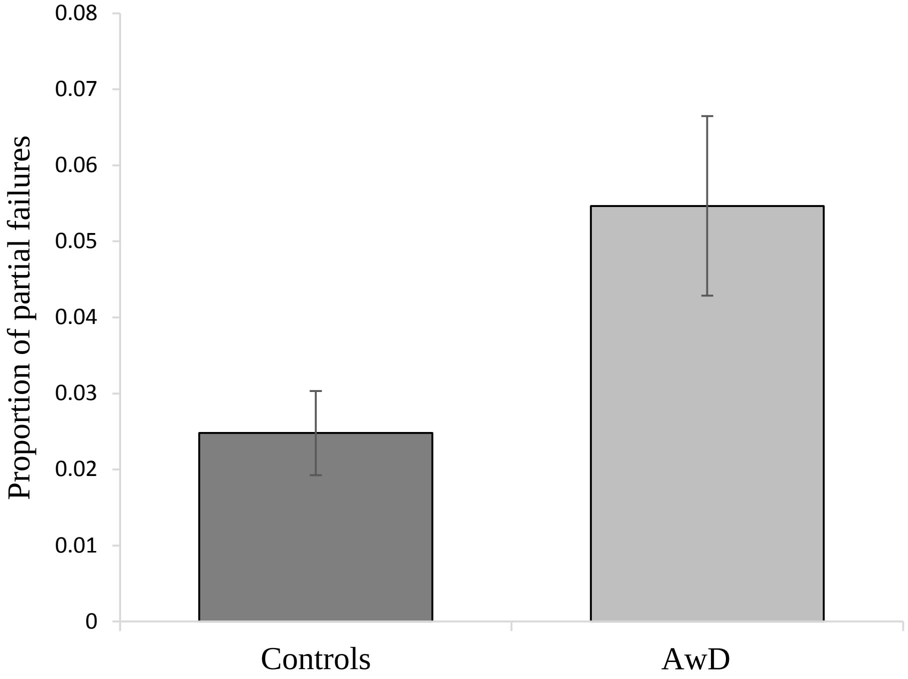

Figure 2-7 Proportion of partial failures for each of the two participant groups. Error bars represent standard error.

2.4.2.2 Response time analysis.

Response times faster than 200ms and slower than 2.5 SDs from participant means were considered outliers and excluded from the analysis (responses before exclusion N=3,559). Outliers accounted for 2.2% of the total responses. In addition, all errors (missing responses, perseveration errors, inhibition failures and partial failures) were excluded from the analysis. The total number of data points after removing the outliers and the incorrect responses was 3,251. The best random effect structure for both conditions included random Intercept for Subjects and Items. Table 2-5 shows the dependent variable in both conditions for the group with dyslexia and controls.

Table 2-5 Mean and Standard deviation for the RTs in Automatic and Inhibition conditions for each of the two groups.

Response times	Automatic condition	Inhibition condition
Control group	1000 ms (211)	1623 ms (552)
AwD group	926 ms (248)	1908 ms (698)

There was no effect of Group ($\chi 2$=1.41; df= 1; *p*= .235), with AwD performing similarly to the controls (see Figure 2-8).

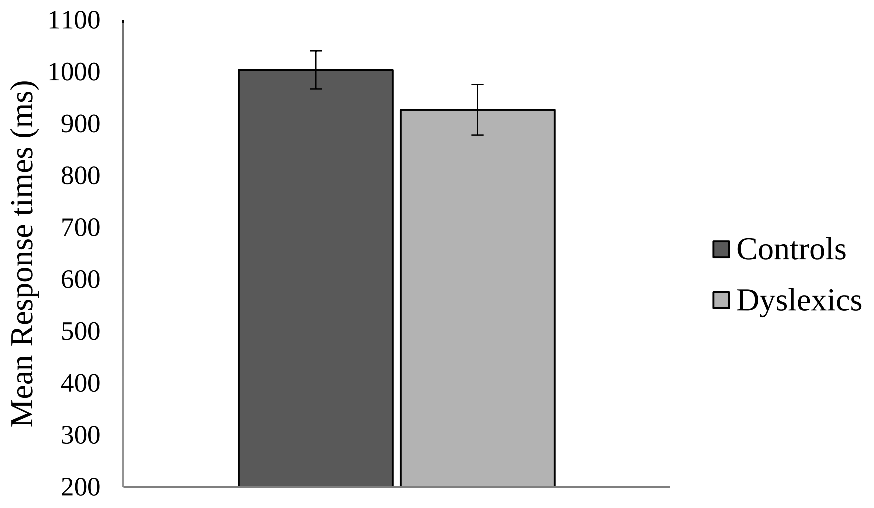

Figure 2-8 Mean RTs for the Automatic condition for the two participant groups. Error bars represent standard errors.

For the inhibition condition, there was a trend towards significance for the main effect of Group ($\chi 2$=3.07; df= 1; *p*= .079), with AwD being slower than the controls (Figure 2-9). This is in line with the overall accuracy and partial inhibition analyses above, where AwD experienced more difficulty with the inhibition condition compared to the controls.

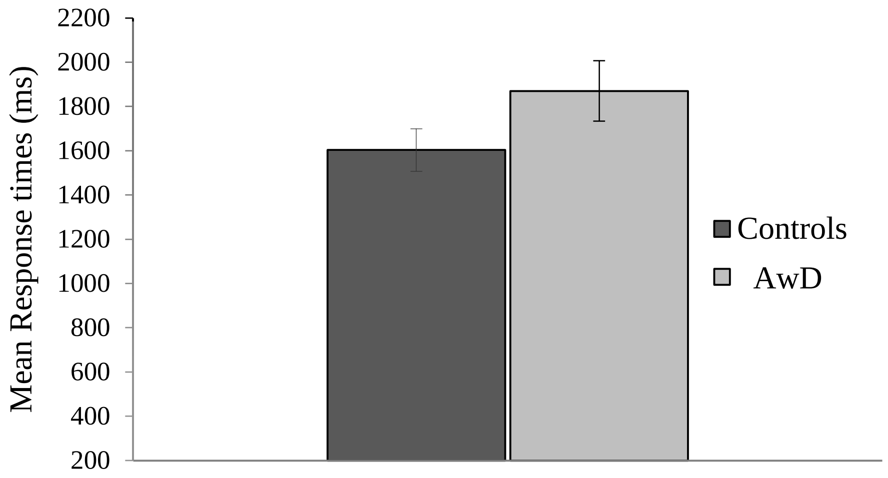

Figure 2-9 Mean response times in the inhibition condition for both controls and AwD. Error bars represent standard error.

2.4.3 Pattern of associations between tasks

In the previous subsection, I found group differences for accuracy in the more demanding conditions of both Hayling and Blocked cyclic tasks. Here, I want to see if these deficits are due to the same underlying mechanisms or not. To assess this, I performed Pearson correlation analyses for the group with dyslexia and the control group separately. The group split is linked to the argument that dyslexia is a multiple-deficit disorder (Peterson & Pennington, 2015), with distinct and atypical cognitive and perceptual processing rather than the lower end of a continuum of reading ability. I correlated all errors and partial failures in the Hayling task, with the semantic accuracy effect (proportion errors in the homogeneous condition minus the proportion errors in the heterogeneous condition) and competitor errors from the semantic blocking task. I wanted to investigate if the increased number of errors in the two tasks is as a result of one underlying mechanism. If AwD deficits in both tasks are caused by lexical semantic competition, then I would expect partial failure in Hayling task and the competitive errors in blocked cyclic task to be correlated.

Some of the variables represent proportions of accuracy, resulted in positively skewed data. In order to investigate the relationship with the effect of response time variables I transformed the data using Arcsine transformation[6].

Table 2-6 Between tasks correlations for the control group of participants and for the group with dyslexia.

		Semantic accuracy effect		Competitor errors homogeneous	
		r	*p*	**r**	*p*
	Control Group				
Hayling task	Overall Accuracy	**-.25**	*.168*	**-.13**	*.477*
	Partial failures	**-.33**	*.065*	**-.12**	*.500*
	AwD				
Hayling task	Overall Accuracy	**.18**	*.370*	**.26**	*.183*
	Partial failures	**.22**	*.261*	**.43**	*.026**

Table 2-6 shows the correlations[7] between two tasks. As expected, there was a significant positive correlation between competitive errors in the blocked cyclic task and

[6] The Semantic Accuracy effect variable represents the difference of proportion between the homogeneous and heterogeneous conditions; as a result, some of its values were negative. In order for the data to comply with the Arcsine range (0 >) I added .5 to all data points. Making all data points positive.

partial failures in the Hayling task, but only in the dyslexia group[8]. This relationship points to a possible connection between the deficits's AwD experienced in both tasks. However, as can be seen from Figure 2-10 the relationship between the two variables should be treated with caution because of the number of zeroes, which do not contribute to the analysis.

For the controls, there was no relationship between the semantic errors in the two tasks. There was however, a trend for a relationship between the partial errors in Hayling task and the semantic effect of accuracy in blocked cyclic naming task. This relationship is in the opposite direction of that of the dyslexia group, suggesting that controls used different mechanisms when making errors in the two tasks. However, it should be kept in mind that after correcting for multicollinearity the trend for a relationship in the control group disappears and the significant relationship between the errors in dyslexics is not as strong which limits the strength of the possible interpretations.

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[7] I also ran log-linear analyses on the data in order to check the strength of the correlations. The results confirmed the pattern of results, with some differences for the strength of the effects: some effects appeared weaker and some stronger compared to the correlations.

[8] I should note that the correlation was not driven by few individuals showing increased error rates, but from the majority of AwD reported competitive and partial errors.

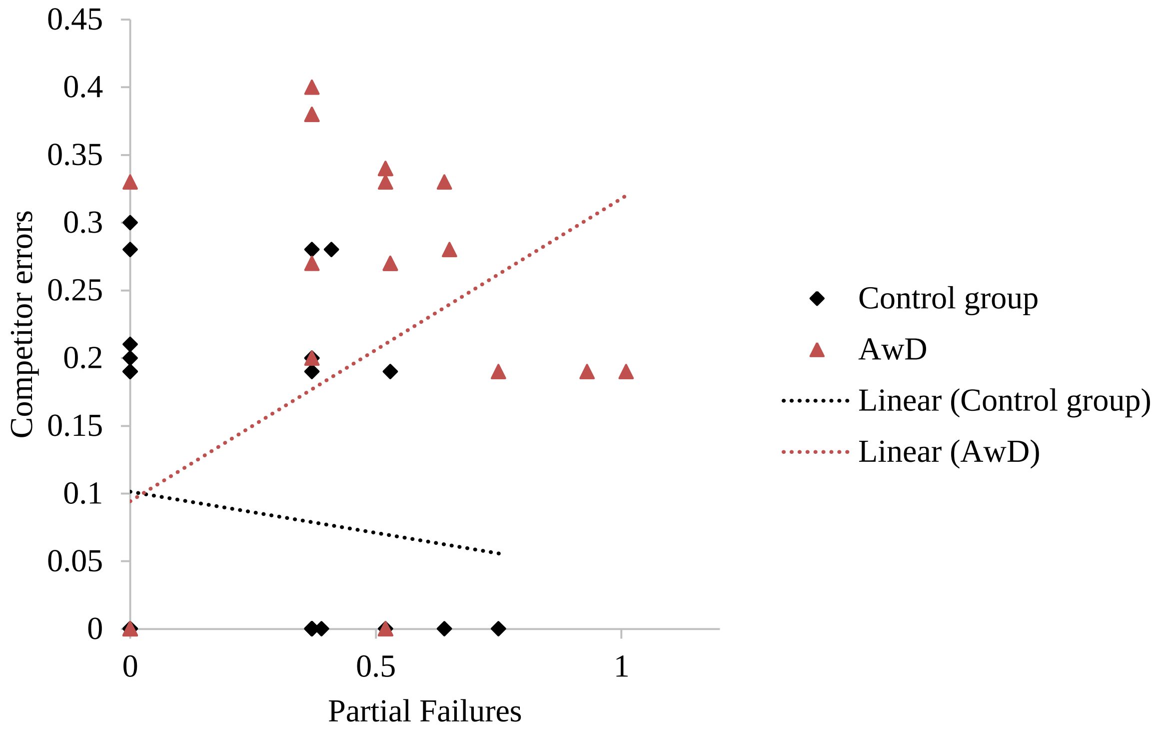

Figure 2-10 Relationship between Competitor errors and Partial Failures for the control group and for the group with dyslexia.

2.4.4 Dyslexia severity and task related deficits

In the previous sections, I established deficits involving lexical-semantic competition in the people with dyslexia group and that these deficits are not task dependant but occur in both tasks. Here, I investigate this further by looking at how the semantic deficits relate to the severity of the dyslexia. I estimated the severity of dyslexia in two ways; a) by weighting all language tests equally and b) by using Principle component analysis, where theoretically determined clusters were created based on the functions of the language tests.

To obtain a single measure of severity while weighting all language tests equally, I averaged the z-scores of all language tests in which the dyslexia group was significantly different from the controls. This included the different word reading tasks and the subtests for phonological awareness, rapid letter naming and phonological memory (see Table 2-1 in the Method section). To assess the pattern of associations between performance on the lexical-semantic tasks and severity of dyslexia I ran correlation analyses.

Table 2-7 Correlations between dyslexia severity (mean z-score of dyslexia assessment measures) and the lexical-semantic measures that showed group differences in the language tasks.

		Dyslexia severity	
		r	*p*
Blocked cyclic naming			
	Semantic effect Accuracy	**-.23**	*.241*
	Competitor errors homogeneous	**-.14**	*.468*
Hayling task			
	Overall Accuracy	**-.16**	*.413*
	Partial failures	**-.08**	*.674*
	RTs Inhibition condition	**-.21**	*.315*

None of the correlations between the lexical semantic measures and the combined score of the language assessments were significant (see Table 2-7). The participants who had the lowest scores on the dyslexia assessments did not make more errors in the experimental tasks. The phonological deficits of the AwD, which strongly influence the outcomes on the assessment tasks, do not seem to be related to the deficits in the language tasks, supporting the conclusion that differences measured by the experimental tasks are, indeed, not of a phonological nature. However, it is possible that AwD competition deficits are related to specific language skills, rather than the overall dyslexia severity. The language assessment tests I used consisted of different language skills such as lexical, phonological memory and phonological processing. The selection of these skills will be evident in the next analysis where different language clusters were investigated.

In my second approach to estimate dyslexia severity, I ran three Principle component analyses (PCA) to reduce the language assessment scores to a smaller set of theoretically defined components. Based on previous research (e.g., Deacon, Benere, & Castles, 2012), the assessment subtests were grouped into three theoretically defined factors named lexical skills, phonological short-term memory and phonological manipulation. The participants' measures for sight word reading, irregular word reading, rapid letter naming and the Gray Silent Reading Test all required visual/lexical processing. Thus, these were grouped into principle component factor score named lexical skills. In the second PCA analysis, the factor score reflected phonological STM and included non-word repetition and memory for digits. In the third PCA analysis, I measured phonological manipulation abilities by grouping elision, phoneme reversal and non-word reading tests. I used principal component extraction and one factor for each analysis. The lexical skills factor accounted for 46% of the variance with loadings from sight word reading =.80, irregular word reading=.72, rapid letter naming=-.72 and Gray Silent Reading Test=.43. The phonological STM factor accounted for 65% of the variance with loadings memory for digits=.81 and non-word repetition=.81. Finally, the phonological manipulation factor accounted for 61% of the variance with factor loadings for phoneme-reversal=.83, elision=.69 and non-word reading=.81. I used the factor loadings derived via Barlett's method and correlated the results with the experimental measures as above. The results are displayed in Table 2-8.

Table 2-8 Correlation between the semantic tasks and the factors lexical skills, phonological STM and phonology manipulation in the dyslexia group

		Lexical skills		Phonological-STM		Phonological manipulation	
		r	*p*	**r**	*p*	**r**	p
Blocked cyclic naming							
	Semantic accuracy effect	**-.36**	*.067*	**-.18**	*.369*	**-.09**	*.643*
	Competitor errors homogeneous	**-.06**	*.750*	**.04**	*.861*	**-.26**	*.202*
Hayling task							
	Overall Accuracy	**-.18**	*.356*	**.13**	*.531*	**-.29**	*.148*
	Partial failures	**-.24**	*.248*	**.09**	*.674*	**-.14**	*.484*
	RTs Inhibition condition	**-.37**	*.066*	**-.34**	*.094*	**.01**	*.972*

Interestingly, the results of the PCA are in line with what I hypothesised (see Table 2-8). No correlations reached significance, but there were some trends in two areas. Performance in the cyclic blocking task was related to the lexical skills. People with poorer lexical skills struggled more to resolve the competition between lexical items in the homogeneous condition. In addition, the response times in the inhibition condition of the Hayling task were negatively related to lexical skills. However, as I already noted when corrected for multi-comparison, the trends disappeared.

To see if the relation between tasks was restricted to the dyslexia group, I ran the same set of correlations for *the control group*[9]. The correlation between semantic accuracy and lexical skills was significant (r=-.38, p=.028; Figure 2-11). The relationship between lexical skills and performance in the cyclic blocking task was not limited to the AwD.

[9] Before running the correlations for the control group, I repeated the PCA dimension reduction procedure in the same way as the AwD group.

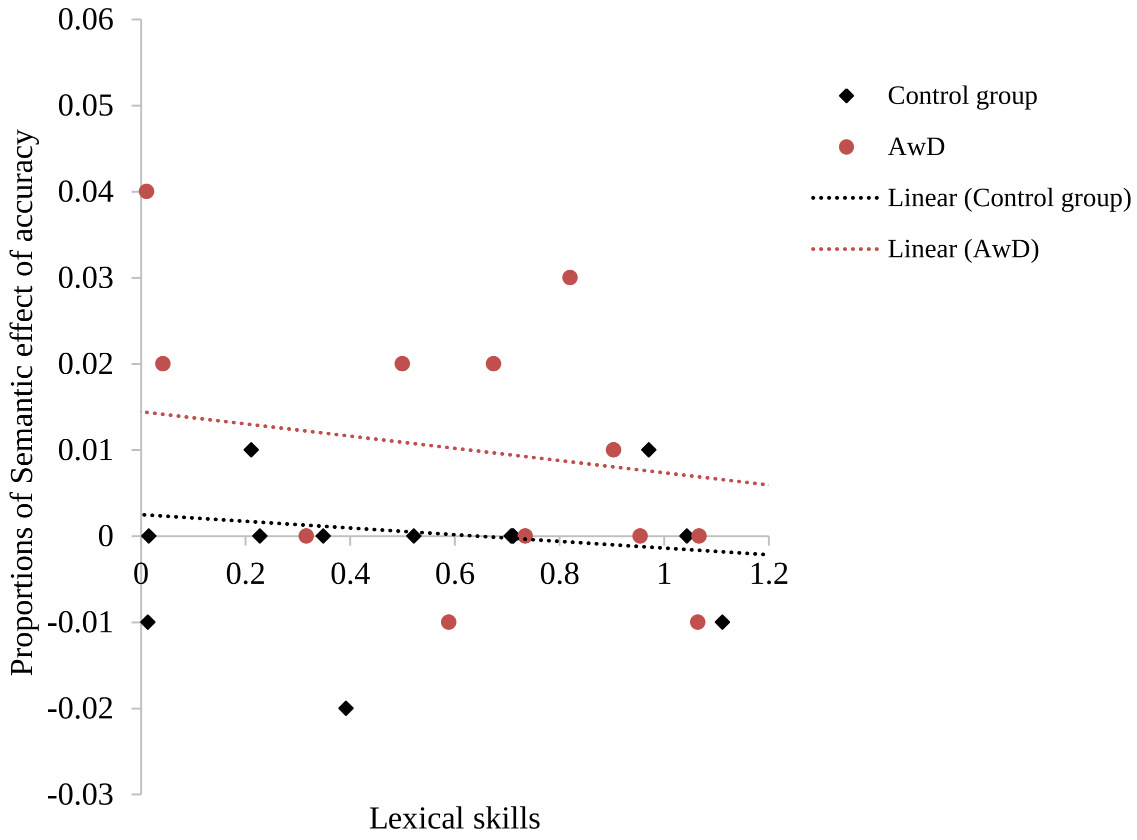

Figure 2-11 Correlations between lexical skills and the semantic effect of accuracy for the control group and the AwD group.

The relationship between inhibition RT and lexical skills that was present in the AwD group was not present in the control group. See Figure 2-12 for details. Since the performance in the task is associated with generation of alternative responses from a large array of alternatives (see discussion in de Zubicaray et al., 2000), the internal generation of a novel response will requires additional mechanisms like lexical access, good short term and long term memory. It is possible that lexical skills are more important for AwD participants, who have weaker phonological STM, but this compensatory effect is not present in controls because they have stronger STM.

Therefore, it is possible that the trend toward group differences in the Inhibition RTs might be influenced partly by AwD lexical strategy in generating a novel response due to their weakness in their verbal STM, which when operating in full could be better strategy itself.

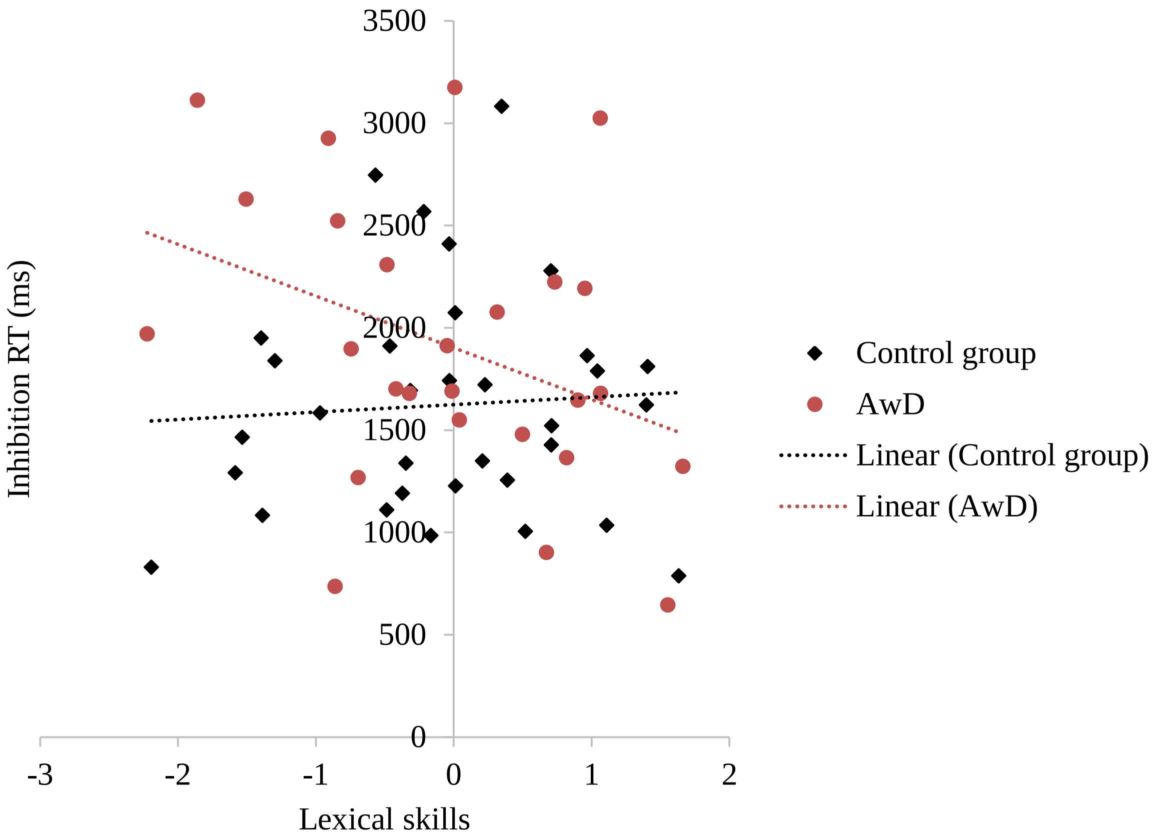

Figure 2-12 Correlations between lexical skills and the RTs in inhibition condition of the Hayling task. There was no linear relation in the control group. The relationship exists only for the group with dyslexia.

2.5 Discussion

The aim of the present study was to explore whether AwD have lexical-semantic retrieval deficits that involve resolution of lexical competition. More specifically, I was interested in lexical retrieval in conditions where lexical-semantic competition was increased. I used the blocked cyclic paradigm and the Hayling sentence completion task. With the Hayling task, I looked at the additional mechanism of task-related suppression of prepotent responses. For the blocked cycling naming task, I predicted that if AwD have a deficit in resolving lexical competition then they would have a larger semantic blocking effect in response times and/or errors. The results for accuracy were as predicted, with AwD performing less accurately than controls in the homogeneous but not the heterogeneous condition. They also made with significantly more semantic errors. The predicted effect was not present in the RTs of the AwD. With regards to the Hayling task, I predicted that AwD would be slower and/or make more errors in the inhibition condition compared to controls, but there would be no difference in the automatic condition. AwD were, indeed, less accurate in the inhibition condition. The ceiling effect for accuracy in the automatic condition and the lack of a group difference in inhibition failure errors in the inhibition condition suggests normal prepotent response suppression in AwD. However, AwD experienced more partial inhibition errors compared to controls. This finding is in line with the findings of the blocked cyclic naming task and suggests increased-lexical semantic competition. This conclusion is supported by the trend for AwD to be slower than the controls in the inhibition condition, but not in the automatic condition. In what follows, I will first discuss how the results support my hypothesis of a more competitive lexicon in AwD and the possible underlying processes. I will then discuss how the results can be accounted for by different speech production models. Finally, I will discuss alternative interpretations of the results and evaluate the link to AwD reading deficits.

2.5.1 Adults with dyslexia have a more competitive lexicon.

The results in the blocked cyclic naming experiment were not in line with previous research reporting slower RTs for participants with dyslexia when naming pictures (Katz, 1986; Swan & Goswami, 1997a). This is probably due to participants naming the same pictures repeatedly, which reduces the influence of initial access to the picture names and initial phonological encoding. The larger proportion of errors in the dyslexia sample, however, even if small in terms of numbers, is in line with previous studies with CwD (e.g., Nation et al., 2001; Swan & Goswami, 1997a).

In these studies, the predominant view of the origin of individuals with dyslexia' picture naming errors is an underlying phonological deficit (Nation, 2005). Even though manipulating phonological representations is a necessary step in the cyclic blocking task, current results cannot be explained in this way. Swan and Goswami (1997a) found that CwD experience a large proportion of phonological errors only when there are polysyllabic picture names and more complex phonological representations were required. The picture stimuli I used were all matched for phonological overlap and were all monosyllabic (Belke, Meyer, et al., 2005). This means that the homogeneous condition was not more demanding than the heterogeneous condition in terms of phonological processing. Perhaps more importantly, the error distribution across different cycles did not support the typical pattern of errors caused by phonological deficits. A phonological deficit should have led to errors at the beginning of a block, when participants are less familiar with the picture names, and fewer errors later in the block. Instead, errors were relatively constant across cycles.

In Hayling task, I obtained a similar pattern of performance. AwD produced more errors in the inhibition condition, particularly partial errors, which were contextually appropriate, not unrelated, and also semantically related to the target word. This finding fits well with the results from blocked cyclic naming, because it suggests there is a difficulty resolving strong lexical competition. Another explanation of the increase of partial errors could be a problem in generating random words in dyslexics. However, such difficulty would also be evident in increase number of no responses, which was not the case. Together, both results are consistent with the individuals with dyslexia deficit in suppressing lexical competitors.

The experimental results are also in line with the finding by Jones, Branigan, Hatzidaki and Obregón (2010b) that highly functioning AwD (a similar sample to the one used in this chapter) performed worse in both a picture-naming task and in an object-categorization task. The latter result is especially important because object categorization requires only access to semantic and syntactic properties of target words without access to the words' phonological codes. While their results are in line with a visual account of dyslexia (Stein & Walsh, 1997), the results from my study raise the possibility that lexical-semantic retrieval deficits are involved. Importantly, present results cannot be due to the visual similarity of the pictures because the stimuli I used were controlled for visual similarity by using visually dissimilar category items (Belke, Meyer, et al., 2005). In addition, a visual deficit would have led to slower responses for the AwD compared to the controls in both conditions, which I did not find. Finally, I obtained similar errors in the Hayling task, which is an auditory task that does not require visual discrimination. Taken together these results point to an increased competition in the interaction between semantic and lexical-phonological representations.

The present experimental findings are not consistent with previous studies with CwD that reported deficits in supressing prepotent responses (i.e. reading the word) in Stroop-like paradigms (Faccioli et al., 2008; Helland & Asbjørnsen, 2000; Kapoula et al., 2010; Protopapas et al., 2007). I found no evidence for prepotent inhibition deficits in the high-functioning adult sample. No group difference in inhibition failure errors in the Hayling task suggests normal general response suppression abilities. However, as described in the introduction, the Stroop effects could also originate at the lexical level where closely related semantic representations (e.g. red and blue) compete for selection (Roelofs, 2003). AwD made more errors in the more competitive condition of both of the experimental tasks, in line with the suggestion that individuals with dyslexia perform worse in Stroop-like paradigms because of a possible deficit in suppressing lexical competitors.

2.5.2 Top-down control modulation

It has been suggested that in addition to the bottom-up spreading activation process during lexical retrieval there is also top-down mechanism involved, dependent on the task-specific requirements (Belke & Stielow, 2013; Roelofs, 2003; Thompson-Schill & Botvinick, 2006). Top-down mechanisms are also found in language production models such as WEAVER++ and Dark Side model (Oppenheim et al., 2010; Roelofs, 2003). Similar top-down processes have been proposed to have an influence in blocked cyclic naming in addition to the lexical competition (Belke, 2008).

According to Belke (2008), participants encode the object names from each set in the first cycle and use this knowledge in the subsequent cycles to restrict within-lexicon activation to only the names in the set. This leads to fast RTs in heterogeneous blocks, where the competition for selection is restricted only to one item per semantic category, thus limiting within-lexicon competition, but not in the homogeneous condition, where the strategy of restricting names to those in the set will not eliminate the competition, because the set members are from the same semantic category. Since, the top-down modulation represents task-specific biases applied on the lexical selection, it was proposed that this modulation depends on working memory processes, used to hold the task goal active (Roelofs, 2003). By manipulating WM load during blocked cyclic naming task, Belke (2008) found increased semantic effect resulted from the limited STM resources. Since, the group with dyslexia was characterised with weaker verbal STM this could have had an influence on their poor accuracy performance in the homogeneous conditions of blocked cyclic naming tasks. However, I believe that this is not likely since I found the correlation between the STM factor and the accuracy effect in blocked cyclic naming task not to be significant (refer to Table 2-8).

In her later study Belke, extended the role of top-down mechanisms, into biased-selection account (Belke & Stielow, 2013). The model assumes lexical selection by competition and, when high competition between lemmas occurs, additional top-down mechanisms are recruited that aid selection of the correct lemma by using verbal STM and executive functions. A crucial element for this mechanism is the task in which participants can distinguish between task-relevant and task-irrelevant features (Belke & Stielow, 2013). Crucial, element in this model is that STM is not the only mechanism involved in top-down modulation, and there could be other processes influencing modulation such as executive functions.

Studies looking at aphasic patients (Schnur et al., 2006) and executive function patients (Belke & Stielow, 2013) performance in the blocked cyclic literature found increase semantic effect in errors that accumulated over cycles in patients but not in controls. It was argued, that this increased effect is due to deficits in the top-down mechanisms (Belke, 2017; Belke & Stielow, 2013; Schnur et al., 2006 attributed it to potential executive influence).

In order to investigate if AwD experienced differences in their performance over cycles I added the factor *cycle* to the statistical models. The results showed no group difference by cycle for either accuracy or RTs. Interference was not increasing over cycles, which suggest that AwD' accuracy deficit found in the homogeneous condition of blocked cyclic task was not because of top-down control deficits.

In summary, I raised the possibility that the accuracy deficits observed in the AwD group in blocked cyclic naming task could be as a result of an increased lexical competition, as a deficit in the top-down mechanism and/or STM deficits. I further ruled out top-down control deficits in AwD and found no evidence for a relationship between the participants with dyslexia STM deficits and their performance in clocked cyclic naming task. Therefore, the current evidences suggest that AwD deficits in blocked cyclic naming task are as a result of increased lexical competition (possibly generated by reduced lateral inhibition).

2.5.3 Language production models

I have hypothesized that errors in cyclic blocking and errors and slowing in the Hayling task may be due to increased lexical competition in participants with dyslexia. It should be noted, however, that the assumption that lexical selection is a competitive process has been debated. According to the competitive view (Levelt et al., 1999; Roelofs, 2018), a lexical unit can be selected when its activation exceeds the activation of its semantic competitors (according to the “Luce ratio”, Roelofs, 1997). In contrast, the non-competitive view suggests that the most activated lexical unit is selected regardless of the activation level of co-activated units (see Oppenheim et al., 2010). In order to achieve this, activation in the semantic network is boosted until one item is selected (Navarrete et al., 2014; Oppenheim et al., 2010).

The question arises as to how the results can be explained by existing lexical production models. For example, in blocked cyclic naming task competitive models like WEAVER++ (Levelt et al., 1999) could explain increased semantic errors through increased within-category activation. Belke's (2013) view of a conceptual level origin for the semantic effect is in line with the competitive model predictions and with the current experimental results. According to Belke, repeated access to a semantic category causes leftover activation to build up in the conceptual level. This activation extends to other lexical items from the same category, leading to higher competition in the homogeneous condition. Similar logic could be applied in the Hayling task. If AwD generally experience stronger competition among related words in the lexicon, activation of the target by the sentence context will also lead to activation of other semantically related responses. Because some of these highly activated related words will fit the sentence context, partial failure errors are predicted. The partial failure words would have higher activation compared to unrelated words and, therefore, a higher chance to be selected, in line with the lexical competition implemented in the model.

As I mentioned earlier, not all production models include lexical selection by competition (Navarrete et al., 2014; Oppenheim et al., 2010). For example, Oppenheim et al., (2010) suggests that lexical-semantic encoding is a result of an incremental learning mechanism that changes the weights of the links between semantic features and lexical representation. After production of a word, the links between the semantic features and its lexical representation are strengthened, while at the same time the links between the semantic features and the co-activated non-target lexical representations are weakened[10].

It is possible that this incremental learning mechanism is not functioning as well in AwD and as a result, the links of the co-activated competitors are not weakened as a result reached level of activation before the target. However, one of the clearest predictions in the model is that when there is a semantic effect (either in RT/ errors) it grows over cycles. Therefore, the learning account can explain the result of blocked cycling naming task if the issue of increased semantic effect across cycles is addressed.

I should note that the lack of an interaction between sentence presentation order and participant group in the Hayling task (refer to footnote 5) is an issue for the incremental

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[10] I should note the weakening of the links is not “suppression” per se, but the effect is the same.

learning account. This account predicts that it would be harder to produce a different response (whether this is the prepotent response or a different response) the second time a particular sentence is presented, leading to slower responses and or more errors. Even though this finding is an issue for the learning account it should be interpreted with caution given the lack of correlation between the Hayling Inhibition RT and the Semantic effect (accuracy/RTs), suggesting for a different source of a deficits or several different mechanisms playing role in in the two tasks. I believe the later to be more likely, taking into consideration the possible lexical generation strategies taking place in Hayling task, as reported in the literature (Collette et al., 2001) and the possibility of different strategy used as suggested by the correlation with STM in both participant groups and the additional correlation with lexical skills only in the dyslexia group.

Most importantly, the lexical competition seems to be part of both tasks, as indicated by the significant correlation between partial failure errors and the competitor errors in both groups. To conclude lexical selection by competition, offer better explanations for my experimental results. The incremental learning model could also offer plausible explanations as long as the model account the issue of increased semantic effect across cycles in blocked cyclic task. The lack of effect in sentence order in Hayling task might also be problematic for learning account.

2.5.4 The underlying cause of Lexical competition

As I already noted the lexicon, in the dyslexia sample, appears to be less able to separate the activation of targets and the co-activated words. This creates increased lexical competition that could be result from several mechanisms, such as lateral inhibition or general inhibition deficits and increased activation for strategic reasons. Another mechanism that was a plausible candidate for the underlying mechanism behind AwD' lexical selection deficit was the weaker incremental learning that I ruled out in the previous sub-section.

As some authors suggest lexical-semantic competition is resolved via inhibition of co-activated competitors, also called lateral inhibition (Feldman, 2005; Harley, 1990; McClelland & Rumelhart, 1981). The "winner" of the competition is the lexical node with the highest activation. Lateral inhibition for resolving lexical competition is implemented in some speech production models (Dell et al., 1997a; Howard et al., 2006; McClelland & Rumelhart, 1981), but not in others (Levelt et al., 1999). Evidence that deficits in lateral inhibition mechanisms can increase semantic errors in naming tasks comes from clinical populations with impaired inhibition abilities (e.g., Alzheimer (Belleville et al., 2006) and Parkinson disease (Obeso et al., 2011) . However, these findings could also point to a more general inhibition deficits not restricted to the lexical competition domain (from which lateral inhibition could also be part, but for now, these will be discussed separately). Such domain general inhibition deficit would create not only an over-competitive lexicon, but also create more competition in situations where conflict is observed i.e., in tasks like Eriksen Flanker Task and/or Simon task or in situation where sets were generally competing for resources.

Importantly, lexical-competition resolved via all three mechanism, might explain lexical retrieval problems in the sample with dyslexia. In a blocked cyclic task, less inhibition applied(both lateral and general) to semantic competitors (as proposed by Howard et al., (2006) model) would result in a higher chance of erroneously selecting competitors over the target name, due to higher activation of co-activated word nodes. This is also in line with the strategic account.

In the Hayling task, all of the three-lateral inhibition, the strategic account and the general inhibition mechanism could have had an effect of the performance. However, additional explanation is required if I want to consider the general inhibition deficits. Hayling task includes not only resolution of lexical-completion, but also suppression of a proponent response, expressed as inhibition errors in which AwD did not differ from the controls. Therefore, one can argue that not having deficit in inhibition errors would go against the hypothesis of a general inhibition as underlying mechanism. However, I believe that this finding by itself is not a strong argument against the general inhibition mechanism.

It is possible that the increased competition at lexical level was side effect of strategic behaviour rather than deficit in the inhibition per se. As previous research, point out individuals with dyslexia sometimes used strategic behaviour to compensate for their reading deficits (Chiarello, Lombardino, Kacinik, Otto, & Leonard, 2006; Gelbar, Bray, Kehle, Madaus, & Makel, 2018). Therefore, it is possible that the participants with dyslexia learn to allow a higher level of activation among semantically related items as a compensatory mechanism for weaker bottom-up activation from the lexicon. If a person's lexicon is not that reliably activated by the input (either because the input isn't great or because the lexical representations aren't very good) they may learn to allow a stronger influence from semantic context to help them select the correct word by combining the poor lexical information about written words with the context. This would, however, be a mechanism that operates to help with written input, so why would you see it in picture naming? The explanation would have to be that it is essentially a semantic effect. AwD would allow higher activation of semantically related words, in general, to help with their input problem and this spills over into the output system via semantics so that even tasks that do not involve written words, like cyclic blocking, are affected. This strategic account could offer plausible explanation for these results.

2.6 Conclusion

In conclusion, I found that AwD experience difficulties with resolving lexical competition in verbal task. However, currently I am unable to tell if the origin of these deficits is located in the lexicon or extend to more general control responses/central resources. In order to address this, I want to test the same participants with tasks not related to language, but that are having components of resolving competition during highly demanding conditions. In the literature, the non-verbal Simon and Erikson Flanker tasks are widely used for measuring conflict resolution. Another task involving the resolution of competition but without conflict is the Preview search task. The competition resolution explicitly involves inhibition. It is also possible that AwD' lexical selection problems are due to attentional deficits. Kleiman (2013) has argued that lexical selection requires capacity-limited central attentional resources. If AwD' deficits are due to central attentional resources these deficits, will not be limited to verbal tasks but will extend to non-verbal tasks as well. Therefore, by testing the three non-verbal tasks in the same group of participants, I will be able to tell if the origin of the increased lexical competition in AwD is only lexical or extend to more general control responses/central resources.

CHAPTER 3

Is lexical competition in adults with dyslexia part of domain-general competitive resolution deficit?

3.1 Abstract

In my previous study, I found lexical retrieval deficits in AwD as a result of increased lexical competition. In the current study, I wanted to test if the increased lexical competition in dyslexia was part of domain-general cognitive control deficit or was a result of language specific competition deficit. I re-tested all participants from study one with two conflict task (the Simon task and the Flanker task) and with a task measuring top-down inhibition (Preview-search task). I found group differences in the response times only in the Flanker task, with AwD experiencing slower response times in the conflict condition compared to the controls. The effect of flanker task was not related to the lexical competition tasks, finding speaking against AwD deficit in general cognitive control. These results suggest that the lexical retrieval difficulties in AwD were a result of language specific competition deficit.

3.2 Introduction

In the previous study, I found that AwD participants have a more competitive lexical-semantic network. Moreover, I proposed a specific deficit in supressing strong competitors as a possible source for this over-competitive lexical network. In this chapter, I study the potential AwD competitive resolution deficit further by investigating whether AwD might have a domain-general competitive resolution deficit that is not restricted to the language domain. For that, I distinguish between suppression resolving competition in response conflict situations and suppression in situations without response conflict.

Cognitive control processes have been suggested to be involved in the resolution of general conflict that occurs in the information processing system (Botvinick et al., 2001). Such conflict resolution has been studied by means of the Simon task (Simon & Rudell, 1967) and the Flanker task (Eriksen & Eriksen, 1974). The Simon task has similarities with the Hayling task in the previous chapter, more specifically the inhibition condition of the Hayling task, where highly likely responses need to be suppressed. Both tasks require the suppression of a prepotent that is dominant response. While the Flanker task is a conflict interference task like the Simon task, it is different in that it involves the suppression of visual distractors, rather than suppressing proponent response. For both Flanker and Simon tasks, it has been proposed that a conflict between the stronger distractor response and the target response is resolved at a response selection stage (Ridderinkhof, 2002b; Rubichi & Pellicano, 2004). Testing AwD on the Simon and Flanker tasks in addition to the Hayling task can therefore reveal a potential domain-general deficit in supressing dominant responses in conflict situations.

AwD deficit in resolution of competition might not be restricted to situations that lead to response conflict, but might also extend to situations that involve competition, but not at a response level. Such competition is part of the Preview-search task (Watson & Humphreys, 1997), a paradigm that involves inhibition of previously seen items without the need of resolving response conflict. In what follows, I will explain these tasks in detail, describe their proposed underlying processes, and list the study predictions based on various deficit scenarios in individuals with dyslexia.

3.2.1 Conflict-interference tasks

3.2.1.1 Simon task.

In the classical Simon task (Simon & Rudell, 1967), participants respond to the colour of a stimulus (green or red), by pressing a left (e.g., green) or right (e.g., red) response key. Stimuli are presented randomly at the right or left side of a computer screen. Even though the spatial position of the stimulus is irrelevant to the task, participants are usually faster and more accurate when the position of the stimulus matches the response side (compatible trials) than when they do not match (incompatible trials). This difference is also called the Simon effect. As indicated above, it is usually assumed that incompatible trials create conflict at a response selection stage (Rubichi & Pellicano, 2004), similar to the mechanism assumed to be involved in the inhibition condition of the Hayling task.

Bexkens, Van Den Wildenberg, and Tijms (2015) used the Simon task as a measure of interference control in children with dyslexia and age-matched controls but did not find differences in the Simon effect between the groups. This suggests that CwD might not have a domain general response selection or conflict resolution deficit. However, in the present study I tested adult participants and the same participants that showed deficits in the Hayling task of chapter 2. It is therefore still possible that I will find deficits in the Simon task.

3.2.1.2 Eriksen Flanker task.

The Eriksen Flanker task (Eriksen & Eriksen, 1974) is a widely used attentional conflict-interference paradigm that measures cognitive control processes that enable humans to resist visual distraction. In a typical version of this task, five-arrow arrays are presented. Participants are instructed to respond to the direction of the central arrow (either left or right), by pressing one of two response keys. The surrounding arrows, also called flankers, are either compatible with the direction of the target arrow (congruent condition) or incompatible (incongruent condition). Although, the flankers are task irrelevant, responses are slower and more inaccurate when the flankers are incompatible compared to when they are compatible with the target. This impaired performance is known as the *flanker interference effect* and it is assumed to represent the speed with which the conflict is resolved. In order to reduce the effect of the flankers, it is assumed that suppression mechanisms are applied in order for the distracting stimuli to be ignored (Eriksen & Eriksen, 1974; Lachter, Forster, & Ruthruff, 2004; Max & Tsal, 2015).

It is often assumed that the suppression needed in the Flanker task is at a response selection stage (Ridderinkhof, 2002b), but some models also include earlier selection mechanisms that operate as part of the initial processing of the stimuli. Several hypotheses have been proposed for the nature of this earlier selection process, including attentional leakage to distractors (Yantis & Johnston, 1990), crowding (Miller, 1991) or slippage to the distractors as a result of poor control of attention (Lachter et al., 2004). These earlier selection mechanisms could be an additional or alternative component in the Flanker task that could affect dyslexia performance. Previous researches hypothesised that the locus of reading deficits in dyslexia might be at the early processing of letters. More specifically at the level of letter string decoding (Spinelli, De Luca, Judica, & Zoccolotti, 2002). If individuals with dyslexia had a deficit in narrowing of visual attention, this could affect their processing of letters in written words and could therefore be related to their reading problems. To conclude, performance in the Flanker task might not only reflect participants' conflict resolution ability at the response stage, but also earlier visual attention processes, which might be involved in visual word processing.

A number of studies have reported poorer performance by CwD (Bednarek et al., 2004; Buchholz & Davies, 2005; Facoetti & Molteni, 2000; Facoetti et al., 2000; Facoetti & Turatto, 2000) and AwD (Goldfarb & Shaul, 2013; Mahé et al., 2014) in various versions of the Flanker paradigm. These studies consistently found a larger flanker effect for the dyslexia group compared to a control group. For instance, Bednarek et al. (2004) investigated the flanker effect in Spanish CwD and age matched controls and found that CwD showed an increased flanker effect compared to controls, with reduced accuracy and longer reaction times in the incongruent condition. They did not show any deficit in other attentional components (i.e., alertness and orientation), which are measured by visual cues that precede the stimuli. Mahé et al. (2014) confirmed this finding with AwD. In contrast, some studies have found in individuals with dyslexia deficits in orienting attention to a certain location (Brannan & Williams, 1987; Buchholz & Davies, 2007; Facoetti & Molteni, 2001; Facoetti, Paganoni, & Lorusso, 2000, in children and Goldfarb & Shaul, 2013, in adults). However, as suggested by Petersen and Posner (2012), orienting attention and conflict resolution are subserved by independent neural networks. Therefore, the larger interference effect observed in individuals with dyslexia in the conflict condition does not have to be linked to a deficit in orienting. This view is also supported by Goldfarb and Shaul (2013), who found no relation between the two attentional systems in their dyslexia sample.

Given the various processing components of the Flanker task, the individuals with dyslexia poor performance in the inhibition component could mean a difficulty in resolving the conflict at the response stage or at an early processing stage that involves, for instance, narrowing the focus of attention. Bednarek et al. (2004) interpreted their findings as evidence for an attentional deficit in CwD reflecting a poorer conflict resolution ability (see also Rizzolatti, Riggio, Dascola, & Umiltá (1987) for a similar conclusion). However, they also pointed out that the conflict resolution deficit could be due to later response stage processes associated with more general cognitive processes, selective attentional process related to focus of attention or even earlier stimulus detection processes.

A study by Facoetti and Turatto (2000) raised the possibility that the dyslexia impairment in visual attention in the Flanker task might be restricted to the right visual field (RVF), as a result of asymmetric distribution of visual attention between the two fields, and not because of a deficit at response selection stage. They found that CwD had a larger flanker effect in the right-visual field and no effect in the left-visual field. The authors argued that the larger interference effect in RVF could be related to CwD word reading deficit. During reading, the information from the RVF might not be filtered efficiently causing processing difficulties that could also influence performance in the Flanker task where discrimination of string type stimuli is required. However, there is evidence against a RVF deficit. For instance, Mahé et al. (2014) adapted the classical Flanker task into a version consisting of vertical, instead of horizontal stimuli string, with appearance in both visual fields. They found significant group difference in accuracy, with AwD being less accurate in the conflict/incongruent condition compared to controls. In addition, AwD showed overall slower reaction times compared to controls. Critically, they did not find a significant difference between stimuli presented in the left and right visual field (see also Bednarek et al., 2004).

In addition to behavioural performance, Mahé et al. (2014) also looked at the neurobiological basis of the attentional and control mechanisms, by comparing event-related potentials (ERPs) to the flanker stimuli in AwD and control groups. They reported a reversed congruency effect in the dyslexia group in the fronto-central N1 component, associated with early visual processing. The authors interpreted this difference as a deficit in shifting the attention in relation to the congruency of the flankers. In addition, the authors reported group differences in the fronto-central N2 component, with a congruency effect for the controls and no such effect for the AwD. This was interpreted as an impaired conflict monitoring mechanism in the individuals with dyslexia group. The authors also investigated the later P3b component as a measure of distractor inhibition/conflict resolution but found no group difference for this component. Based on these findings, Mahé et al. (2014) concluded that individuals with dyslexia have a deficit only in early visual processing and conflict monitoring, but not in conflict resolution.

However, not all studies shared the same interpretation of the N2 modulation as a conflict monitoring deficit. For example, Matthews and Martin (2015) used the flanker task in good and poor phonological decoders to compare cognitive control mechanisms. Even though, similarly to Mahé et al. (2014), they reported a reduced N2 component in poor decoders compared to good decoders, they interpreted the finding differently. They linked the reduced N2 to a deficit in suppressing conflicting information as a result of reduced cognitive control. This view of the N2 is in line with studies testing typical control participants (for a review see Folstein & Van Petten, 2007).

To conclude, deficits in the inhibition component of the Flanker task has been found for both CwD and AwD. Evidence suggests that this deficit is due to difficulty with conflict resolution, the underlying nature of which could be a result of early visual selection processes and/or late response exclusion difficulties.

3.2.1.3 Similarities and differences of the Simon and Flanker tasks.

The conflict interference involved in both Simon and Flanker tasks is generally viewed as being similar. Both tasks have been described with dual-process models (De Jong, Liang, & Lauber, 1994; Kornblum, 1994; Ridderinkhof, 2002a) in which distinction is made between two routes: an automatic direct route, which is independent from the task instructions, and a conditional route, which involves controlled processes that are guided by task instructions. The slower responses in the interference condition are assumed to be a result of a conflict between these routes. In the dimensional overlap theory (Kornblum, Hasbroucq, & Osman, 1990; Kornblum, Stevens, Whipple, & Requin, 1999) this type of conflict is described as automatic stimulus-response conflict (S-R) and can be categorised based on the similarities between task relevant and irrelevant stimuli information and how these are grouped in the specific task.

For example, in the Simon task, the target and distractor share two dimensions of information. The target information is symbolic (i.e. colour), while the distractor information is spatial location. The conflict in the incongruent condition is caused by the task irrelevant stimulus location that automatically activates the corresponding response, but this is opposite to the task relevant response. Even though the spatial location is not relevant to the task, the stimulus location and response position associations are automatically defined, which results in fast and automatic perceptual response activation. The S-R conflict is also found in the version of the Flanker task that uses left and right-pointing arrows (opposed to, for instance, letters), where the spatial stimulus features of the flankers will activate a left or right response via the automatic route (S–R priming) and the target stimulus features will activate the response more slowly via an indirect controlled route.

Even though some dual-process models suggest suppression mechanisms at the response selection stage to resolve the conflict in both Simon and Flanker task (see Ridderinkhof (2002a) *activation-suppression hypothesis*), the source of the conflict in the two tasks is not the same. Therefore, different mechanism might be involved to resolve the interference. In the Simon task, the target information is symbolic and the distractor information is not, thus the source of conflict stems from a task irrelevant, but target-defining feature. While in Flanker task, both target and distractor information are symbolic, thus the source of conflict emerges from a similar target-defining feature that belongs to a non-target element. , In addition, as pointed out above, Flanker distractors are located close to the target meaning that early visual attention/selection mechanism are involved. Specifically, while theoretically speaking selection processes could prevent the conflict in the Flanker task; this could not be the case in the Simon task. This assumption is based on hypotheses arguing that the conflict is a result of attentional modulation to distractors, which is reduced when spatial attention is focussed on the target (Yantis & Johnston, 1990).

In sum, while both Simon and Flanker tasks are often viewed to entail similar stimulus response conflicts and therefore to require the same suppression mechanism at the response stage, task differences might mean that the conflicts are not resolved in the same way. I will return to this in the predictions section below.

3.2.1.4 Relationship of conflict resolution ability with dyslexia profile.

Individuals with dyslexia performance in both Simon and Flanker tasks have previously been linked to their reading performance. Bexkens et al. (2015) found that interference control in the Simon task was a significant predictor for performance in the rapid automatized naming

(RAN) task. Similarly, Bednarek et al. (2004) reported that the CwD interference effect in the Flanker task was related to their reading and writing. More specifically, authors found that word reading time and the errors made in the less frequent words were significantly correlated with the increased conflict effect in CwD. Similar relations have been reported between the Flanker conflict effect and the number of errors writing regular and in writing irregular words (Bednarek et al., 2004). Because I was interested in whether a deficit in conflict resolution ability in AwD might be related to their literacy deficits, I tested whether any deficit that I encountered in the Flanker and Simon task was related to performance in the dyslexia assessment tasks (e.g., RAN or Gray Silent Reading test; see sub-section *2.3.1.1.2*).

3.2.2 Preview-search task

As mentioned, I investigated AwD potential deficit of general suppression mechanisms without the need of response conflict with the means of the Preview-Search task, a task that involves visual attention and spatial selection in competitive situations. The task was originally developed by Watson and Humphreys (1997) and combines a visual-search task (see Treisman & Gelade, 1980)with a measure of distractor suppression. More precisely, it requires participants to search for a pre-determined target amongst a set of distractors and in three conditions. 1) In the *single search condition*, the target shares a feature, such as colour, with the distractors. This condition is believed to depend on parallel spatial processing. It is relatively easy and independent of the number of distractors. 2) In the *conjunction condition*, participants search for a target amongst conjunctions of two features (e.g., a blue H amongst green Hs and blue As). The search process in this condition is assumed to involve serial processing. It is highly demanding, and its efficient performance depends on the number of distractors in the display (more distractors means more time needed for the visual search). 3) In the preview-search condition, the number and type of distractors are the same as in the conjunction condition, but half of the distractors (e.g., all green Hs) are displayed first, while the other half of the distractors plus the target are displayed later. By previewing half of the distractor set, performance of the search is greatly improved, resulting in faster responses in the *preview condition* compared to *the conjunction condition* (Watson & Humphreys, 1997). The process underlying this efficiency is called *visual marking*. It is understood to be an inhibition mechanism where previewed items are first encoded and later actively inhibited. This inhibition process is found to be dependent on top-down control, because it was applied only in situations when it was required and only when enough attentional resources were available (Olivers, Humphreys, & Braithwaite, 2006; Watson & Humphreys, 1997). Thus, this top-down inhibition optimises the selection of the new objects by top-down control process and de-optimising selection of the old items by active inhibition (Watson & Humphreys, 1997). Thus, by comparing the performance in the preview condition with that in the conjunction condition, I can investigate AwD top-down suppression abilities.

3.2.3 Visual attentional deficit.

While I am not aware of any other dyslexia studies that have tested suppression using the preview-search task, individuals with dyslexia have been reported to show impaired performance in visual search tasks (Iles, Walsh, & Richardson, 2000; Moores, Cassim, & Talcott, 2011; Vidyasagar & Pammer, 1999). While some authors have attributed these to visual crowding deficits (Moores et al., 2011), others have argued that they result from more general visual attentional deficits (Iles et al., 2000; Vidyasagar & Pammer, 1999). Despite the different conclusions drawn by the authors, they all agree that the poor performance in visual search tasks in individuals with dyslexia is a result of a deficit in the visual pathway, more specifically the magnocellular visual pathway. It might be that not all individuals with dyslexia show this deficit, because other studies have linked visual attentional deficits to a specific subgroup of people with dyslexia, namely those characterised by an impairment in the magnocellular system (Cornelissen, Richardson, Mason, Fowler, & Stein, 1995; Lovegrove et al., 1982; Stein, 2001).

While visual attention deficits per se are not in the focus of the present study, since I also tested the single-search and conjunction conditions, I was able to see if the sample with dyslexia had deficits with early visual processing and/or more general attentional deficits. Early visual deficits might also have an effect in the Flanker task, which has been argued to involve early visual selection processes, pronounced in general slower RTs that will be correlated with the impaired visual search performance in the dyslexia group.

In other words, I might not only see AwD deficits in the preview condition, but also in the single search and conjunction conditions of the Preview-search task. If such deficits were present in the sample with dyslexia, they should be seen in the interaction of display size and condition. While difference between the conjunction and simple condition get larger for larger display sizes, this increase should be larger in AwD compared to controls.

3.2.4 Predictions

The main aim of the present chapter was to investigate whether AwD might have a domain-general competitive resolution deficit that is not restricted to the language domain, as found in Chapter 2. For that, I studied AwD performance in three non-verbal suppression tasks, two response conflict tasks (Simon and Flanker) and suppression paradigm that does not involve response conflict (Preview-Search Task).

AwD might have a domain-general suppression deficit in situations of response conflict. If this was true, I might see a decreased performance of the participants' with dyslexia in the competitive conditions of both Flanker and Simon tasks, i.e. in conditions of response conflict. In other words, I might find increased Flanker and Simon effects in AwD compared to controls. It should be noted that this prediction is based on the assumption that the conflicts in both tasks are resolved by suppression at a response selection stage and that this suppression is similar to the one used in the language tasks in Chapter 2. This assumption is based on the dual-process models suggestion that suppression mechanisms at the response selection stage resolve the conflict in both Simon and Flanker task (see Ridderinkhof's (2002a). In this case, I would also expect to see that the interference effects in the Flanker and Simon tasks correlated with each other. In case of a true domain-general suppression deficit in situations of response conflict, I should then also find that the two effects correlate with the accuracy effect (homogeneous-heterogeneous condition) in the blocked cyclic task and the proportions of semantic errors in the Hayling task of Chapter 2 (as suggested by domain-general control process in production by Nozari and Novick, 2017).

While AwD might show deficits in both tasks, it is also possible to find group differences only in one of the conflict tasks. As I have discussed, some flanker task models suggest suppression mechanisms that operate at an earlier selection level. If AwD performed worse than controls in the Flanker task, but not in the Simon task, this could be the result of a stimulus-processing deficit due to early impaired visual filtering and/or visual flanker suppression. Such early visual and/or attentional deficits should also show up as a larger effect in the visual search component of the Preview-search task. Therefore, if I found an increased Flanker effect for AwD that was due to an early visual deficit, I would expect the effect sizes of Flanker task and the visual search component of the Preview-search task to be correlated (especially so in the participant group with dyslexia). Nevertheless, since in this case the dyslexia effect would not be expected to be due to a response selection stage, I would not expect to find correlations of the Flanker interference effect with the Simon effect or with effects in the language tasks in Chapter 2.

If AwD suppression deficits were not limited to response conflict, but were of a general nature, more specifically related to goal-oriented suppression mechanisms, I should find AwD not to benefit as much as the control group in the preview search condition of the Preview Search task, where suppression of distractors leads to better performance by relying on goal-directed top-down suppression processes. This would mean that their performance difference between the preview search condition and the conjunction search condition (= preview effect) should be smaller than that of control participants. Such a general goal-oriented suppression deficit would mean I should find correlations of the preview effect with the conflict effects in the two response conflict tasks (Simon and Flanker) as well as with the competition resolution effects of the language tasks in Chapter 2.

Alternatively, to the scenarios above, I might find AwD deficit in more than one task, but that the deficits do not correlate with each other. In this case, I would be dealing with independent suppression deficits.

3.3 Methods

3.3.1 Participants

The same participants as in Chapter 2 took part in the tasks of this chapter.

3.3.2 Experimental tasks

Participants completed the tasks together with the language tasks reported in Chapter 2. The order of the tasks was fixed for all participants, with the Cyclic Semantic Blocking Task first, followed by the Simon Task, the Hayling Task, the Flanker Task, and the Preview Search task. This was followed by a further task, namely the Stop Signal Task presented in Chapter 4. For all tasks, participants were sat approximately 65 cm away from a computer monitor. Before each task, both written and oral instructions were given.

3.3.2.1 Flanker task.

I used the version of the Erikson Flanker paradigm by Costa, Hernández, Costa-Faidella and Sebastián-Gallés (2009; see also Zhou & Krott, 2018). Each stimulus consisted of a row of five horizontal black arrows, with arrowheads pointing either leftwards or rightwards. The target was the central arrow. The orientation of the target and the adjacent flanker arrows either matched (congruent condition) or mismatched (incongruent condition). A single arrow consisted of about 0.55 degrees of visual angle. The contours of the adjacent arrows or lines were separated by 0.06 degrees of visual angle.

The task consisted of five blocks, with the first block being a practice session of 24 trials. The experimental blocks consisted of 48 trials each. Participants were instructed to press the left and right button of a Cedrus RB-844 response pad to indicate the direction of the target arrow. Each trial started with a fixation cross displayed for 800 ms, followed by the stimuli displayed either above or below the centre of the screen.

The stimulus was presented until a response was made or for a maximum duration of 5000 ms. In order to make the experiment demanding in terms of conflict monitoring, 75% congruent and 25% incongruent trials were presented (Costa et al., 2009). The use of this specific congruent display requires the use of reactive control, which is one of the two operating modes in cognitive control (i.e., of the other is proactive control). The stimulus presentation was randomised for each participant.

3.3.2.2 Simon task.

For the Simon task, participants were required to press a left (red) or right (green) button on a Cedrus RB-844 response pad, according to the colour of the square that was presented on a computer screen. Each trial began with a fixation cross in the centre of the screen, displayed for 800 ms, followed by a blank screen for 250 ms. Then a red or a blue coloured square (22 mm^2 wide/high) appeared on either the left or right side of the white screen. The stimulus remained until a response was made or for the duration of 5000 ms. A blank screen was displayed for 500 ms before the onset of the next trial. The task consisted of a practise phase (24 trials) and two experimental blocks (64 trials each). The 50% congruent display in Simon task requires the use of both cognitive control processes i.e. reactive and proactive control. The stimuli were arranged into pseudo-randomized orders so that combinations of colour and location occurred with equal likelihood.

3.3.2.3 Preview search task.

For the Preview Search task, I used a modified version of the Visual Marking paradigm (Watson & Humphreys, 1997). Participants performed a visual search to determine the presence of a target. The task consisted of three conditions (Single-search condition, Conjunction search condition, and Preview condition) presented in counterbalanced order and each preceded by written instructions and a practice session. I adapted the Preview search task by changing the letter stimuli (as used in the original Preview search task) to shapes because of the well-known dyslexia deficit with letters and reading. This was the only modification I made to the original paradigm created by Watson and Humphreys (1997). The different conditions are displayed in Figure 3-1.

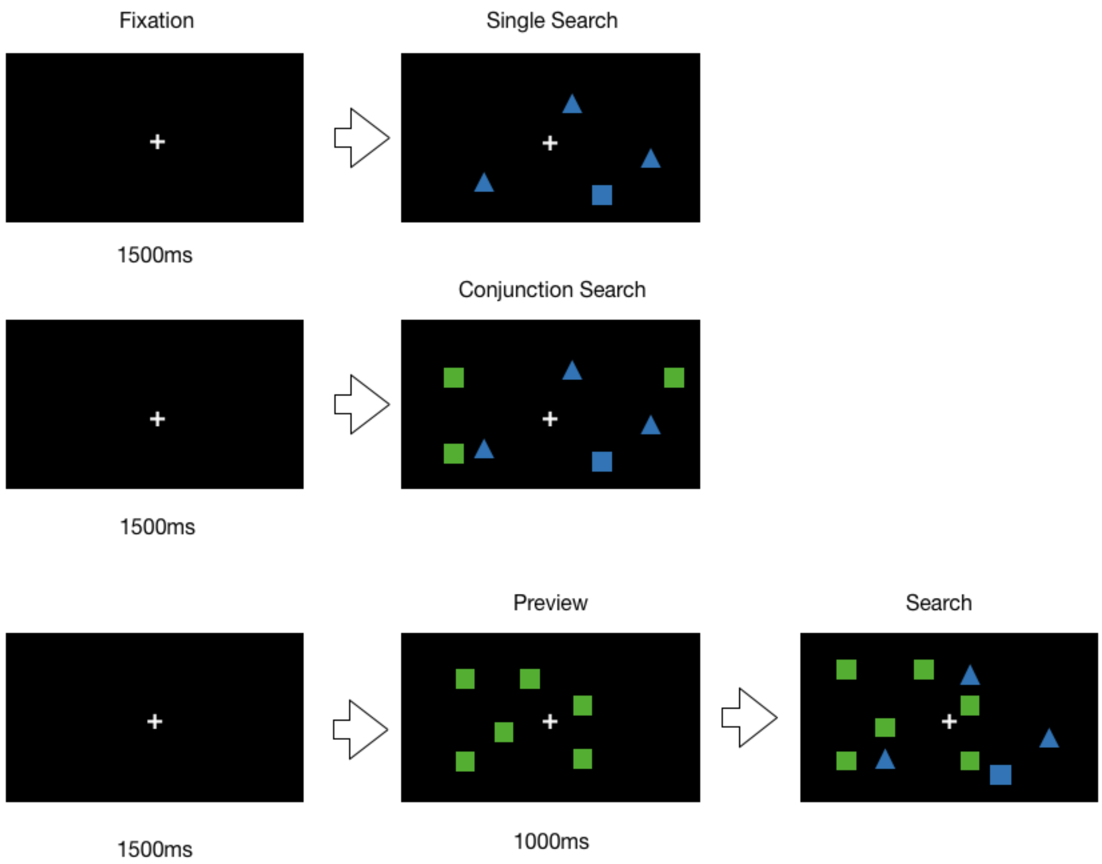


Figure 3-1 The Single-search baseline condition (upper row of panels) started with a fixation cross, followed by the search display consisting of blue triangles and potentially the target, a blue square. In the Conjunction search condition (second row of panels), both blue triangles and green distractors were added to the display. Finally, the Preview search condition (lower row of panels) was similar to the Conjunction search condition, but the green squares appeared earlier than the blue items.

In all three conditions, a white fixation cross was presented on the centre of the screen for 1500ms and then remained visible throughout the whole search trial. The participants were instructed to fixate on the cross until the search display appeared, i.e. the single-search display in the conjunction search and single-search conditions and the second display in the preview condition. Participants were instructed to look for the target on the screen and to respond by pressing a Yes or No button on a Cedrus RB-844 response pad, depending on the presence of the target. The display was present either until a response was made or for 5000 ms. Participant completed one block of 120 trials for each of the three conditions. The order of the condition was counter-balanced across participants. The stimuli were 4 mm wide and 8mm high. The search display was generated by randomly positioning the stimuli within the cells of a 10 x10 matrix. The overall matrix dimensions were 90 mm wide x 105 mm high, but the matrix cells were not visible on the screen. The number of displayed items varied (display size of 2, 4, 6, 8, 10 or 16), and an equal number of blue and green items were presented on the screen (only blue items in the Single-search condition). The target was presented in 50% of the trials.

3.3.3 Data analysis

I analysed both accuracy and response times for the three tasks presented in this chapter. The data analyses followed the same procedure as for the tasks of Chapter 2 (see sub-section *2.3.3*). The only difference was that random intercepts for items were not meaningful for the non-language tasks and thus not used. For response time analyses, only accurate responses were included. In addition, all responses deviating from the means by more than 2.5 SDs or responses below 200 ms were considered outliers and were not included in the analyses. The percentage of errors and outliers are reported with each task.

3.4 Results

3.4.1 Flanker task

3.4.1.1 Accuracy.

The total amount of errors in the Flanker task accounted for 3.6% of the whole data. I fitted a full model with Accuracy as the dependent variable, Group (Control and AwD) and Condition (Congruent and Incongruent) and their interaction as fixed factors. The final Random effect structure included random intercept for Subject and random slopes for Condition. Table 3-1 shows the dependent variable accuracy in the congruent and incongruent conditions for the group with dyslexia and controls.

Table 3-1 Means and SDs for the congruent and incongruent flanker task conditions for each of the two groups.

Accuracy	*Congruent condition*	*Incongruent condition*
Control group	0.99 (0.01)	0.90 (0.08)
AwD group	0.98 (0.01)	0.85 (0.13)

I found no Group by Condition interaction ($\chi 2$=0.11; df= 1; *p*=.745) and a trend for a main effect of Group ($\chi 2$=3.47; df= 1; *p*= .063). The effect of Condition was significant ($\chi 2$=681.54; df= 1; *p*<.001), with reduced accuracy in the incongruent condition compared to the congruent condition. Accuracy results are shown in Figure 3-2.

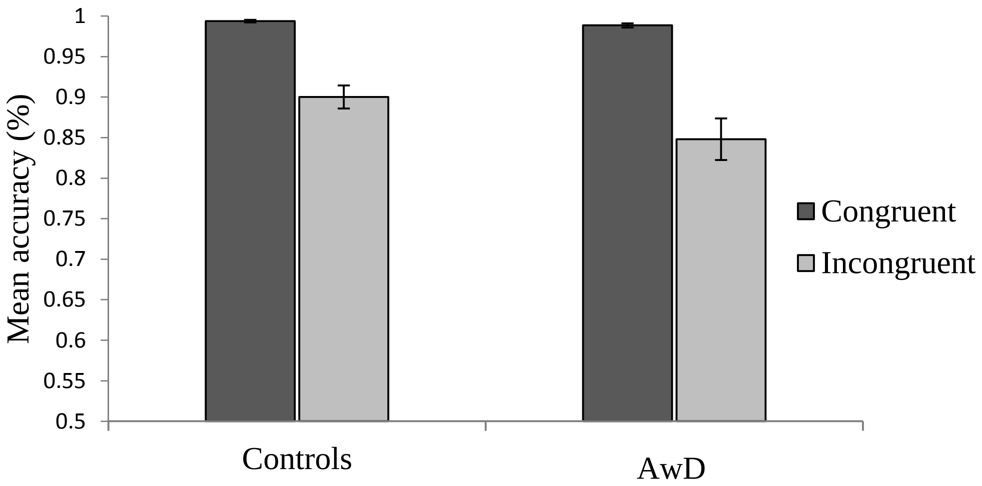


Figure 3-2 Mean accuracy for control and AwD participants for congruent and incongruent conditions of the Flanker task. Error bars represent standard errors.

3.4.1.2 Response time analysis.

The percentage of RT outliers in the Flanker task accounted for 2.2 % of the total responses (N=11,518). The total number of data points after removing the outliers and the incorrect responses was 10,850. I fitted a full model with Response time as the dependent variable, Group (Control and AwD) and Condition (Congruent and Incongruent) and their interaction as fixed factors. The final random effect structure included by-subject intercept and by-subject random slopes for Condition. Table 3-2 shows the dependent variable Response times in the congruent and incongruent conditions for the group with dyslexia and controls.

Table 3-2 Means and Standard deviations for the RTs in both of the flanker conditions.

Response times	*Congruent condition*	*Incongruent condition*
Control group	463 ms (42)	572 ms (43)
AwD group	477 ms (54)	644 ms (164)

I found a significant Group by Condition interaction ($\chi 2$=5.80; df= 1; *p*= .016). There was no main effect of Group ($\chi 2$=0.22; df= 1; *p*= .639), but a significant effect of condition ($\chi 2$=66.38; df= 1; *p*<.001), with slower responses [11]in the incongruent condition than the congruent condition. Follow-up tests showed that the two groups did not differ on mean response times for the congruent stimuli ($\chi 2$=1.30; df= 1;*p*=.254), but differed for the

[11] The results remained the same when I removed from the analysis the AwD who performed 2SDs less than the control group in the Processing speed subtest of WAIS-IV. This indicates that the processing speed does not seem to be the cause of the effect.

incongruent stimuli ($\chi 2$=5.80; df= 1; *p*=.016), suggesting that AwD participants were slower than controls in the incongruent condition only. RT results are displayed in Figure 3-3.

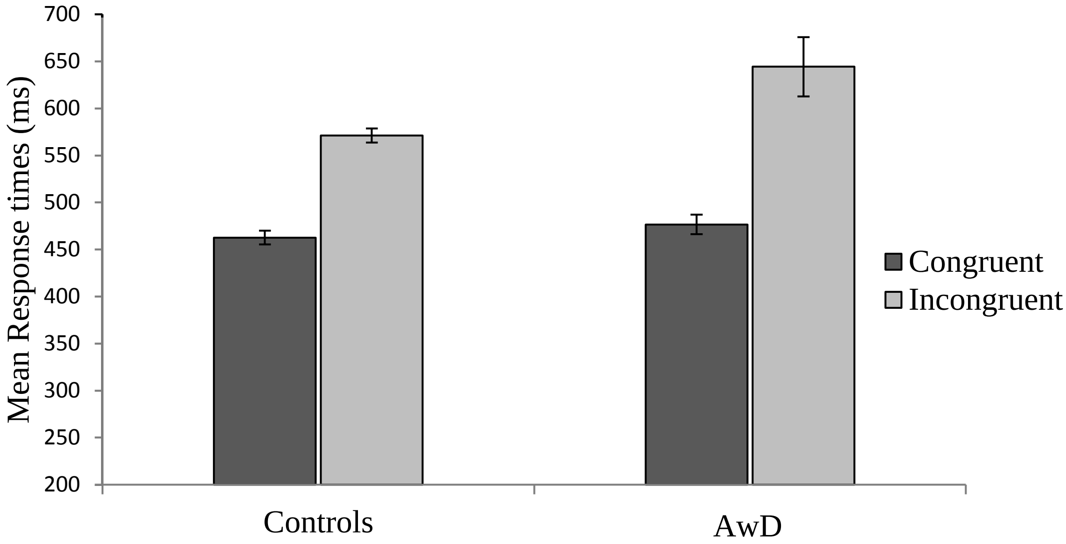


Figure 3-3 Mean response times for congruent and incongruent conditions for control and AwD participants in the Flanker task. Error bars represent standard errors.

3.4.2 Simon task

3.4.2.1 Accuracy.

Errors in the Simon task accounted for 4% of all responses. I started the model fitting analysis with a model with Accuracy as the dependent variable, Group (Control and AwD) and Condition (Congruent and Incongruent) and their interaction as fixed factors. The final Random effect structure include the random intercept for Subject and random slopes for the Condition by Subject interaction. Table 3-3 shows the dependent variable accuracy in the congruent and incongruent conditions for the group with dyslexia and controls.

Table 3-3 Means and SDs for the accuracy in the congruent and incongruent Simon task conditions for each of the two groups.

Accuracy	*Congruent condition*	*Incongruent condition*
Control group	0.99 (0.02)	0.95 (0.05)
AwD group	0.97 (0.03)	0.92 (0.08)

The accuracy results are shown in Figure 3-4. I found no significant Group by Condition interaction ($\chi 2$=0.33; df=1; *p*= .563). I did find a significant effect of Condition ($\chi 2$=34.96; df=1; $p < .001$), with the congruent condition leading to more accurate responses than the incongruent condition. The main effect of Group was also significant ($\chi 2$=7.52; df=1; *p*=.006), with AwD participants being less accurate than the control participants, regardless of condition[12].

[12] In the dyslexia literature there is a strong argument about neglecting left visual field, a deficit that would induce higher error and response time rates when the stimulus is located on the left. To rule out such possible deficit I added the factor Location (right versus left stimulus appearance) to the model in order to compare if there is a significant difference in the AwD performance based on target location. However, I found no effects of Location or any interaction with Location for neither accuracy nor response times.

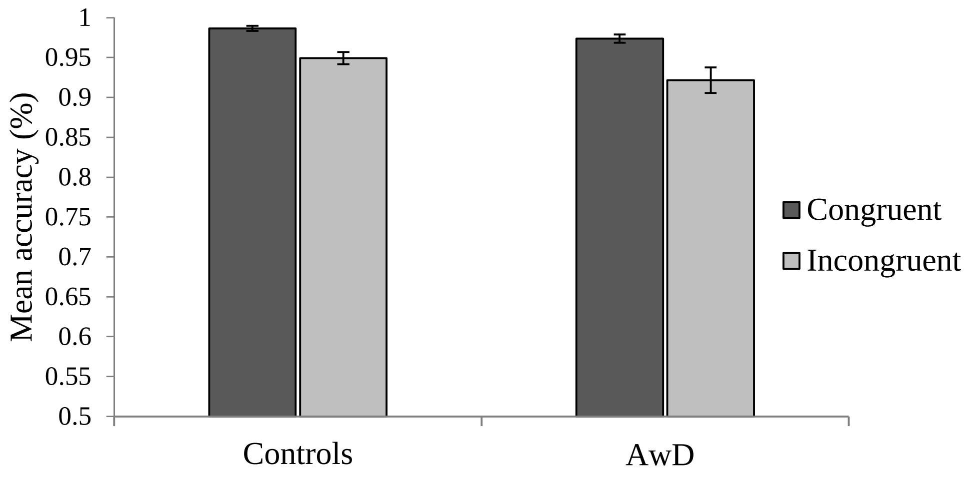


Figure 3-4 Mean accuracy rates for AwD and control participants for the congruent and incongruent conditions in the Simon task. Error bars represent standard errors.

3.4.2.2 Response time analysis.

Response time outliers in the Simon task accounted for 2% of the total responses (N=7,739). The total number of data points after removing the outliers and the incorrect responses was 7,314. I fitted a full model with Response time as the dependent variable, Group (Control and AwD) and Condition (Congruent and Incongruent) and their interaction as fixed factors. The random effect structure of the final model included by-subject intercept and by-subject random slopes for Condition. Table 3-4 shows the dependent variable response times in the congruent and incongruent conditions for the group with dyslexia and controls.

Table 3-4 Means and SDs for the response times in the congruent and incongruent Simon task conditions for each of the two groups.

Response times	*Congruent condition*	*Incongruent condition*
Control group	362 ms (48)	389 ms (47)
AwD group	382 ms (68)	417 ms (72)

The Group by Condition interaction was not significant (χ^2 =2.65; df= 1; *p*=.103). Neither was there a significant Group effect ($\chi2$=2.14; df=1; *p*=.144), but a significant effect of Condition ($\chi2$=61.96; df= 1; *p* <.001), with the incongruent condition leading to significantly longer response times than the congruent condition (independently of Group). Response time results are shown in Figure 3-5.

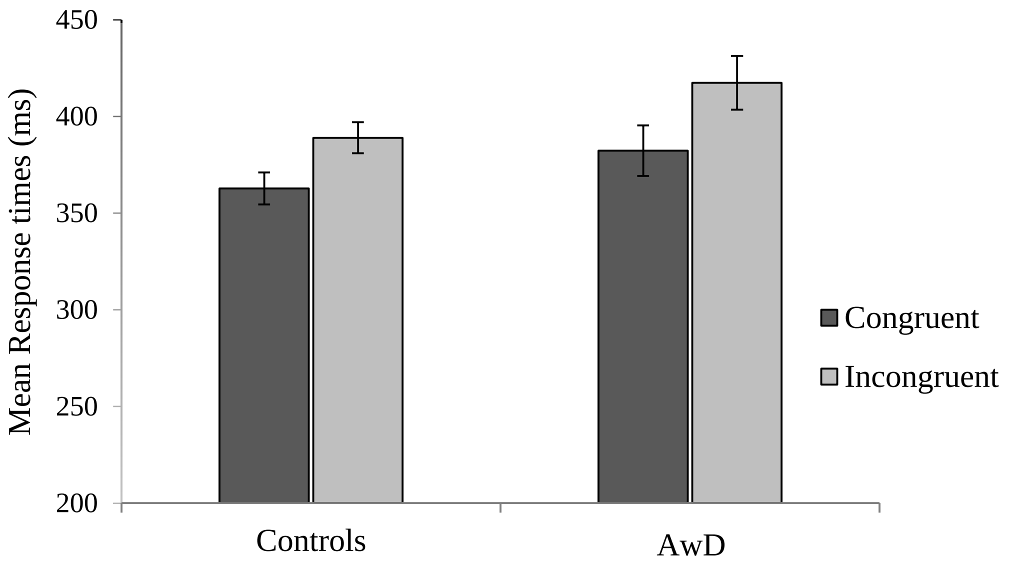


Figure 3-5 Mean response times for congruent and incongruent conditions for AwD and control participants in the Simon task. Error bars represent standard errors.

3.4.3 Preview search task

For the Preview search task, I analysed only the trials where the target was present (N=10,618). The total amount of errors in these trials accounted for 3.2%. Response Times were trimmed for outliers per participant and for each display size separately, since larger displays are expected to lead to longer response times than smaller displays. Outliers accounted for 2.8% of the data where the target was present. Errors and outliers were excluded from the analysis (overall 6% of all responses) resulting in 9,980 trials in total.

In order to investigate if AwD have top-down control deficits as well as in order to investigate if the same search mechanisms are used in both groups, three comparisons were performed. Each compared two of the conditions. An initial comparison between the single-search and conjunction conditions was required to confirm that the search mechanisms operating in the two conditions were different from each other. If participants only searched the blue items, performance should be as efficient in the conjunction as in the single-search condition (i.e. when only the blue items appeared). If the search was less efficient in the conjunction condition than the single-search condition, then this would confirm that the green items interfered with the search.

Comparisons with the preview condition were made in two ways, with the Single-search baseline condition and with the Conjunction condition. To compare with the conjunction, the analysis of the preview condition was based on the total number of items in the final display once the blue items had been added to the green preview (2, 4, 6, 8, 10, and 16). Thus, I investigated whether performance in the preview condition differed from the performance when all items in the display were searched. This could show us if the participants were able to supress the previewed green items successfully. To compare with the single-search condition, analysis of the preview condition was based on just the number of blue items presented (1, 2, 3, 4, 5, and 8). This comparison investigated whether performance in the preview condition differed from that expected if only the new blue items were searched (see also Mason, Humphreys, & Kent, 2003; Watson & Humphreys, 2002).

I first analysed the accuracy of the responses and then the mean reaction times. For accuracy, I fitted full *GLMER* model with Accuracy as the dependent variable and Group (Control and AwD), Condition (two of the three possible conditions Single-search, Conjunction and Preview), Display size (2, 4, 6, 8, 10, 16) and their interaction as fixed factors. However, none of the models including the three-way interaction converged. I therefore removed the fixed factor that was least important for the current research question, which was the display size. Thus, I fitted models without the display size. The final random effect structure included random intercept for Subjects and was the best random structure for all three accuracy analyses. Table 3-5 shows the dependent variable accuracy in the Single-search, Conjunction and Preview conditions for the group with dyslexia and controls.

Table 3-5 Means and SDs for the accuracy in the Preview-search task conditions for the group with dyslexia and the control group.

Accuracy	*Single-search*	*Conjunction*	*Preview-search*
Control group	0.98 (0.02)	0.96 (0.03)	0.98(0.02)
AwD group	0.97 (0.03)	0.95 (0.03)	0.97 (0.03)

For response times, I fitted full models with Response time as the dependent variable and Group (Control and AwD), Condition (two of the three possible conditions Single-search, Conjunction and Preview), Display size (2, 4, 6, 8, 10, 16) and their interaction as fixed factors. I report the best random effect structure for each analysis. Table 3-6 shows the dependent variable RTs for each of the display sizes in the Single-search, Conjunction and Preview conditions for the group with dyslexia and controls.

Table 3-6 Means and SDs for the RTs in each of the display sizes for the single-search, conjunction and preview conditions for the group with dyslexia and the control group.

Display size RTs	*Single-search*	*Conjunction*	*Preview-search*
Control group			
2	567 ms (103)	612 ms (95)	628 ms (107)
4	585 ms (84)	662 ms (104)	688 ms (125)
6	600 ms (98)	705 ms (105)	694 ms (114)
8	601 ms (112)	732 ms (103)	720 ms (116)
10	626 ms (117)	788 ms (102)	738 ms (122)
16	652 ms (91)	906 ms (157)	807 ms (148)
AwD group			
2	616 ms (135)	635 ms (101)	657 ms (141)
4	633 ms (129)	697 ms (119)	708 ms (142)
6	635 ms (127)	712 ms (145)	715 ms (164)
8	643 ms (124)	757 ms (130)	762 ms (182)
10	654 ms (165)	809 ms (175)	757 ms (142)
16	677 ms (132)	922 ms (220)	832 ms (170)

3.4.3.1 Single-search condition versus conjunction condition.

3.4.3.1.1 Accuracy.

In terms of accuracy, I found main effects of Group ($\chi2$=5.43; df=1; *p*=.019) and Condition ($\chi2$=33.69; df=1; *p*<.001). Overall, AwD made more errors than controls and both groups were less accurate in the conjunction condition compared to the single-search condition. The interaction between group and condition was not significant ($\chi2$=1.89; df=1; *p*= .169). Results are shown in Figure 3-6.

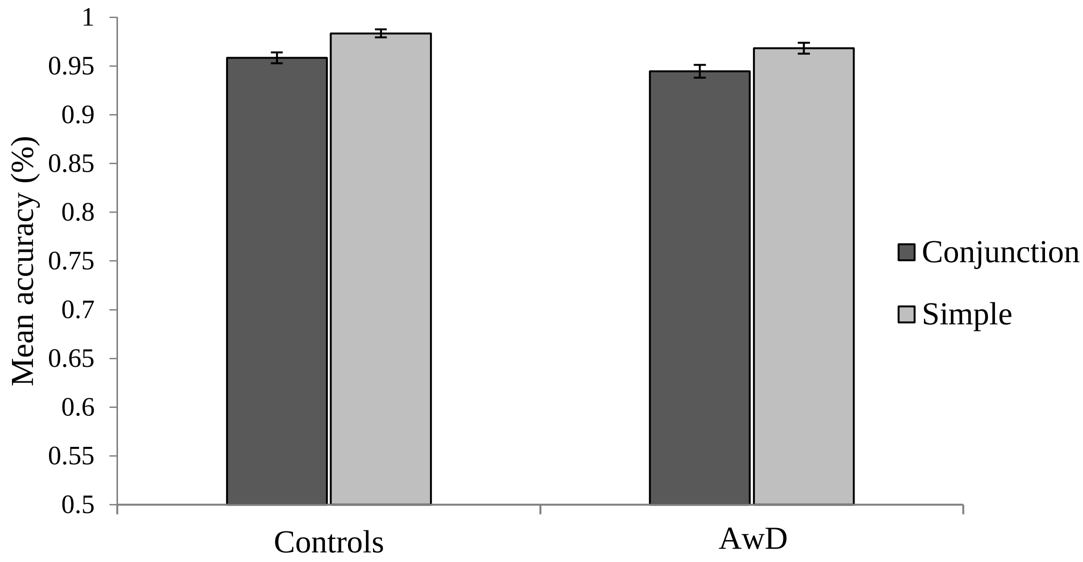


Figure 3-6 Mean accuracy for control and AwD participants for the conjunction and single-search conditions of the Preview-search task. Error bars represent standard errors.

3.4.3.1.2 Reaction times.

Results for response times are presented in Figure 3-7. The best random structure included intercept and random slopes for the interaction of condition by display size for participants. Confirming previous results (e.g.,Watson & Humphreys, 1997), the main effects of condition and display size were significant, with the conjunction condition being slower than the single-search condition ($\chi2$=9.29; df=1; *p*=.002) and RT increased in line with the display size ($\chi2$=33.06; df=1; *p*<.001). The main effect of group was not significant, showing no difference between AwD and control participants ($\chi2$=2.80; df=1; *p*=.094). There was no significant three-way interaction ($\chi2$=0.232; df=1; *p*=.630), no significant group by condition two-way interaction ($\chi2$=2.913; df=1; *p*=.144), and no significant group by display size interaction ($\chi2$=1.25; df=1; *p*=.265). In line with previous studies (e.g.,Watson & Humphreys, 1997), though, I found a significant interaction between condition and display size ($\chi2$=84.82; df=1; *p*<.001), where RT increased with increasing display size to a greater degree in the conjunction condition compared to the single-search condition (for both AwD and control participants).

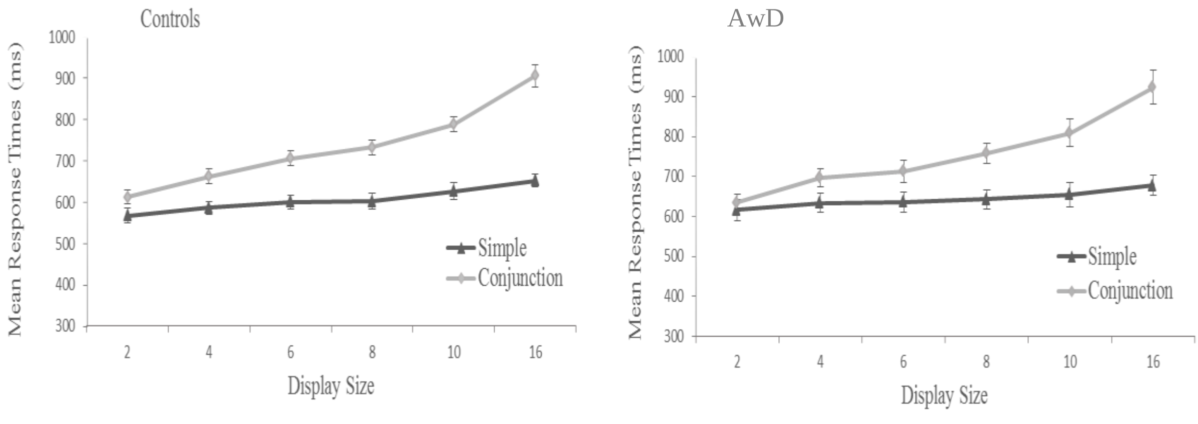


Figure 3-7 Mean RTs for each display size for conjunction and single-search conditions of the Preview Search task for both participant groups. Error bars represent standard errors.

3.4.3.2 Single-search condition versus preview condition.

3.4.3.2.1 Accuracy.

In terms of accuracy, I found a main effect of group ($\chi2$=4.23; df=1; *p*=.039), but no main effect of condition ($\chi2$=1.77; df=1; *p*=.183). The interaction between group and condition was not significant either ($\chi 2=2.15$; df=1; $p=.143$). The results show that the conditions did not differ in terms of accuracy, but AwD made very slightly, but significantly more errors than controls (regardless of the condition). For results see Figure 3-8.

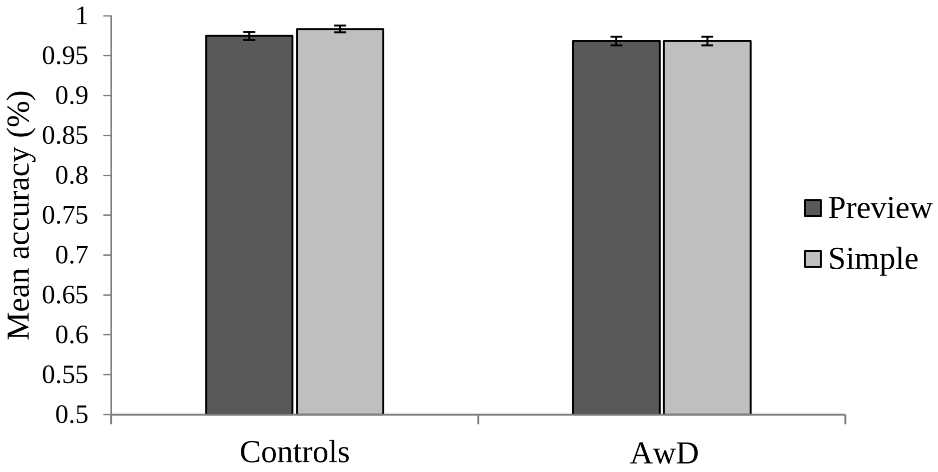


Figure 3-8 Mean accuracy rates for participants with dyslexia and controls for the preview and single-search conditions of the Preview search task. Error bars represent standard errors.

3.4.3.2.2 Reaction times.

The best random structure for the comparison of the single-search and preview conditions included random slopes for condition and random intercept for subjects. In line with previous findings (e.g.,Watson & Humphreys, 1997), the main effects of condition and display size were significant ($\chi 2=64.71$; df=1; $p<.001$), with the preview condition being slower than the simple condition and RTs increasing in line with the display size ($\chi 2=340.91$; df=1; $p<.001$). The main effect of group was not significant ($\chi 2=1.69$; df=1; $p=.192$), showing no RT differences between groups. There was no significant three-way interaction ($\chi 2=1.04$; df=1; $p=.307$), no significant group by condition interaction ($\chi 2=0.363$; df=1; $p=.545$), and no significant group by display size interaction ($\chi 2=1.06$; df=1; $p=.302$). As found before (e.g.,Watson & Humphreys, 1997), there was a significant two-way interaction between condition and display size (χ2=55.97; df=1; *p*<.001), with RTs increasing with increasing display size to a greater degree in the preview condition compared to the single-search condition. Results are displayed in Figure 3-9.

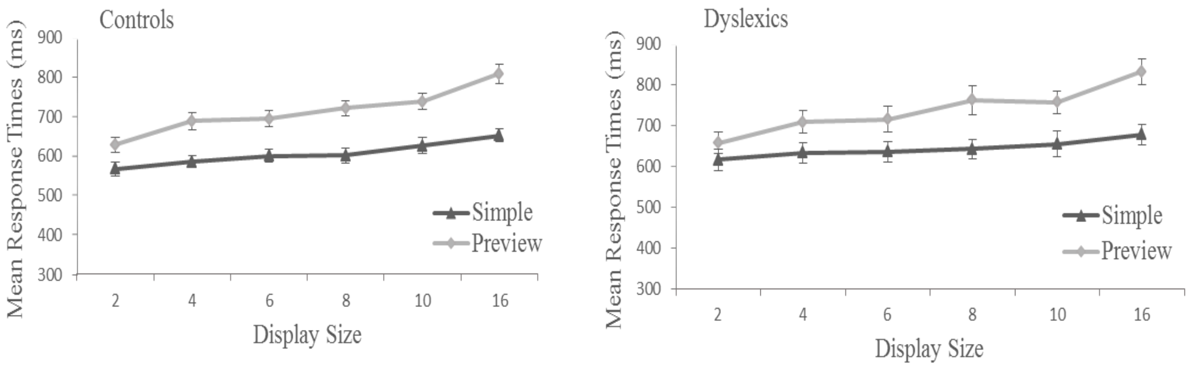


Figure 3-9 Mean RT for both participant groups and for each display size in preview and single-search conditions of the preview search task. Error bars represent standard errors.

3.4.3.3 Preview condition versus conjunction condition.

3.4.3.3.1 Accuracy.

In terms of accuracy and in line with accuracy analyses for the other comparisons, there was a trend for a main effect of group (χ2=3.31; df=1; *p*=.068). The main effect of condition was significant (χ2=20.07; df=1; *p*<.001), with participants being less accurate in the conjunction condition than in the preview condition. The interaction between group and condition was not significant (χ2=0.65; df=1; *p*=.798). Thus, AwD were somewhat less accurate overall in the two conditions; see Figure 3-10 for results.

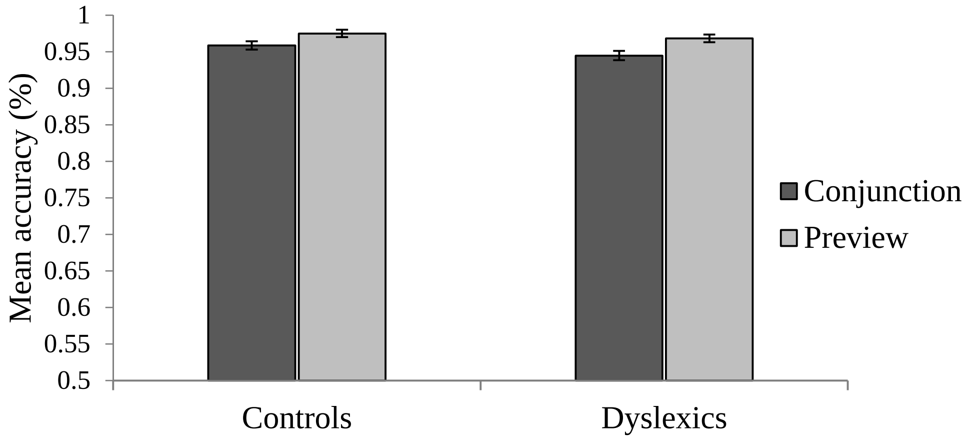


Figure 3-10 Mean RTs for both participant groups for preview and conjunction conditions of the Preview search task. Error bars represent standard errors.

3.4.3.3.2 Reaction times.

The best random structure for the comparison of the preview condition and the conjunction condition included intercept and random slopes for the interaction of condition by display size for participants. As expected, the main effect of condition was significant ($\chi 2$=4.79; df=1; *p*=.030), with the conjunction condition being slower than the preview condition. Similarly, the main effect of display size was significant ($\chi 2$=72.61; df=1; *p*<.001), with RTs increasing in line with the display size increase. The main effect of group was not significant ($\chi 2$=1.276; df=1; *p*=.259), showing no RT difference between AwD and controls. There was no significant three-way interaction ($\chi 2$=0.03; df=1; *p*=.865), no significant group by condition interaction ($\chi 2$=0.01; df=1; *p*=.919) and no significant group by display size interaction ($\chi 2$=0.02; df=1; *p*=.899). In line with previous findings(e.g., Olivers et al., 2006; Watson & Humphreys, 1997), though, I found a significant interaction between condition and display size ($\chi 2$=40.76; df=1; p<.001), with RTs increasing with increasing display sizes to a greater degree in the conjunction condition compared to the preview condition (see Figure 3-11).

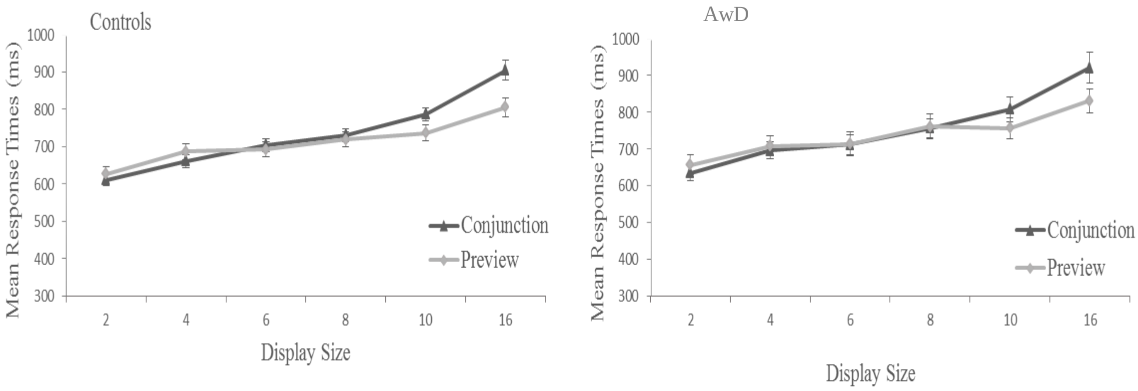


Figure 3-11 Mean RTs for both participant groups for each display size in conjunction and preview conditions of the Preview search task. Error bars represent standard errors.

Taking the results of the Preview-search task together, I saw that AwD and controls were not different in the size of the preview effect, suggesting for normal top-down suppression deficits operating in AwD. In addition, no group difference was found for the visual search effect of the Preview-search task (difference between conjunction and single search condition). Therefore, I can conclude that there were no attentional deficits in the sample with dyslexia.

When considering all three non-verbal tasks tested in this chapter, I found very few differences between the two participant groups. I found decreased accuracy for AwD for all three tasks. But I did not find that accuracy depended on the conditions of the task. Most interestingly for the question of AwD's suppression deficit, participants with dyslexia showed an increased Flanker effect in terms of response times. But I did not find any evidence of such a deficit in the Simon or the Preview-search task.

3.4.4 Dyslexia severity in non-verbal task performance and related deficits

As in Chapter 2, I next investigated how AwD performance in the suppression measures that showed group differences were related to the dyslexia severity. As before, I focused for these analyses on the participants with dyslexia and correlated measures that showed group differences with two types of dyslexia measures: overall averaged z-scores of the dyslexia assessment measures and the individual factors form the three PCA components Lexical skills, Phonological STM and Phonological manipulation (see subsection *2.4.4* in Chapter 2).

Table 3-7 Correlations between dyslexia severity (measured by mean z-scores of dyslexia assessment measures and with factor analysis) and the Flanker RT effect, which was the only task showing effect size group differences in the nonverbal tasks of chapter 2. All accuracy measures are log transformed.

Overall z-score of dyslexia assessment measures			Lexical skills		Phonological STM		Phonological manipulation	
	r	*p*	**r**	*p*	**r**	*p*	**r**	*p*
Flanker effect RTs	**.15**	*.460*	**.09**	*.639*	**-.09**	*.635*	**.13**	*.533*

As can be seen in Table 3-7, the suppression deficit in the RTs in the Flanker task was not related to the dyslexia severity profile. Nevertheless, the directions of the relationships are in the right direction, where poorer performance in the experimental task seems to be associated with higher dyslexia severity. The lack of reliable relationships could be due to the small sample size and the large variability in the sample.

3.4.5 Domain general deficit or task related deficits

3.4.5.1 Associations between non-verbal tasks.

The predominant view in the literature suggests that the Simon and the Flanker task measure similar response suppression mechanisms, namely those that operate on the response selection stage (Ridderinkhof, 2002a). However, as indicated in the introduction, the two tasks might not assess the same type of mechanisms or they might not assess them in the same way. For instance, some studies argue that the conflict in the Flanker task also includes resolution of additional early processing mechanisms (Miller, 1991; Yantis & Johnston, 1990). If the tasks are not equal measures of the same mechanisms, then it might not be that surprising that the AwD only showed a deficit in one of the tasks. In this section, I therefore investigated if the performances in the Flanker and Simon tasks show evidence that the tasks share similar suppression mechanisms. In a similar question, I investigated whether the Preview-search task was a measure of similar suppression mechanisms as the two conflict tasks, which could be top-down inhibition. If all three tasks were measures of goal-oriented suppression mechanisms, then I would expect the performance in the three non-verbal tasks to be correlated with each other. It is possible that due processing differences in the control and dyslexia group, different type of control processes are used to different degrees in the two participant groups. For instance, control participants might engage more early suppression mechanisms in the Flanker task, while participants with dyslexia engage more late response suppression mechanisms. I therefore investigated these relationships for the control and dyslexia groups separately.

Table 3-8 Between task correlations for control and AwD groups.

		Simon effect RTs		Preview search RTs	
		r	*p*	**r**	*p*
Control group					
	Simon effect RTs	**-**	-	**-.07**	*.967*
	Flanker effect RTs	**.31**	*.084*	**.27**	*.132*
AwD group					
	Simon effect RTs	**-**	-	**.25**	*.200*
	Flanker effect RTs	**.49**	*.01***	**-.16**	*.435*

Table 3-8 shows an indication for a correlation between Flanker and Simon RT effects for the control group, with a trend for significance, which disappear after Bonferoni correction. The correlation is stronger and significant for participants with dyslexia. However, Figure 3-12a shows that the correlation is largely driven by outliers. If I remove the three outliers from the dyslexia group, the relationship between the tasks is no longer significant (r=.05; p=.836. See Figure 3-12b). Table 3-8 also shows that there was no relationship between the interference effect in the two conflict tasks and the top-down suppression measured by means of the preview search effect in the Preview search-task, and this was true for both participant groups. Thus, I only have weak indication that control participants use the same suppression mechanism in the Simon and Flanker tasks. The weak correlation might be due to a noise resulted by the extra selection mechanisms involved in the earlier stages in Flanker task.

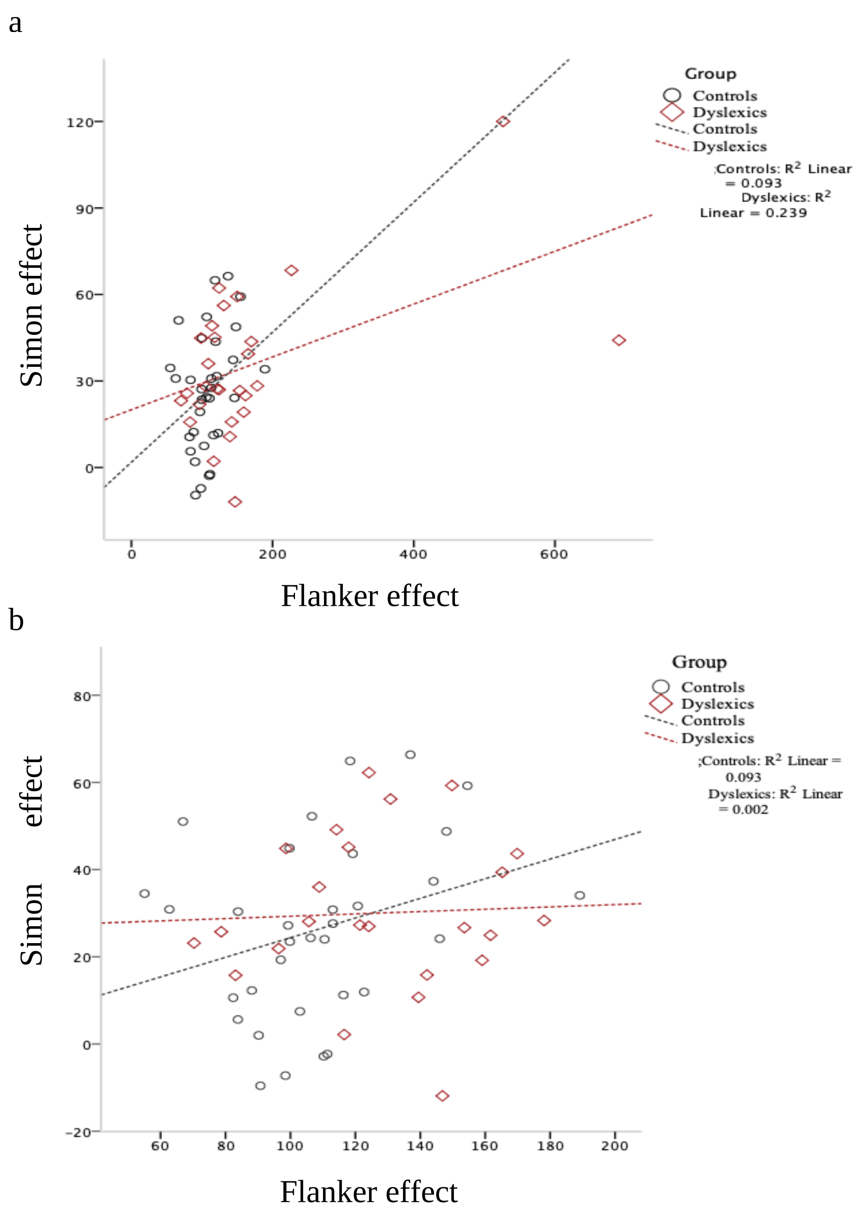


Figure 3-12 Correlations between RTs effect sizes for Flanker and Simon tasks for the control group and the dyslexia group. Panel a) shows the correlation for all participants. The strong relationship between the variables in the dyslexia group is clearly driven by three outliers. Without these outliers (panel b) the relationship between the variables is no longer significant.

3.4.5.2 Non-verbal task mechanisms versus lexical competition.

The next question asks if the cognitive control mechanisms used for resolving the conflict in the Flanker task involve the same competitive resolution mechanisms observed in the verbal tasks of Chapter 2 for controls and AwD.

Table 3-9 shows no relationships between the inhibition effects in the verbal tasks of Chapter 2 and the Flanker effect for the AwD. For the control group there was a significant correlation between flanker effect and the partial suppression failures in the Hayling task.

Table 3-9 Correlations between suppression performance in verbal tasks and the non-verbal Flanker task for AwD and control group of participants.

		Flanker effect RTs	
		r	*p*
Control group			
Blocked cyclic naming			
	Semantic effect in Accuracy	**.27**	*.135*
	Competitor errors in homogeneous condition	**.04**	*.842*
	Semantic effect in RTs	**.03**	*.861*
Hayling task			
	All errors in Inhibition condition	**-.27**	*.132*
	Partial failures	**-.39**	*.028**
	RTs Inhibition condition	**-.26**	*.158*
AwD group			
Blocked cyclic naming			
	Semantic effect in Accuracy	**-.11**	*.604*
	Competitor errors in homogeneous condition	**-.21**	*.306*

	Semantic effect in RTs	**.16**	*.422*
Hayling task			
	All errors in Inhibition condition	**.06**	*.791*
	Partial failures	**-.03**	*.897*
	RTs Inhibition condition	**.14**	*.494*

However, as can be seen in Figure 3-13 that relationship is largely driven by the people who did not produce any partial failure errors. If I remove these participants the relationship is no longer significant (r=.12, *p*=.582).

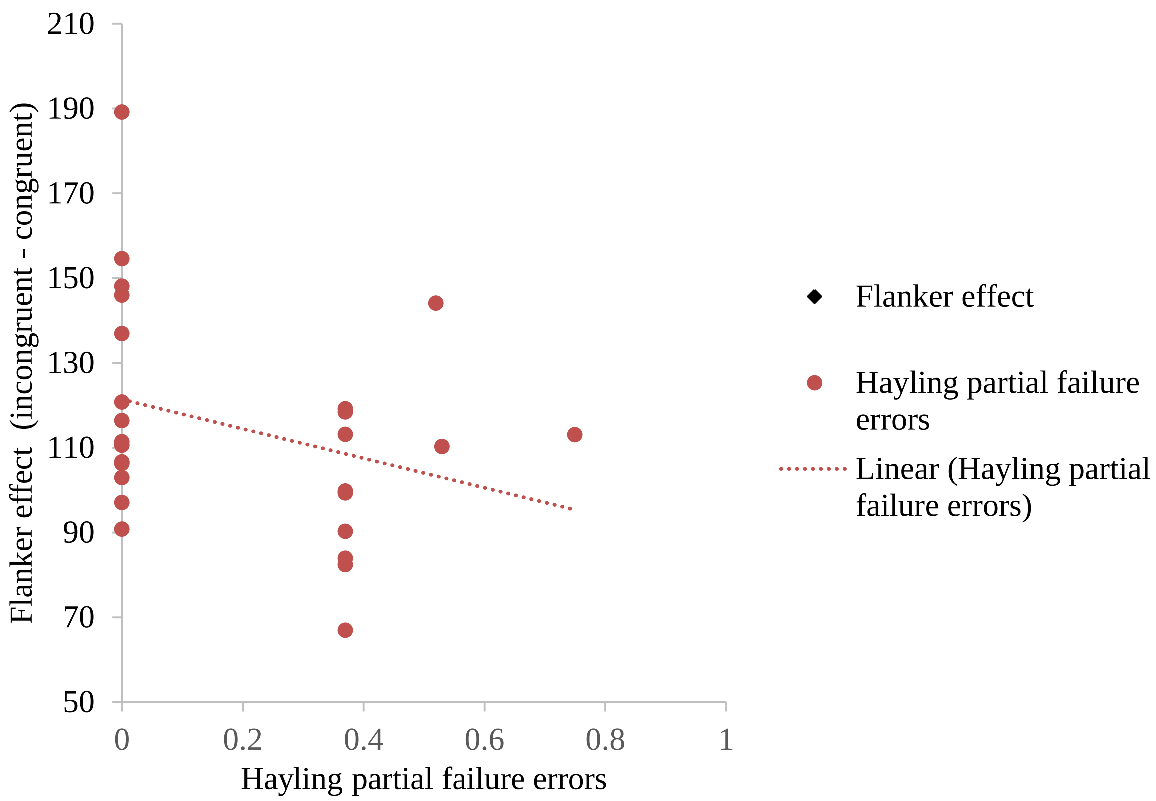


Figure 3-13 Correlations between Flanker RTs effect size and Hayling partial failure errors for the control group. The moderate relationship between the variables is clearly driven by the participants who did not make errors.

3.5 Discussion

The aim of this chapter was to explore whether the AwD deficit in supressing strong lexical competitors is part of a domain-general competitive resolution deficit, thus one that is not restricted to the language domain. I investigated this by means of the Simon, Flanker and Preview search tasks, which all involve resolutions of competitive situations. But only the Simon and Flanker tasks involve response conflict. In contrast, the Preview Search task allowed us to investigate a top-down inhibition deficit that does not involve response conflict.

I found a suppression deficit in the dyslexia sample only in the Flanker task, not in the other two tasks. This suggests that AwD have a deficit in mechanisms specific to the Flanker task and it speaks against a domain-general suppression deficit. However, in order to interpret these results adequately, I need to check whether there is evidence for shared suppression mechanisms in the tasks in either the control or the dyslexia group.

I therefore investigated whether the suppression effects correlated across the tasks and if so, whether in both groups. I found indicative evidence for a relationship between the interference effects in the Simon and Flanker tasks for control participants, but not for participants with dyslexia (after taking out extreme outliers). This suggests that these two tasks tap into similar processing mechanisms to some degree for control participants, presumably into the controlled process involved in resolving the conflict interference at the response stage. The results for the group with dyslexia showed that a small number of AwD in the sample had a large RT effect in both Flanker and Simon tasks. It is possible that these people had a response suppression deficit. However, this was not true for the majority of the participants with dyslexia. Importantly, the lack of a correlation between the interference effects in the two tasks for AwD suggests that individuals with dyslexia might rely more strongly on different suppression mechanism in the two tasks.

I also found no relationship between the interference effects in conflict tasks and the top-down suppression effect in the preview search condition in the Preview search-task in either of the groups. This points toward different processes involved in resolving the competition when conflict is present versus not presented.

Based on the results I can conclude that there is some indication of a relationship between the suppression mechanisms in the Simon and Flanker tasks, possibly suppression mechanisms that overlap in the response selection stage. However, this is not seen in the dyslexia participants as a group and it is weak in the control group, suggesting other mechanism that played a role in both tasks. This would be in line with the idea that there are several cognitive control networks that are active in different conflict situations (Egner, 2008). But it could also be the case that the primary processes differ between the tasks and that shared suppression mechanisms only play a minor role. I will return to the differences between the tasks and the interpretation of the increased Flanker effect in the group with dyslexia below.

These results notwithstanding, I also did not find any evidence for shared cognitive control mechanisms for the suppression in the verbal tasks in Chapter 2 and in the Flanker task in participants with dyslexia. These results speak again against a domain-general suppression deficit and instead suggest that the dyslexia deficit in the Flanker task and the lexical competition resolution deficit observed in Chapter 2 are independent deficits. In order to see whether the two groups used different mechanisms in the two types of tasks I also looked at the correlations for the control group. For the control group there was a significant relationship between the flanker effect and the Hayling partial failures. However, since this relationship was driven from the people who did not produce any partial failures, I can conclude that there is no evidence of a reliable relationship between the partial failures and the flanker effect. Evidences suggest that both controls and individuals with dyslexia used different mechanisms in the two types of tasks arguing against domain general suppression mechanisms.

I also investigated whether the dyslexia group had any top-down inhibition deficit by means of performance in the preview-search task. The results showed that AwD preview-search effect was not different from that of the control group. This speaks against an AwD deficit with regards to top-down inhibition mechanisms.

3.5.1 What is the nature of the suppression deficit in the Flanker task?

The results from the Flanker task are in line with the number of studies reported difficulty in resolving conflict in CwD (Bednarek et al., 2004; Buchholz & Davies, 2005; Facoetti & Molteni, 2000; Facoetti et al., 2000; Facoetti & Turatto, 2000) and AwD (Goldfarb & Shaul, 2013; Mahé et al., 2014) with various versions of the Flanker paradigm. More specifically, the current experimental results replicate and further support Goldfarb and Shaul's (2013) finding that high-functioning AwD experience deficits when resolving conflict in the incongruent condition of the Flanker task.

But what is the nature of this deficit? Ridderinkhof suggested that both the Flanker and Simon task measure suppression at the response selection stage (Ridderinkhof, 2002b). Thus, do individuals with dyslexia have a response selection deficit? The lack of deficits in the AwD group for the Simon task, together with an equivalent finding for the Simon task in Bexkens et al., (2015) for CwD, suggests that this might not be the case. However, the fact that I found only a trend of a relationship between the tasks' effect sizes in the control group and no relation in the group with dyslexia suggests that the tasks are not equal measures of suppression at the response selection stage. I therefore need to establish what mechanisms might be involved in the tasks and where suppression mechanisms might operate.

As mentioned in the Introduction, the dual-process models (Hommel, 1993, 1994, Ridderinkhof, 2002a, 2002b) of conflict tasks such as the Simon and Flanker tasks assume that conflict is accumulated as a result of different information coming from two routes, that is an automatic/direct route and a controlled route. According to Hommel's (1993) model, the conflict in the incongruent Simon condition is resolved as a result of automatic decay of the spatial code without the need of inhibition, while others argue for active suppression mechanism to be applied on the automatic route during response stage (e.g., Ridderinkhof, 2002a, 2002b). There are also models that do not take stand on the exact mechanism behind the reduction of the spatial code information in Simon task (De Jong et al., 1994; Zorzi & Umiltá, 1995).

On the basis of differences in lateralised ERPs for the Simon and Flanker tasks, Mansfield, van der Molen, Falkenstein and van Boxtel (2013) argues that the conflict in the two tasks is resolved by different suppression mechanisms. For the Simon task, they found a congruency effect (a lateralised stimulus-response priming effect) in an early time-window (160-190 ms) and no evidence for conflict on the N2 component, a later component. In contrast, for the Flanker task, flanker congruency affected the N2 and P350 components, suggesting that conflict being resolved later than in the Simon task. This was interpreted as evidence for a quick resolution of the conflicting information in the Simon task and fits Hommel's (1994) assumption of an automatic decay of the direct unconditional response activation. Therefore, the direct route might be the main location of the Simon effect, which decays and interferes little with the controlled route. They also found behavioural evidence for differences in the two tasks, as the flanker effect was significantly larger than the Simon effect. Moreover, the authors also found evidence that the Flanker effect required later cognitive control (indicated with P350 component) than the effect in the Simon task. All these results suggest that the conflict resolution mechanisms in the two tasks are not the same and that response inhibition mechanisms might play a smaller role in the Simon task.

In line with these findings, the interference effect in the Flanker task was also larger than in the Simon task (task by condition interaction: ($F(1,65)= 92$, $p<.001$), suggesting that the conflict was harder to resolve in the Flanker than the Simon task. In addition, I found a trend for this difference being larger for the dyslexia than the control group (group by task by condition interaction: $F(1,65)=$, $p<.085$), in line with the finding that AwD showed an increased interference effect in the Flanker task, but not in the Simon task. However, I have no measure of the time window of the conflict resolution in either of the tasks. Therefore, I cannot tell when the conflict was resolved, early or later.

Another difference between the Flanker and Simon tasks was the congruent display ratio in both tasks. In flanker task, I used the 75% congruent displays and in the Simon task, the number of congruent and incongruent trials was 50%. This difference in congruency proportion possibly affected the nature of the cognitive control used in both tasks. According to Braver (2012) the cognitive control operates via proactive control and reactive control. The proactive control relies on goal-relevant information and occurs before the cognitively demanding trial. In contrast, reactive control is recruited after the detection of the conflict. In the flanker task I used, the majority of trials are congruent and there is no need for strong control processes to take place. Similarly, the use of unpredicted position for the task stimuli goes against the proactive selection processes. Therefore, it is likely that participants only use reactive control mode on the minority of incongruent trials when control is required in other to suppress the distractors (Braver, 2012). In contrast, in the Simon task the congruency ratio of 50% makes it more likely for the participants to use a proactive control in addition to the reactive control. However, within the current experimental design I am not able to distinguish if AwD have deficit with proactive and/or reactive control.

Previous studies that reported an increased flanker effect in individuals with dyslexia accounted this result to an attentional deficit in selection the target (Bednarek et al., 2004; Buchholz & Davies, 2005; Facoetti & Molteni, 2000; Facoetti et al., 2000). Bednarek et al. (2004) proposed that the attentional deficit in CwD is specific to their conflict resolution ability (see also Rizzolatti et al., 1987 for a similar conclusion) and proposed that their tendency to process stimuli such as words globally rather than locally is the cause of their attentional problem. But CwD larger Flanker effect might also indicate poorer attention to the target as a result of increased flanker noise. Mahé et al., (2014) found AwD to have reduced fronto-central N1 in the incongruent condition when compared to the controls. In accordance to previous findings that linked increased N1 (in occipital areas) to increased focus on the target a result of a strategy to reduce the distractor noise (e.g.,Hsieh & Fang, 2012), Mahé et al., (2014) interpret their finding as individuals with dyslexia having deficit in attentional orientation leading to shifting attention toward the flankers. This explanation also fits with previously reported dyslexia deficits in discriminating objects due to noise generated by spatially adjacent distractors (an effect known as crowding) (e.g., Miller, 1991). Thus, the increased interference in dyslexia population might be a result of poorer early perceptual target selection/distractor suppression. This hypothesis is also in line with some dual-processing models of the flanker task, suggesting that the closely positioned conflicting stimuli generate early noise processing mechanism that take place before the response stage (e.g., Kornblum et al., 1999). It is assumed that this conflict generated by closely positioned distractors need to be resolved, before selecting the target, either by facilitating the target or by suppressing the distractors (see Max & Tsal, 2015 for the latter).

As I briefly mentioned in the introduction, conflict interference at the stimulus stage has been linked to the N2 peak in the Flanker's incongruent condition (Folstein & Van Petten, 2008). Mahé et al., (2014) found a reduced N2 interference effect in AwD when compared to controls. They attributed their finding as deficit in conflict monitoring in AwD. I suggest that the reduced N2 in AwD points to a deficit in suppressing distractors or selecting the target at an early processing stage. My hypothesis is in line with the previous hypothesis for inhibition mechanisms involved in resolving conflict (e.g., Heil, Osman, Wiegelmann, Rolke, & Hennighausen, 2000). However, I should also note that independent of the exact mechanisms, it is generally believed that the N2 represents the cognitive control required to resolve the conflict (for a review see Folstein & Van Petten, 2007). Therefore, the outcome of both hypotheses of the deficit (conflict monitoring and early distractor suppression) would lead to the same conclusion, namely poorer cognitive control in AwD at the early stimulus level, which leads to increased interference.

It needs to be mentioned that some of the conclusions of previous deficits in individuals with dyslexia in the Flanker paradigm need to be generalised with caution to the paradigm used here. For instance, Mansfield et al., (2013) as well as Mahé et al., (2014) used a vertical version of the Flanker task, while I used a horizontal version. They also used an arrow version of the Simon task, while I used colours. I might find different ERP effects with an arrow version of the task. I also need to be careful in generalising their conclusions about differences in conflict mechanisms in the Simon and Flanker tasks to the paradigms and findings used in this study. I therefore cannot determine if the increased flanker effect in AwD found in this study is a result of early processing deficits of stimuli in a noisy environment and / or the result of deficits of resolving conflict at a later response stage.

3.5.2 The role of attention in the task performance

While visual attention deficits were not the focus of the present study, by using visual search task (part of the preview-search), I was able to see if the group with dyslexia had deficits with early visual processing and/or more general attentional deficits. I found no attentional deficits in the sample of dyslexia, contrary to previous studies reporting participants with dyslexia experiencing deficits in visual search (Iles et al., 2000; Moores et al., 2011; Vidyasagar & Pammer, 1999). My results could be in line with Iles et al.'s (2000) proposal of a subgroup of individuals with dyslexia with visual processing deficits, with current sample being limited to no such subgroup of AwD.

Importantly, AwD’s normal performance in the visual search task speaks against early visual attentional deficits as the source of the interference deficits in the Flanker task, suggested by previous researchers (Buchholz & Davies, 2005; Facoetti et al., 2003; Facoetti & Molteni, 2000).

3.5.3 Relation between AwD language performance and the non-verbal tasks

Previous studies reported links between Flanker task performance and individuals with dyslexia word reading and writing performance Bednarek et al., (2004). Even though I have not measured writing ability in this study, I have tested a constellation of language tasks tapping into skills like lexical processing and phonological manipulation involving word and non-word reading. In addition, I also tested speed of naming and reading comprehension skills crucial for reading performance.

I found that the performance in the Flanker tasks was not related to AwD phonological deficits. While these findings are not in line with what had been found by Bednarek et al. (2004), they support the findings in Matthews and Martin's (2015) study which showed no significant relationship between non-word decoding and Flanker effect in adult poor phonological decoders. Current results therefore extend these results to the dyslexia population. It should also be noted that my participant sample was different from the one by Bednarek et al. (2004) who tested CwD. Instead, I focused on highly achieving adults and it is possible that task similarities are found only during development, when reading skills are still acquired, but not once readers are proficient. Proficient readers might not use the same conflict resolution processes when reading that children use. For instance, proficient readers might process words as wholes and therefore do not need to focus on individual letters in words. Thus, my study findings do not rule out that selection processes in the Flanker tasks are related to reading.

3.5.4 Limitation and open questions.

I found no evidence for domain general cognitive control deficits in highly functioning AwD. The only group difference found in my study was in the Flanker task, with AwD showing a greater flanker effect compared to controls. The lack of a strong relationship between Simon and Flanker effect sizes, the potentially later cognitive control mechanism in the Flanker task and the lack of Simon task deficits in the AwD could suggest that additional conflict processes might take place in the Flanker task. However, inconsistent assumptions of the exact mechanisms involved in resolving the Simon task effect does not allow us to rule out a response suppression deficit in the AwD. This raises the possibility that both early noise resolution and later response conflict in the Flanker task could be affected in participants with dyslexia. With the current experimental design, I cannot tease these two processes apart. I therefore focussed on early processes in the Flanker task in Chapter 5 by means of the Flanker Mutation paradigm (Max & Tsal, 2015), which allowed to investigate the time course of distractor processing in the Flanker task.

3.6 Conclusion

In conclusion, I replicated previous findings of deficits in the Flanker task in AwD. I proposed that this deficit arises from deficits in earlier conflict resolution mechanisms. However, this hypothesis needs further investigation because the current experiment cannot tease early and late conflict suppression stages apart. I also investigated for the first-time visual marking/top-down goal suppression mechanisms in dyslexia population and found no evidence for such deficits in individuals with dyslexia. Furthermore, the current chapter suggests that the deficit in the Flanker task in high functioning AwD is not related to their lexical and sub-lexical deficits. Most importantly, the results of this chapter suggest that AwD do not seem to have a domain general competition resolution or suppression deficit.

CHAPTER 4

Stop-it: Investigating the role of domain specific response inhibition in adults with dyslexia and typically reading control.

4.1 Abstract

The aim of this chapter was to study the domain-general suppression mechanisms in individuals with dyslexia and more specifically, to investigate if AwD experience deficits with response suppression in addition to their lexical competition deficits. The results from the experimental trials in this chapter did manifest group differences in the response suppression measured with the Stop-signal tasks, with AwD performing poorer than controls. The poorer inhibition of controls was related to the semantic effect of accuracy in the blocked cyclic task, but this is not the case for AwD. For the dyslexia group, the deficit in response inhibition was secondary to their lexical competition difficulties, evidence against the domain-general hypothesis. In order to investigate the locus of the poorer response suppression in participants with dyslexia I isolated the potential influence of sensory and/or more general processing deficits that could have contributed to the dyslexia performance, by testing response inhibition within the visual and auditory domains. The study findings suggest that AwD do not have difficulty suppressing response in general, but only in situations where an auditory signal needs to be processed. The largest deficit in the response suppression was observed in the cross-modal condition, where the communication between domains was more difficult, which could potentially be a result of the auditory deficit. The lack of relationship between lexical and sub-lexical deficits in participants with dyslexia and their stop-signal reaction time (SSRT), confirming previous hypothesis that suppression deficits and auditory deficits are secondary to dyslexia reading difficulties.

4.2 Experiment 1

4.2.1 Introduction

In my previous chapter, I found that the lexical competition deficits observed in AwD are not general-cognitive control deficits. I also found evidence that the response selection and top-down control mechanisms are unimpaired in the participants with dyslexia. In this chapter, I focus on global response inhibition/suppression mechanisms and their potential involvement in lexical selection and reading deficits. If the Stop-signal task taps into the same kind of suppression mechanism, then I would expect AwD to show a deficit in the response inhibition. This hypothesis was based on previous studies that have linked response inhibition to lexical selection as a mechanism either to inhibit semantic associates (Shao et al., 2015) or orthographic neighbours (Altemeier et al., 2008).

4.2.1.1 Stop-signal paradigm

The stop-signal paradigm has been widely used as a measure of response inhibition (e.g.,Logan & Cowan, 1984; Verbruggen, Logan, & Stevens, 2008). It usually consists of a primary task, where participants are asked to respond to go-stimuli as quickly as possible (e.g., press the left key when you see a circle on the screen and press the right key when you see a square). After the go stimulus is presented, a stop signal is occasionally presented (often an auditory tone) and participants are instructed to withhold their response when they hear the signal. The time between the go stimulus and stop signal is the stop signal delay (SSD). Participants are usually more successful in withholding their response when the signal occurs closer to the presentation of the go-stimulus (short SSD), in comparison to when it appears closer to response execution (a long SSD). Taking into account mean reaction times to the go trials when no stop signal is presented (go-RT) and the average SSD that allows participants to withhold a response, one can calculate a Stop-signal RT (SSRT) which can be used to measure the response inhibition (for details see methods section below).

The most prominent model used to explain the processes engaged by the stop-signal task is the Horse-race Model. According to this model, task performance is governed by a race between go and stop processes (Logan, 1994; Logan & Cowan, 1984a). The two processes are assumed to be independent (Logan & Cowan, 1984b). If the stop process finishes before the go process, the response can be inhibited, but if the go-process finishes first, then inhibition is unsuccessful, and the participant response is executed. Although go and stop processes are assumed to be independent, it has been observed in several studies that when the likelihood of a stop-signal to appear is increasing, so does the length of the RTs in the go-trials (Logan, 1981; Verbruggen, Liefooghe, & Vandierendonck, 2004). The observed behavioural change is explained with the proactive response strategies, where the response speed in the go-trials is traded for accurate stop trials (Verbruggen & Logan, 2009). Monitoring the use of strategies will be a concern for the data analysis.

4.2.1.2 Response inhibition in developmental dyslexia

The stop-signal task has been used to test inhibition in CwD and adolescents. The literature reports mixed and inconclusive results. Some studies have reported group differences in the SSRT measure between participants with dyslexia and controls (De Jong et al., 2009; Purvis & Tannock, 2000; Van der Schoot & de Sergeant, 2003; Van der Schoot et al., 2002; Willcutt et al., 2005), while other studies have found no group difference (Bexkens et al., 2015; Gooch, Snowling, & Hulme, 2011; Liotti et al., 2010; Rucklidge & Tannock, 2002; Schmid et al., 2011; Wang & Yang, 2015). In all studies, the derived SSRT measure for response inhibition was used. However, not all studies reported other measures of the Stop-signal task, like go-RT and accuracy. For example, Wang and Yang, (2015) and Bexkens et al. (2015)

focused only on the SSRT without reporting other task measures. In contrast, some of the studies found SSRT group differences reported slower go-RT (De Jong et al., 2009; Van der Schoot & de Sergeant, 2003) increased commission errors, pressing a key when inhibition is required (De Jong et al., 2009; Willcutt et al., 2005) and increased omission errors, inhibiting a response when response press is required (De Jong et al., 2009; Purvis & Tannock, 2000) in the dyslexia group. Suggesting for a wider processing deficit not restricted to suppression.

Most of the studies looking at the response inhibition abilities in individuals with dyslexia were mainly interested in the co-morbidity between the reading difficulties and the Attentional Deficit Disorder (ADHD) (De Jong et al., 2009; Gooch et al., 2011; Liotti et al., 2010; Purvis & Tannock, 2000; Rucklidge & Tannock, 2002; Willcutt et al., 2005). All of these studies compared the SSRT performance in RD, ADHD, controls and co-morbid RD+ADHD groups. While the studies were inconclusive about the SSRT differences between the RD and control groups, they all showed that the co-morbid RD +ADHD group was performing the worst in term of response inhibition. In my thesis, I did not include participants with dyslexia who have co-morbid disorders, including ADHD. While this would potentially limit the variability in the dyslexia group, it would help us potentially to generalise the results to dyslexia, not to be limited to the specific dyslexia sub-population. Only handful of studies were interested in response inhibition as part of the dyslexia reading deficits (Bexkens et al., 2015; Schmid et al., 2011; Van der Schoot & de Sergeant, 2000; Van der Schoot et al., 2002; Wang & Yang, 2015). However, only one of these studies reported group differences in the response inhibition.

4.2.1.2.1 The relationship between SSRT and AwD language deficits.

If AwD perform worse in the Stop signal task, then the question is whether this deficit is related to their reading deficit. Van der Schoot and de Sergeant (2000)suggested that there is relationship between word recognition, activation in the orthographic lexicon and response suppression in individuals with dyslexia. Their sample consisted of two types of dyslexia (classified based on a sentence reading task): guessers, or individuals with dyslexia who read fast and inaccurately, made more than 60% substantive errors, and spellers, who read slowly but accurately, made more than 60% time-consuming errors (see Van der Schoot & de Sergeant, (2000) for more information on the classification). It was found that response inhibition deficits, measured with Stop signal task, were apparent only in guessers, but not in spellers. The authors hypothesised that the suppression performance of both groups could be linked to their reading styles. In particular, they linked suppression deficits to inefficient suppression of competitors in the orthographic lexicon. Items are accepted before enough information has arrived to pick the correct word. The authors argue that there should be a large number of orthographically related real word errors resulting in fast but inaccurate reading in the guesser type of dyslexia. In contrast, spellers had better suppression in the stop-signal task. This was linked to excess suppression in the lexicon so that more time is required for words to reach the activation threshold. This results in slow, but accurate reading. However, authors did not report a relationship between the guessers and spellers reading scores and response inhibition, providing no evidence for these interpretations.

The relationship between individuals with dyslexia naming speed and phonological processing with the response inhibition was explored in several tasks where with and without group differences. For example, Bexkens et al. (2015) compared the performance of typically reading controls and participants with dyslexia on the Stop signal task and rapid automatized naming. They found no group differences in response suppression and no relationship between stop signal task and rapid naming task in either group. Authors concluded that response suppression was not related to rapid naming. In another study, Schmid et al. (2011)

looked at response suppression in AwD and its potential involvement in phonological short-term memory measured with digit span. They found no group difference for the response suppression and no relation with the verbal memory within the dyslexia group. However, in the control group the verbal working memory and the stop-signal measure of response suppression were negatively correlated, with poorer response inhibition being linked to better verbal short-term memory.

In a recent study published study, Roe et al. (2018) tested children who struggle on fluency and reading comprehension with variation of the Stop-signal paradigm. They found no group difference for the SSRT, go-RT or number of errors supressing stop signals. The only significant group difference was for accuracy on the go trials, which was also correlated with word reading efficiency and comprehension abilities. Authors concluded that children with reading and comprehension difficulties did not experience general cognitive control deficits, deficits were only apparent when reading was involved.

In conclusion, there is a limited number of studies explored the relationship between dyslexia reading deficits and the response inhibition measure, but they all found no evidence for such relationship.

4.2.1.3 Response inhibition in typical developing readers

The relationship between response inhibition and reading is also not well established in the neuro-typical literature. Previous studies relating SSRT to word reading skills in typically developing children report inconsistent results. Christopher et al. (2012) tested younger (ages 8 to 10) and older typical adolescents (ages 11 to 16) and did not find response inhibition to be significant predictor of word reading capabilities or reading comprehension. In contrast, Arrington, Kulesz, Francis, Fletcher and Barnes (2014) found response inhibition measured with SSRT to be a significant predictor for word decoding in typical adolescent participants (age 11 to 17). They hypothesised, similar to Van der Schoot and de Sergeant (2003), that response inhibition might be an essential part of the word decoding process by supressing the orthographic neighbours that become activated as a word is read. More specifically, response inhibition was thought to be an automatic process that inhibits the co-activated neighbours by preventing them from entering working memory (Arrington et al., 2014). The role of response inhibition in suppressing co-activated lexical neighbours has been proposed in other studies. For example, Shao, Meyer and Roelofs (2013;2012) suggested the involvement of response inhibition in lexical selection (but see Shao et al., 2015). More specifically, the authors explained the involvement of response inhibition in lexical selection with supressing activation of the irrelevant semantic associates to the target word within the lexicon.

4.2.1.4 Study aim

The main aim of this study is to investigate if the increased lexical competition found in AwD is a result of domain general form of suppression. To test this, I used the same dyslexia sample that showed differences in the lexical tasks from Chapter 2. The present study also aims to extend the existing literature by testing response inhibition in highly functioning AwD instead of children. In particular, previous studies have reported the significance of age differences in response inhibition, with typical adults being better in inhibiting a response compared to children (Carver, Livesey, & Charles, 2001; Williams, Ponesse, Schachar, Logan, & Tannock, 1999).

Given the conflicting results in the literature, I could find group differences in the SSRT. If AwD report poorer SSRT compared to controls and SSRT were correlated to their lexical competition skills, this would suggest that the earlier lexical effects might be due to general issues with response inhibition. Alternatively, I could find group differences for the SSRT that are not correlated to the lexical tasks; this would suggest that AwD have domain specific suppression deficits. I could also find no group difference in the SSRT measure, suggesting that the lexical effects were not due to general issues. This would also suggest that group differences in studies with younger samples might be because of developmental changes that are resolved by adulthood. Overall, the link or lack of a link between different tasks may be clearer in the adult data where developmental change is less influential. To conclude, in this study I could better understand the role of response inhibition in language production and comprehension in both AwD showing specific language deficits and in typical control adults.

4.2.2 Method

4.2.2.1 Participants

The same participants as in Chapter 2 and 3 took part in the Stop-signal task.

4.2.2.2 Stimuli and Procedure

The Stop Signal task started with a practice phase consisting of 32 trials, followed by an experimental phase, which consisted of three blocks of 64 trials. Each trial started with a fixation cross for 250 ms. After that, a white stimulus (square or a circle) was presented on a black background in the centre of a computer screen. Participants were asked to respond as quickly and as accurately as possible by pressing the "Z" key (on a standard keyboard) with the left index finger when a *circle* appeared and by pressing the "/" key with the right index finger when a *square* appeared. In 25% of the trials, a stop signal (i.e., 750 Hz, 75 ms) was presented shortly after the stimulus onset (see Verbruggen et al., 2008). The stop signal tells participants to suppress their response. The signal occurred after a variable time, the *stop signal delay* (SSD; the interval between the go-stimulus and the stop signal). On a short signal delays participants can easily suppress their response, in contrast when the delay is longer the participants execute a response more often. The stop signal delay was initially set to 250 ms and it was continuously adjusted according to an adaptive staircase procedure (Levitt, 1970), dependent on whether or not the inhibition succeeded. When the participant successfully inhibited the response the SSD increased by 50 ms, in contrast when the inhibition failed the SSD decreased by 50ms. For each participant the mean SSD was calculated as the final SSD measure. The tracking procedure results in an overall p (respond | stop–signal) of 0.50 for each participant (Verbruggen et al., 2004). Trials without stop signals will be referred to as no-signal trials, while trials with stop signals will be referred to as stop-signal trials (following Verbruggen et al., 2008). Participants were asked to withhold their response whenever the stop signal occurred. They were instructed not to wait for the stop signal to occur, but to respond as fast as they could. Each stimulus remained until a response was made or until 1250 ms post stimulus-onset. Stimuli were presented with a fixed inter-stimulus interval of 2000 ms.

4.2.2.3 SSRT method of analysis

I used the *integration method* (Verbruggen, Chambers, & Logan, 2013) to produce an unbiased estimate of SSRT (Band, van der Molen, & Logan, 2003; Verbruggen et al., 2013). This method assess the point at which the stop process finishes by integrating the RT distribution and finding the point at which the integral equals the probability of responding *p*(respond|signal) for a specific delay. This method assumes that the finishing time of the stop process correspond to the number of RTs in the go RT distribution (nth RT) multiplied by the overall probability *p*(respond|signal) (Logan, 1981). SSRT is estimated by subtracting the mean SSD from the nth RTs. Figure 4-1 illustrates the relationship between the go-RT distribution and the (derived) SSRT distribution.

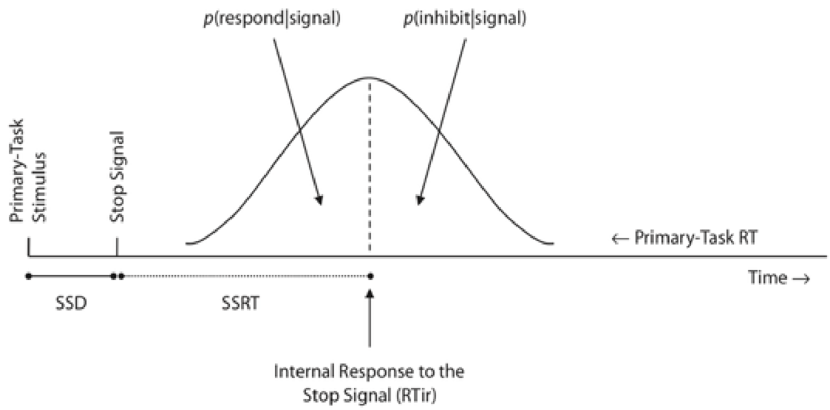


Figure 4-1 The figure is from Verbruggen et al. (2008) study. It illustrates the probabilities of responding p(respond|signal) based on the horse-race model (Logan & Cowan, 1984). The distribution represents the go-RTs (SSD=stop signal delay; SSRT=stop signal RT). The stop-signal is presented after a delay (SSD) relative to the go-signal. The stop process finishes after the SSRT and it is relative to the onset of the stop signal. The finishing times of the SSRT intersects the go-RT density function with responses from the left part of the go-RT function being too fast to be inhibited while the responses from the right part are inhibited correctly.

4.2.2.4 Exclusion criteria

4.2.2.4.1 Violation of assumptions.

I excluded the data for one control and three participants with dyslexia whose mean RTs in the stop trials (trials in which participants pressed the key instead to suppress the response) were slower than their mean *go*-RT. According to Matzke, Verbruggen, and Logan (2018) this is an important criterion, as these participants violate the independence assumption of the race model. This is based on the prediction that the mean go-RT should be longer than the signal- respond RT. The go-RT include all responses in the distribution, including the very slow RTs (the mean of the whole distribution represented in figure 4-1), in contrast the signal-respond RT include those responses that were fast enough to finish before the stop signal (mean of the proportion of responses positioned on the left of the RTir dashed line on figure 4-1). Therefore, a violation of this assumption could affect the validity of the SSRT which estimation relies on methods based on the race model (Logan & Cowan, 1984).

4.2.2.4.2 Strategy outlier's selection criteria.

I also excluded participants who were potential strategy users. Slowing the go-RT is a strategy that some participants use in order to more easily supress their response when the stop signal appears. Using this strategy produces a characteristic slowing of go responses over the course of the experiment to try to beat the tracking algorithm by waiting for the signal. Speed in the go-trials is traded for more accurate stop trials (Leotti & Wager, 2010; Verbruggen & Logan, 2009), and this results in a very shorter estimated SSRT, but not because of good suppression abilities. To exclude participants who used this strategy, I used *p(*respond|signal), which represents the probability of successfully responding to stop-signal trials. If a participant is not applying a strategy, the probability of responding, rather than successfully inhibiting a response on a stop-signal trial should be 50% due to the adaptive staircase. If participants are waiting for a stop signal, they will succeed at inhibiting a response more often, producing a lower response probability and an increasing response time across the experiment. I excluded all participants where the probability of responding was 40% or lower. This resulted in two participants being excluded from the control group. The final analysis included data from thirty–one control participants and twenty-four participants with dyslexia.

4.2.2.5 Data analysis

The Group comparison on the derived SSRT was analysed with linear model, while the go-RT with mixed effect models. For the analysis of accuracy, I conducted binomial logistic regressions with generalised linear model (GLM) analyses. For all analyses, I employed the lmer function of the lme4 package (Bates et al., 2013) using R version 3.5.1(R Development Core Team, 2009). For all analyses, the main effect of group was estimated by comparing models with and without the group term using likelihood ratio chi-square tests (Bates et al., 2013).

4.2.3 Results

4.2.3.1 Go-RT accuracy

The error rate for the go-RT trials in the Stop signal task was overall 3.2 %.I started the model fitting analysis with a model with Accuracy as the dependent variable and Group (Control and AwD) as fixed factor. The random effect structure included random intercept for participants.

Accuracy results are shown in Figure 4-2. Controls and AwD accuracy in the *go trials* did not differ ($\chi 2$=2.55; df=1; p= .109).

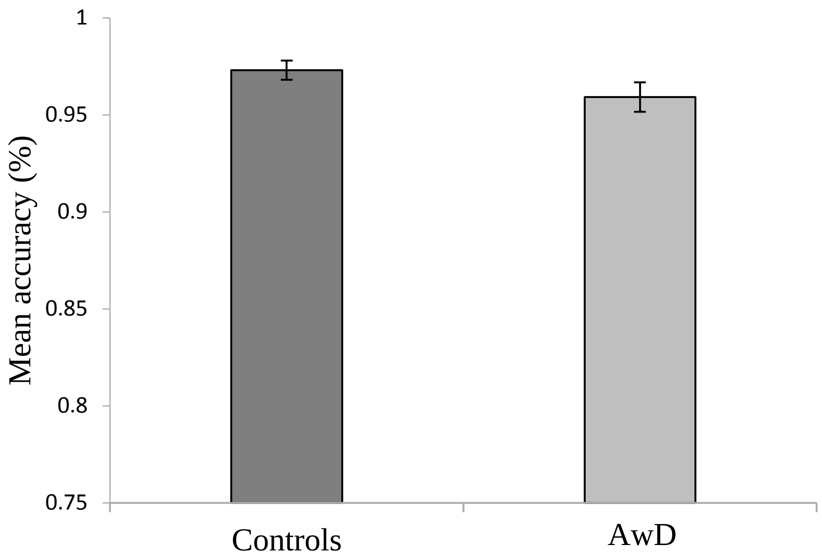


Figure 4-2 Mean accuracy for the no-signal trials in the Stop-signal tasks of Experiment 1. Error bars represent standard errors.

4.2.3.2 SSRT and Response times

I next analysed the SSRT using linear models. I found a significant effect of group, F (1,55) =4.09, p=.048. AwD's SSRT was significantly higher than controls. Results are displayed in Figure 4-3. Higher SSRT scores indicate poorer response inhibition/suppression abilities.

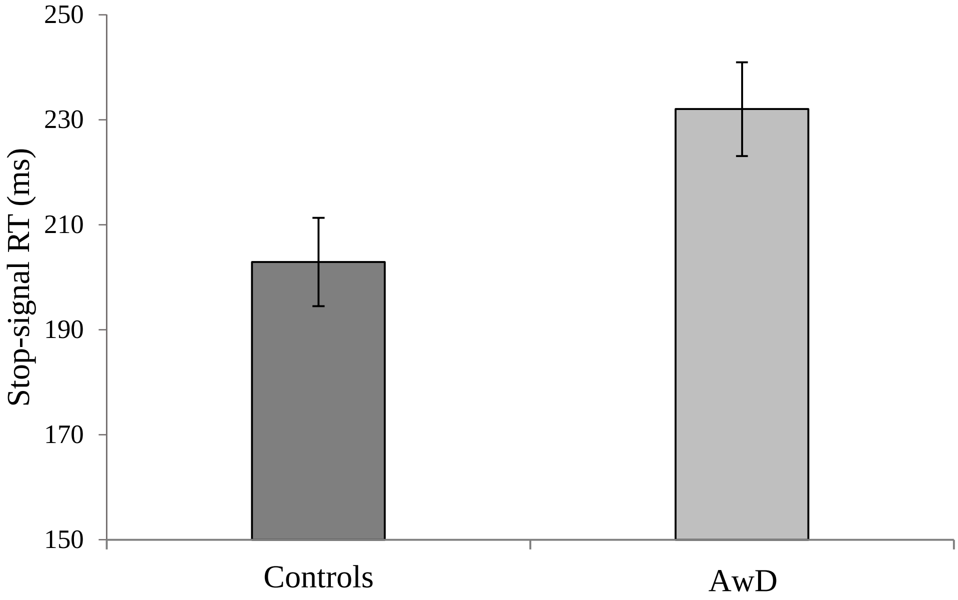


Figure 4-3 Mean stop-signal reaction times (SSRT) for control and participants with dyslexia in the Stop Signal task of Experiment 1

To investigate if the poor response suppression performance in the group of dyslexia was indeed due to inhibition/suppression deficit and not to a general deficit in cognitive control, I fitted a mixed-effect model with go-RT as a dependent variable. Response times more than 2.5SDs from participant means were considered outliers and were removed from the analysis. These accounted for 2% of the total responses (N=7920). The total number of trials after removing the outliers and the incorrect responses was 7,549. The full model included Response time as the dependent variable and Group (Control and AwD) as fixed factor. The random effect structure of the final model included a random intercept for participant. The effect of Group was not significant (χ^2 =0.59; df= 1; *p*=.441). Thus, the mean go-RTs did not differ for the two participant groups. Together these results suggest inhibition/suppression deficits in the dyslexia group. See Table 4-1 for the two dependant variables go-RT and SSRT, and the p(respond|signal) and SSD results.

Table 4-1 Number of participants after applying exclusion criteria, probability of responding on valid–signal trials [p(respond)], average of the stop-signal delay(SSD),stop-signal reaction time (SSRT) and go- RT of Experiment 1.

Group	N	*p*(respond|signal)		SSD		go-RT		SSRT	
		M	SD	M	SD	M	SD	M	SD
Controls	31	.47	.03	353	116	582	176	207	47
AwD	24	.49	.05	309	126	557	182	232	44

In addition, I tested whether the data violated the assumptions of the Independent Race-model, namely that response latencies in the stop signal trials were not significantly slower than response latencies in go trials for either of the groups. If the race model is violated, derived SSRT is not a reliable measure of response inhibition (Verbruggen et al., 2013).

Fitting a linear mixed model with Type of Response times (go-RT and stop-RT latencies) as and Group (Controls and AwD) as fixed factors and with the random effect structure including random intercept for participant. I found no significant Group by Condition interaction (χ2=0.9; df= 1; *p*=.319) and no Group effect (χ2=0.60; df= 1; *p*= .437). Only the effect of Condition was significant (χ2= 293; df = 1; *p*< .001), with go-RTs being significantly slower than Stop signal RTs. Results are shown in Figure 4-4. Thus, the data did not violate the assumptions of the Independent Race-model.

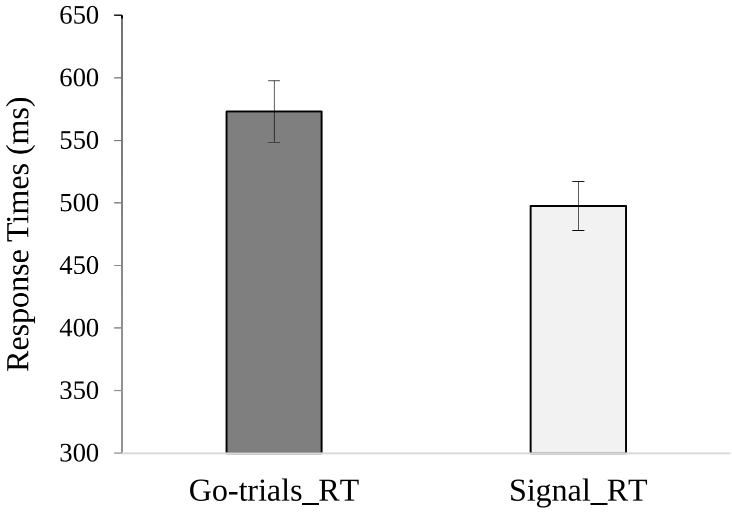


Figure 4-4 Average RTs on go-RT trials (no signal) and on Stop RT trials (latency of the incorrectly executed response on signal trials) of Experiment 1. Error bars represent standard errors.

4.2.3.3 Correlations with language tasks

In the previous analysis, I found that AwD took longer to suppress responses in the Stop-signal task. Here, I investigate the relationship between this deficit and performance on the verbal-tasks used in Chapter 2. Correlations between the SSRT and the effects in blocked cyclic naming tasks and the Hayling tasks are displayed in Table 4-2. Some of the variables represent proportions of accuracy, resulted in positively skewed data. In order to investigate the relationship with the effect of response time variables I transformed the data using Arcsine transformation[13].

[13] The Semantic Accuracy effect variable represents the difference of proportion between the homogeneous and heterogeneous conditions; as a result, some of its values were negative. In order for the data to comply with the Arcsine range (0 >) I added .5 to all data points. Making all data points positive.

Table 4-2 SSRT of Experiment 1 and verbal tasks correlations for the control group of participants and for dyslexia group.

		AwD SSRT		Controls SSRT		Whole Group SSRT	
		r	*p*	**r**	*p*	**r**	*p*
Blocked cyclic naming							
	Semantic accuracy effect	**-.10**	*.605*	**.57**	*.001***	**.21**	*.117*
	Competitor errors homogeneous	**-.09**	*.677*	**.397**	*.027**	**.19**	*.147*
	Semantic effect (RTs Homogeneous - Heterogeneous)	**.09**	*.623*	**.17**	*.340*	**.11**	*.436*
Hayling task							
	Overall Accuracy	**.05**	*.827*	**-.03**	*.856*	**.09**	*.490*
	Partial failures	**-.10**	*.629*	**-.05**	*.803*	**-.00**	*.981*
	Inhibition RTs	**-.14**	*.499*	**.00**	*.985*	**-.02**	*.898*

There was no relationship between the SSRT and the verbal task performance in the dyslexia group[14]. Interestingly, in the control group the semantic effect of accuracy performance in blocked cyclic naming task was positively correlated with the SSRT severity, with more errors in the homogeneous condition related to poorer suppression performance. This relationship could be seen in Figure 4-5.

[14] It needs to be acknowledged that the group with dyslexia is likely to be noisier compared to the controls which possibly make it harder to find significant correlations.

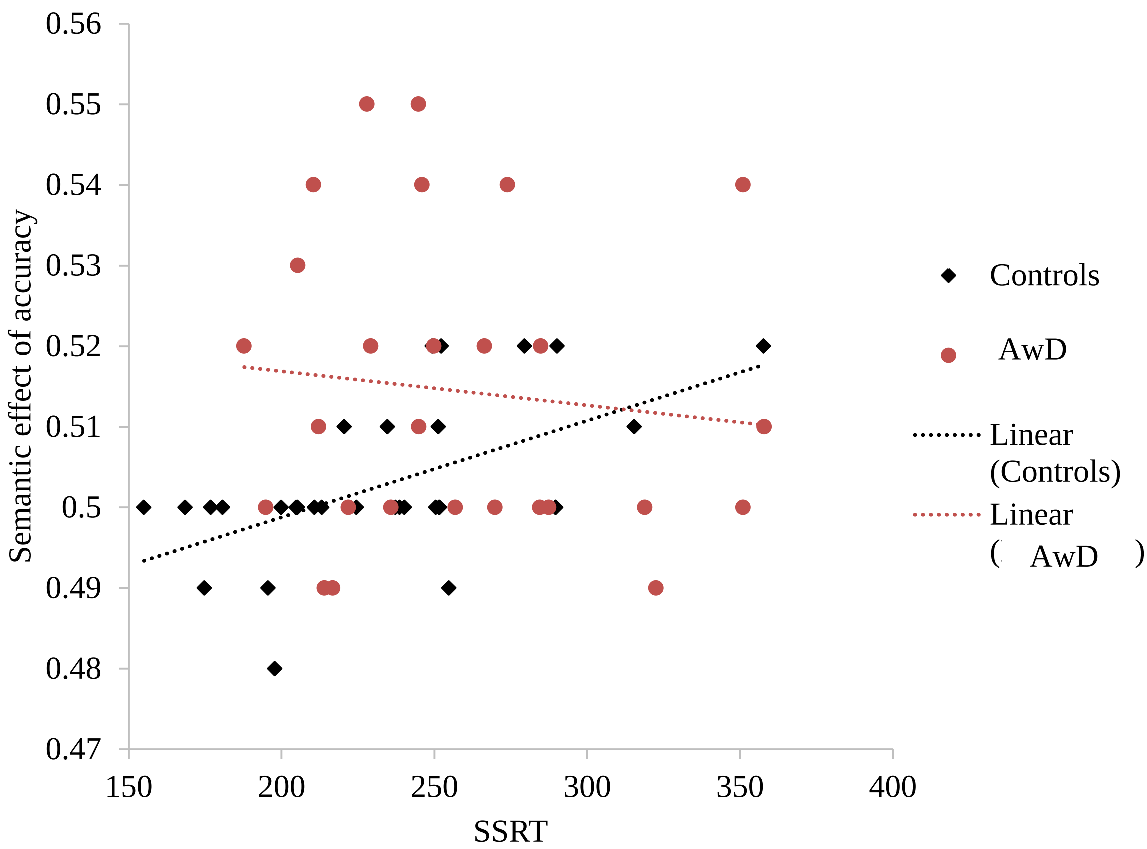


Figure 4-5 Semantic effect of accuracy shows a positive correlation with the controls SSRT and no correlation to the AwD SSRT of Experiment 1.

In the control group, I also found moderate relationship between the SSRT and the number of competitor errors in blocked cyclic naming task, with poorer inhibition related to more competitor errors. The relationship is displayed on Figure 4-6. The figure suggests that the significant relationship was largely driven by the participants who were not making competitive errors, making it less reliable.

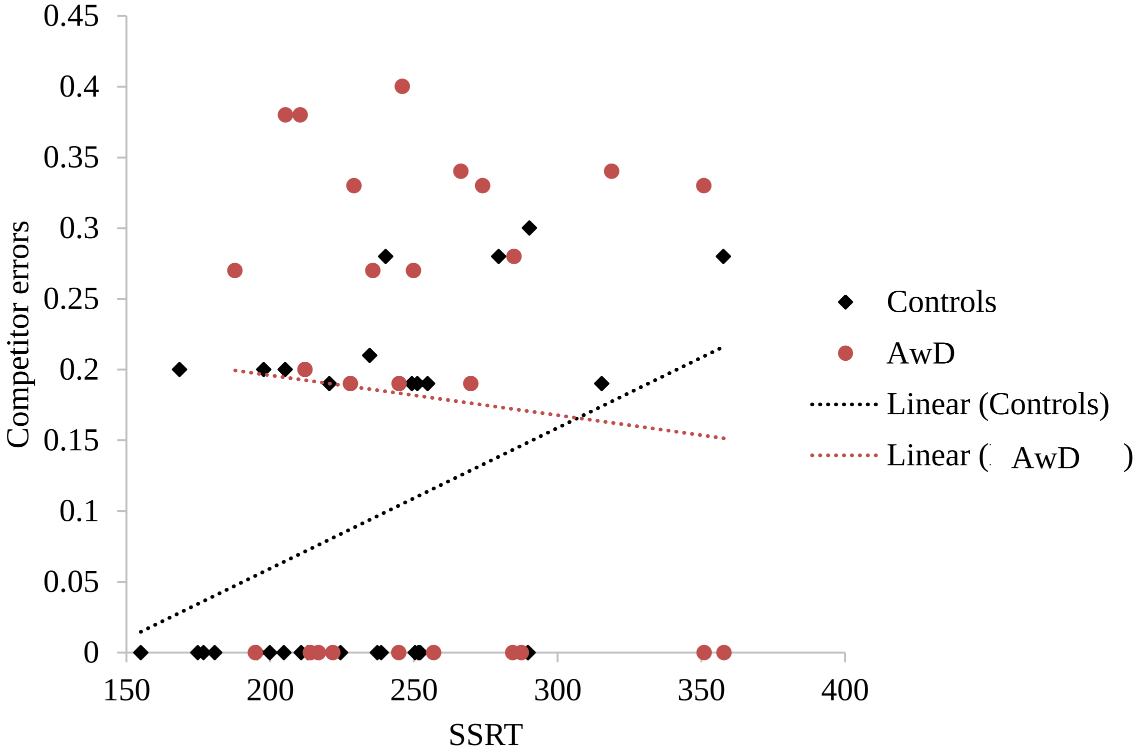


Figure 4-6 Competitor errors in blocked cyclic naming task shows a positive correlation with the controls SSRT and no correlation to the AwD SSRT of Experiment 1.

4.2.3.4 Language assessments and SSRT

In the previous subsection, I saw that suppression mechanism in stop signal task is related to the lexical competition in cyclic blocking task only for the control group. This observation suggests that a different mechanism is responsible for resolving lexical competition in the dyslexia group. There is evidence in the literature of response suppression involvement in various lexical and sub-lexical skills. I correlated language performance and SSRT to examine the relationship between language skill and response suppression. The results are displayed in Table 4-3.

Table 4-3 Correlation between the factors form the PCA analysis and the SSRT of Experiment 1 in controls, AwD and the whole group of participants.

		Lexical Skills		Phonological STM		Phonological Manipulation	
		r	*p*	**r**	p	**r**	P
Whole group							
	SSRT	**-.30**	*.022**	**.07**	*.623*	**-.08**	*.536*
Control group							
	SSRT	**-.63**	*<.001****	**-.09**	*.630*	**-.25**	*.160*
AwD group							
	SSRT	**.06**	*.786*	**.24**	*.236*	**.10**	*.618*

I found a significant negative correlation between SSRT and lexical skills in the control and the whole group of participants, with poorer suppression being related to poorer lexical skills. The weaker relationship in the whole group was driven by the control sample. This relationship is displayed in Figure 4-7.

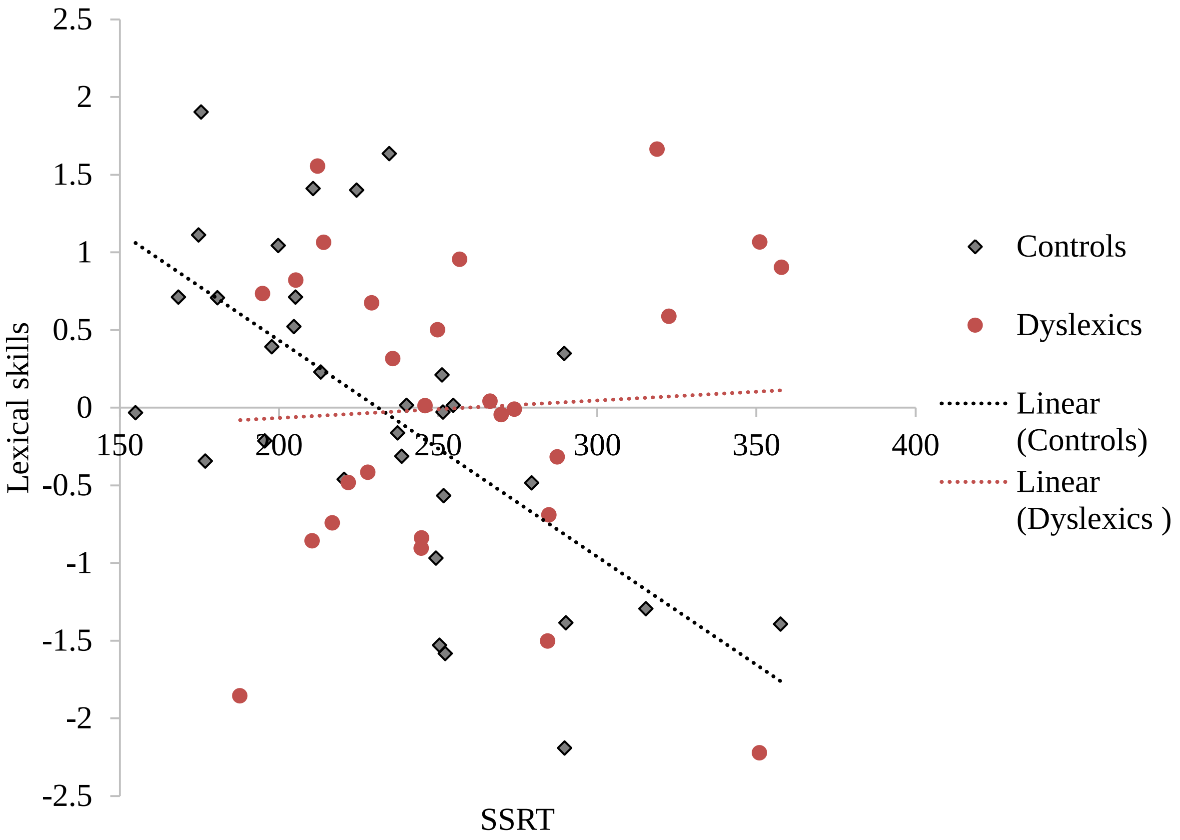


Figure 4-7 Lexical skills factor is correlated with SSRT of Experiment 1 for the control group only.

There was no relationship between the SSRT and phonological STM and phonological manipulation in either group. These results are in line with the view that suppression deficits in dyslexia are not related to lexical and sub-lexical deficits. Implications of these findings are further discussed in the Discussion section.

4.2.4 Discussion

The aim of the study in this chapter was to investigate if AwD experience deficits with response suppression in addition to their selective suppression and lexical competition deficits reported in chapter 2 and 3. Here, as in the previous chapters I am interested in the domain-general cognitive control mechanisms and the between tasks relation in dyslexia participants and controls. In the previous chapter, I found no evidence for a domain general competition resolution deficit and in this chapter, I am interested if dyslexics have domain-general suppression deficit. I found group differences in response suppression measured with the Stop-signal tasks, with AwD performed poorer than controls. There were no group differences for the accuracy or response times in the primary go-task, ruling out general cognitive deficit or speed accuracy trade off as the source of the response suppression deficit. These findings are potentially consistent with my hypothesis of general-suppression deficits in AwD.

Thus, the question arises do lexical competition deficit in AwD could be a result of domain general-suppression deficits, or not? To answer this question, I correlated participants' performance on the SSRT with the performance on the language tasks reported in Chapter 2. I also correlated SSRT with the assessments indicating language skills. In the control group lexical skills factor and the semantic effect in cyclic blocking were related to SSRT, showing that both the semantic effect and one skill that is important for reading can vary with better or worse general inhibition performance as measured by SSRT. On the contrary, in the dyslexia sample, SSRT and cyclic blocking results were not correlated; also there was no correlation between SSRT and tasks that index the severity of dyslexia (i.e., verbal STM, lexical skills and phonological manipulation). This finding is not consistent with the hypothesis of domain general suppression deficit in individuals with dyslexia that affects both lexical competition and motor response suppression. It also raises the possibility that different mechanisms are involved in the resolution of lexical competition in both groups. In the remainder of this section, I discuss the results in relation to studies in literature. Then, I consider potential dyslexia deficits that could have influence the response inhibition measure.

The results of this study are in line with previous Stop-signal studies in which response inhibition deficits were reported in children with dyslexia (De Jong et al., 2009;

Purvis & Tannock, 2000; Van der Schoot & de Sergeant, 2003; Van der Schoot et al., 2002; Willcutt et al., 2005). Moreover, this study expands previous findings by testing highly functioning adults and rejects the hypothesis that suppression deficits in AwD are linked with developmental delay.

Van der Schoot and de Sergeant (2000) found response inhibition deficits in what they called the "guesser" subtype of dyslexia and argued that response inhibition is essential part of individuals with dyslexia word decoding processes. In the current results, there was no relationship between response suppression and lexical or sub-lexical abilities in the dyslexia group. This contradicts Van der Schoot and de Sergeant (2000) hypothesis, and matches other studies which report no relationship between response suppression and phonological and word reading deficits in dyslexia (Bexkens et al., 2015; Roe et al., 2018; Schmid et al., 2011).

4.2.4.1 Response suppression as mechanisms in resolving lexical competition

I found a significant correlation between lexical skills and SSRT in the control group, which extends previous research with the Stop signal task in typical adolescents and adults. In their study Arrington et al. (2014), found SSRT to be a significant predictor for word reading in adolescents. They concluded that response inhibition is an automatic process that suppresses co-activated neighbours in the orthographic input lexicon. Even though that this claim could offer a plausible explanation for the correlation between lexical skills and SSRT, the correlation between the cyclic blocking naming and Stop-signal task suggest that the competition processes are resolved at a lexical-semantic level.

The role of response inhibition in suppressing co-activated lexical competitors has been proposed in Shao et al. (2012) study. In particular, the authors suggest for the involvement of response inhibition in lexical selection by supressing activation of the irrelevant semantic associates to the target word within the output lexicon. In their study, the authors used a picture-naming task where participants were required to name pictures consisting of action and nouns. Some of the pictures were semantically related while others were not, with semantically related pictures taking more time to name. This difference in naming speed is believed to be a result of the spreading activation in the lexicon (for more details see Chapter 2). Using ex-Gaussian analysis Shao et al., (2012) found that response suppression was engaged in most of the trials where action naming was required, but this was only limited to the very slow trials in object naming. Such pattern of results could be due to the complexity of the conceptual processes in verb naming compared to noun naming. These results were further replicated in a subsequent study Shao et al., (2013). However, in their latest study Shao et al., (2015) used cyclic blocking task as a measure of lexical competition and found no relationship between the semantic effect (homogeneous-heterogeneous RTs) in cyclic blocking and an SSRT measure. In my tasks, I found SSRT to be related to the effect size of semantic accuracy. Thus, the current results were not consistent with Shao et al.,(2013) study. However, since accuracy was not reported in the Shao paper, I cannot say for sure if my study findings are not consistent with theirs. In conclusion, I found evidence for shared suppression mechanisms to operate in the lexicon, but since this relationship is not apparent in the dyslexia group suggests that AwD are using different processes from the controls to resolve lexical competition.

4.2.4.2 Response suppression as a separate deficit in dyslexia

In the previous section, I established that response suppression deficit in AwD is secondary to their reading deficits. This brings the question if the suppression deficits could be due to another deficit in developmental dyslexia?

According to the stop-signal literature, in addition to suppression of the motor output there is also non-motor process that also play role in stopping responses (Verbruggen, Stevens, & Chambers, 2014). In order to stop a response successfully first, the signal should be detected therefore the outcome of the sensory process involved in stimuli detection is crucial for the task performance. Some of the deficits previously reported in the dyslexia literature could have an impact on detecting the signal.

One potential candidate is the deficit integrating auditory-visual information (Francisco et al., 2017; Hairston et al., 2005; Kast et al., 2011). Multisensory integration occurs when two or more sensory systems are taking place in close temporal and spatial proximity. The sensory integration is believed to be critical for the developmental of reading skills, where rapid association between the visual stimuli known as grapheme and auditory stimuli or phoneme need to be successfully integrated (Tallal, Miller, & Fitch, 1993). The multimodal integration deficit in AwD is believed to be as a result of having wider temporal-window of integration, where stimuli in close proximity are not perceived as separate events, but as a part of the same event (Hairston et al., 2005). In the context of the Stop-signal task such wider temporal window might result in both the visual go stimuli and auditory stop stimuli to fall in the same temporal window where instead perceived as separate processes (in a race for execution), both would be perceived as one event. According to Aron and Poldrack(2005) one of the main components in the stop-signal task is to detect the stop signal as a different action, which require attentional shift form the visual to the auditory domain. Therefore, in cases of a larger temporal window, the shift from the predominant visual stimuli to the less frequent auditory signal would not be quick enough and keypress would be executed.

Furthermore, difficulties in the perception of non-linguistic auditory stimuli is also reported in the dyslexia literature (e.g. Ahissar, Protopapas, Reid, & Merzenich, 2000; Paula Tallal, 1980; Wijnen, Kappers, Vlutters, & Winkel, 2012). If the sample of dyslexia have such auditory sensory deficit this could leads to reduced sensitivity of the auditory stop signal, which in turn would lead to more failure to suppress the response, resulting in higher SSRT.

Another possible deficit in individuals with dyslexia that could result in response suppression deficit is limited processing cognitive load. Increased cognitive demands are required when maintaining different task goals in the stop-signal task, like going and stopping. Maintaining different task goals require cognitive control mechanisms as well as good Short-term memory (Miyake et al., 2000). Therefore, it is possible that AwD were having difficulties stopping their responses, because of deficits with limited cognitive processing load. In other words, AwD would sacrifice the suppression of the stop signal to perform successfully the primary go-task.

4.2.5 Conclusion

To conclude, I found poorer response inhibition in the sample with dyslexia, with this deficit not related to their reading difficulties. However, the complex structure of Stop-signal task raised the possibility of other dyslexia difficulties to have influenced the performance. Therefore, in order to conclude that AwD have poorer response suppression I first need to isolate the potential deficits that could have contributed to their performance. I did by designing a second Stop-signal experiment.

4.3 Experiment 2

4.3.1 Introduction

In the previous experiment, I found that participants with dyslexia had a deficit with response suppression and that this deficit is not related to their reading difficulties. In order to understand the nature of this deficit, it is important to point out that the Stop-signal task is a complex task requiring not only response suppression, but also auditory signal detection, cross-modal integration of the visual and auditory stimulus, as well as dealing with an increased cognitive load. It has been found that individuals with dyslexia have a deficit of processing auditory information, especially auditory signals in close sequences (e.g. Ahissar, Protopapas, Reid, & Merzenich, 2000; Paula Tallal, 1980; Wijnen, Kappers, Vlutters, & Winkel, 2012) as well as deficit in processing cross modal information (Francisco et al., 2017; Hairston et al., 2005; Kast et al., 2011). Therefore, the response inhibition deficit I found in Experiment 1 might be a result of the poorer processing of the auditory signal and/or poor integration of visual and auditory information.

In order to investigate where the locus of the dyslexia deficits is, I designed a variation of the Stop-signal task, where response suppression is required in three types of conditions. In the first condition I performed a uni-modal auditory condition (i.e., both stimuli and signal were sounds) to investigate if the deficit is in the auditory part of the system and uni-modal visual condition (i.e., both stimuli and signal were visual) to test if the deficit is in the visual part of the system. The third condition was a cross modal (i.e., visual go stimuli and auditory signal; same as in experiment 1) aiming to investigate if AwD have problems when integrating multi-modal information. To address the possibility of AwD having processing difficulty in situations of increased cognitive demands, I included a second double-processing task. This task was the same as the Stop-signal condition, but instead of suppressing a response, two consecutive responses were required to indicate that a signal has been presented. Monitoring for the signal was still required, but there was no requirement to suppress the primary response. If AwD were, having a general inhibition deficit this should affect all Stop-signal conditions, but not the double-task conditions. Deficit with the increased cognitive load should affect all conditions, including both the Stop-signal task and the Double-task. The possible cross-modal processing problems would affect only the cross-modal conditions.

In a study by (Roe et al., 2018), it was found that children who struggled with fluency and reading comprehension experienced no response suppression deficits in a visual Stop-signal task. The result in Experiment 1 seems incompatible with Roe et al. (2018), but would not be if the difficulty is in either cross-modal or auditory processing and visual processing is spared.

4.3.1.1 Predictions

If the SSRT difference between participants with dyslexia and controls in Experiment 1 was due to a deficit in processing auditory signals, I would expect participants with dyslexia to perform poorly in both the mixed condition of the Stop-signal task and in the auditory only condition. Moreover, their performance in the primary go- task of the auditory condition would be severely affected in both tasks.

If individuals with dyslexia have difficulties with multi-sensory integration, then I would expect larger SSRT in the mixed condition but not auditory only or visual only conditions. In the Double-task, such deficit would also have an effect on the double-signal measure/or on the first response (in cases of task prioritisation).

If participants with dyslexia have a global difficulty with response suppression, I would expect poor performance in all three stop signal conditions--visual, auditory and mixed—but not in double-response conditions. If they have a difficulty with cognitive load under double task conditions, they should be affected in all conditions of both stop-signal and double-response trials.

4.3.2 Method

4.3.2.1 Participants.

For the second experiment, I tested 33 AwD and 42 controls. All participants were recruited through study-specific recruitment posters displayed around the University of Birmingham campus and through the School of Psychology research participant scheme. Participants were either paid £20 compensation or given course credits. All participants gave written consent for their data to be used in the analysis. The inclusion criteria were similar to those applied in Experiment 1, where participants were monolingual English speakers with normal or corrected-to-normal vision, with no history of a neurological condition, or any other disability (e.g ADHD). The experiment was split into two sessions. In each session participants completed some dyslexia assessments and one of the experimental tasks. Only participants who completed both sessions where included in the experiment. Three participants with dyslexia and five controls failed to complete both sessions of the experiment and were excluded from the analysis. I also excluded one participant from the dyslexia group for being bilingual. I re-tested four participants with dyslexia and one control participant that took part in the first stop-signal experiment. This resulted in 28 participants with dyslexia and 37 controls included in the dyslexia assessment analysis.

The majority of the participants with dyslexia I recruited suffered from both reading and phonology segmentation and retention difficulties. Participants were categorised as having dyslexia if:

- they had a formal dyslexia assessment,
- they had no history of psychological and/or neurological problems,
- they scored at least 2 SDs below the control mean on at least two dyslexia measures (e.g. word/non-word reading, phonological processing subtests, reading measures; for details of tests see below).
- They were not worse than controls (within 2 SD) on both the non-verbal IQ (Wechsler Adult Intelligence Scale-Fourth edition; Wechsler, 2008) and Visual spatial working memory (Corsi-block test).

Based on the inclusion criteria, four participants formerly diagnosed as having dyslexia were excluded from the analyses. Three were excluded for scores similar to the control group on the language subtests and one was excluded for poor performance on both of the non-verbal tests.

Criteria were also applied to control participants. Participants were accepted as controls if:

- they had no history of psychological and/or neurological problems
- They had non-verbal IQ and Visual spatial working memory scores within 2 SD of the control mean.
- They had no more than one score further than 2 SD from the control mean on the dyslexia measures.

Following the inclusion criteria for the control participants, I excluded two controls for having low scores on more than one language subtest. This resulted in 25 participants with dyslexia (mean age 22.6, SD = 6.8 7 male) and 35 control (mean age 19.6, SD = 1.3, 5 male) participants being included in the analyses.

Participants completed the experiment individually in a quiet testing room at the University of Birmingham over two sessions carried out on two different days, no more than seven days apart. In session one, they were assessed on the following dyslexia tests in order: Grey Silent Reading Test, the Comprehensive Test of Phonological Processing, the Test of Word Reading Efficiency, the Irregular Word Reading Efficiency test and the part one of the experimental tasks. In session two, participants completed the Perceptual Reasoning Index Scale and The Processing Speed Index Scale from the Wechsler Adult Intelligent Scale (WAIS-IV; Wechsler, 2008), the Corsi-block tapping test and the second part of the experimental task. Participants performed the experimental tasks in counterbalanced order.

4.3.2.1.1 Dyslexia defining characteristics assessment tasks.

4.3.2.1.1.1 General cognitive ability.

Non-verbal IQ - WAIS-IV. Non-verbal IQ was measured with both The Perceptual Reasoning Index Scale and The Processing Speed Index Scale. Administration and scoring were done according to the standardised instructions.

Non-verbal working memory - Corsi-block tapping test. Here, as in Chapter 2, a computerised version of the Corsi-block tapping test was used to measure visual-spatial working memory. Memory span was used in analyses (for the specific calculation of memory span see sub-section *2.3.1.1.2*).

4.3.2.1.1.2 Literacy.

Reading comprehension. I administered the Gray-silent reading test to measure reading comprehension(Wiederholt & Blalock, 2000). Raw scores were used for group comparisons.

Phonological processing (CTOPP;Wagner et al., 1999). These tests have been described in sub-section *2.3.1.1.2* of Chapter 2. Raw scores were used for analyses.

Single word and non-word reading. Word and non-word reading were assessed with TOWRE-2 test (Torgesen et al., 1999) and irregular word reading was assessed with TIWRE (Reynolds & Kamphaus, 2007). Scores in both tests were based on the number of words pronounced correctly. For a more detailed description see sub-section *2.3.1.1.2*.

4.3.2.1.2 Group comparison.

Table 4-4 provides an overview of the participants' demographic data and their performance comparison on the assessment's subtests.

Table 4-4 Mean (SD) age and scores on standardised tests of literacy and general cognitive abilities in both dyslexia and control groups.

		AwD				CONTROLS				COMPARISON	
		Min.	**Max.**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Test significance**	**Value**
Gender	Male:female			7:18				5:30		$\chi 2$= 1.7	.190
Age	Years	18	48	22.6	6.8	18	24	19.6	1.3	F= 6.3	.015
Non-verbal tasks											
WAIS Non-verbal IQ	Scaled score	85	130	105.3	10.1	84.5	121	104.2	8.3	F= .22	.638
Spatial memory (corsi-blocks)	N correct	4	7.5	5.5	0.8	4.5	7,5	5.5	0.8	F= .09	.762
Reading											
Reading Comprehension	Time (sec.)	300	2160	1006	414	385	1380	926	252	F=.87	.353
Reading Comprehension	N correct	35	62	52.8	6.8	40	63	57.4	6.0	F= 7.62	.008
Towre word reading	N correct	47	108	79.3	12.7	82	108	96.5	6.4	F= 47.8	$\leq$ .001
Towre nonword reading	N correct	13	60	44.0	13.0	43	66	60.2	5.3	F= 45.4	$\leq$ .001
Tiwre word reading	N correct	38	50	45.2	3.3	46	50	48.2	1.4	F= 23.7	$\leq$ .001
Phonological STM											
Memory for digits	N correct	11	21	15	2.3	12	21	16.9	2.1	F= 11.45	$\leq$ .001
Non-word repetition	N correct	7	16	11.5	2.3	10	17	14.6	1.6	F= 39.5	$\leq$ .001
Phonological awareness											
Elision	N correct	7	20	16.4	3.1	16	20	18.3	.9	F= 12.7	$\leq$ .001
Phoneme reversal	N correct	2	15	8.6	3.4	6	18	11.6	2.9	F= 12.52	$\leq$ .001

Naming speed											
Rapid Letter Naming	Time (sec.)	23	73	32	9.8	17	36	24.1	3.7	F= 18.7	≤ .001

The two participant groups differed significantly in age, with AwD being, on average, slightly older. The difference mainly stemmed from two participants who were much older than the others. Note that these two participants with dyslexia were not the same as those in Chapter 2 where I also reported two slightly older AwD. However, similarly as in the previous chapter since the participants with dyslexia were matched with controls in terms of educational level and IQ, the two participants were kept in the analysis. As expected, the group with dyslexia did not differ from the control group in terms of gender, non-verbal IQ (WAIS-IV), and non-verbal spatial memory (Corsi-block test). The two groups did differ in their text reading comprehension scores. Even though, this is not in line with what I found in the dyslexia sample from experiment one, it is in line with dyslexia reading deficit. As expected, participants with dyslexia showed severe impairments in the word and non-word reading, naming speed, verbal short-term memory and sub-lexical phonology measures compared to the control group. This pattern of impairments is in line with what has been reported in the literature and also with the formal diagnosis of developmental dyslexia.

4.3.2.2 Experimental Task.

4.3.2.2.1 Apparatus and stimuli.

For this experiment, I used an adapted version of the STOP-IT2 MATLAB program (Verbruggen, 2014). The task was presented on 21-inch monitor. The experiment consisted of two tasks with three conditions each. Conditions 1-3 were *Stop-signal tasks.* Participants had to respond as quickly as possible to a stimulus with right- or left-hand responses. On 25% of trials, a stop signal is presented, and participants were instructed to withhold their response. Conditions 3-6 were *Double –response tasks,* like the stop signal task, a stimulus was presented for left and right-hand responses. A signal was also presented on 25% of trials. In the double-response task participants were instructed to proceed with the primary response and then press an additional key to indicate that a signal had been presented. The double-task requires participants to monitor for a second signal, just like in the stop signal task, but no response suppression is required. Both tasks were presented in blocks devoted to three modalities: visual only, auditory only and mixed.

The *go*-stimuli for the visual only and mixed modalities were a circle and a square and participants were required to respond by pressing left and right arrows respectively on an Apple Keyboard (Model No:A1048). The *stop* signal for the visual only modality was the same figure (either circle or square), but in blue colour, and for the mixed modality it was an auditory signal (750Hz). In the auditory only modality, the *go* stimuli were high tones (2000Hz) and the other half were low (250Hz) tones. Participants were required to respond with the left arrow to the high tones and with the right arrow to the low tones. The *stop* signal was a mid-tone auditory signal (750Hz). The frequencies for the auditory condition were taken from previous studies. For the *double-response task* the *go* and *stop* stimuli were identical to the *stop signal task.* Instead of withholding a response when a *stop-signal* was presented, participants were asked to press the down arrow key after responding to the *go* stimulus.

4.3.2.2.2 Procedure.

Testing was conducted in a quiet laboratory at the University of Birmingham with a researcher present at all times. The experiment consisted of two parts of 90 minutes each. In each testing session, participants completed either the linguistic test from the dyslexia assessment battery and one of the experimental tasks, or the non-linguistic tests and the other experimental task. The order of the experimental tasks and the conditions within the tasks were counterbalanced.

Each experimental condition started with written instructions, followed by oral instructions explained by the experimenter. The main emphasis of the instructions was that participants should respond as fast and as accurately as possible and not to wait for the stop signal. After the instructions, before each condition participants did a practice block of 32 trials, with immediate feedback at the end of each trial. The experimental session consisted of three conditions (auditory, visual and mixed). Each condition had three blocks with 96 trials. In 25% of the trials, a stop signal was presented shortly after the stimulus onset (cf. Verbruggen et al., 2008). At the end of each block participants had 12 seconds rest.

All trials started with the presentation of fixation cross. After 250ms the stimulus was presented, which stayed on the screen for 1250ms or until respond was executed. The inter-stimulus interval was 500ms. Once the response was made, or after the maximum time elapsed, the next trial began. On 1/4 of the trials, a stop signal was presented after a variable stop signal delay (SSD). The initial stop signal delay was set to 250ms and increased by 50ms if participants were able to successfully inhibit their response or decreased by 50ms if participants were unable to stop, using a *staircase method* (Logan, Schachar, & Tannock, 1997). In the double-signal task, all of the parameters were the same as in the stop signal task, apart for the tracking procedure for the stop signal. Here, I stimulated a range of SSDs similar to the Stop-signal task. The SOA decreased by 50ms when the latency of the first response (go1 RT) on the double-response trial was shorter than SOA + 250ms (the length of the first SSD in SST), similar to the responded signal in SST. The SOA increased with 50ms when the latency of the go1 RT was longer than SOA+ 250ms, similar to when stop signal is successfully inhibited (for details see Verbruggen & Logan, 2009).

4.3.2.2.3 Exclusion criteria

4.3.2.2.3.1 Violation of assumptions.

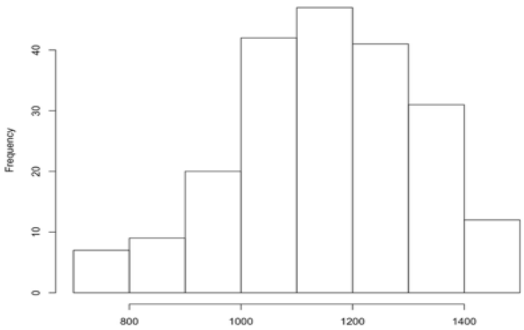
As in Experiment 1, I excluded participants when their performance violated the independence assumptions of the *Horse-race* model (RTs in the stop signal failure trials, were slower than the *go*-RTs (Matzke et al., 2018). Three control participants violated this assumption in one of the three conditions. Their data in the specific condition was removed (one in the auditory and two in the mixed condition). One participant with dyslexia was excluded from the visual condition due to inaccurate key-presses.

4.3.2.2.3.2 Evidence of strategies.

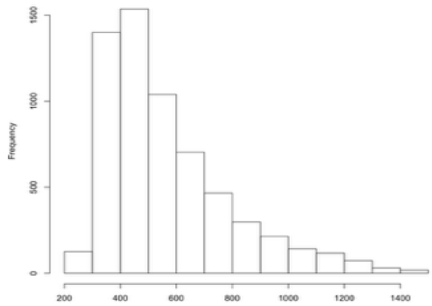
I excluded the participants identified as strategy users. The procedure for exclusion was identical to the one used in Experiment 1. Participants were removed if the *p(*respond|signal) (*presp*) measure is 40 % or less. Applying this criterion, I excluded two participants from the visual condition (one from each group), one participant with dyslexia from the auditory condition and three participants from the mixed condition (two controls and one participant with dyslexia).

I also excluded data from four participants with dyslexia (three in the auditory and one in the mixed condition) with an SSRT estimate that was negative or less than 50ms (Congdon et al., 2012; Schachar, Mota, Logan, Tannock, & Klim, 2000). Even though short SSRTs could be an indication of good response inhibition, very short SSRTs could also be a sign that the task was not performed according to instructions (prioritize the *go* task and do not wait for the stop-signal). In cases where mean stop signal delay (SSD) and go-RT had large and similar magnitudes it is possible that participants were strategically waiting for the stop signal. This strategy will not always be captured by the *presp* measure, but it will inevitability influence the SSRTs. In the second experiment I have several participants with SSRTs less than a 100ms. I did not observe such short SSRTs in Experiment 1. To minimise the possibility of strategies contaminating the results I removed participants with very short SSRT (less than 100) who also had SSDs and go-RT more than 2 SD longer than from the group mean. This criterion selects only the participants with unusually slow performance, an indication that task instructions were violated. I excluded the data from three participants (two with dyslexia and one control) in the mixed condition based on this criterion. See Figure 4-8 for the outliers distributions.

a)



Control outlier 1



Control group go-RT

b)

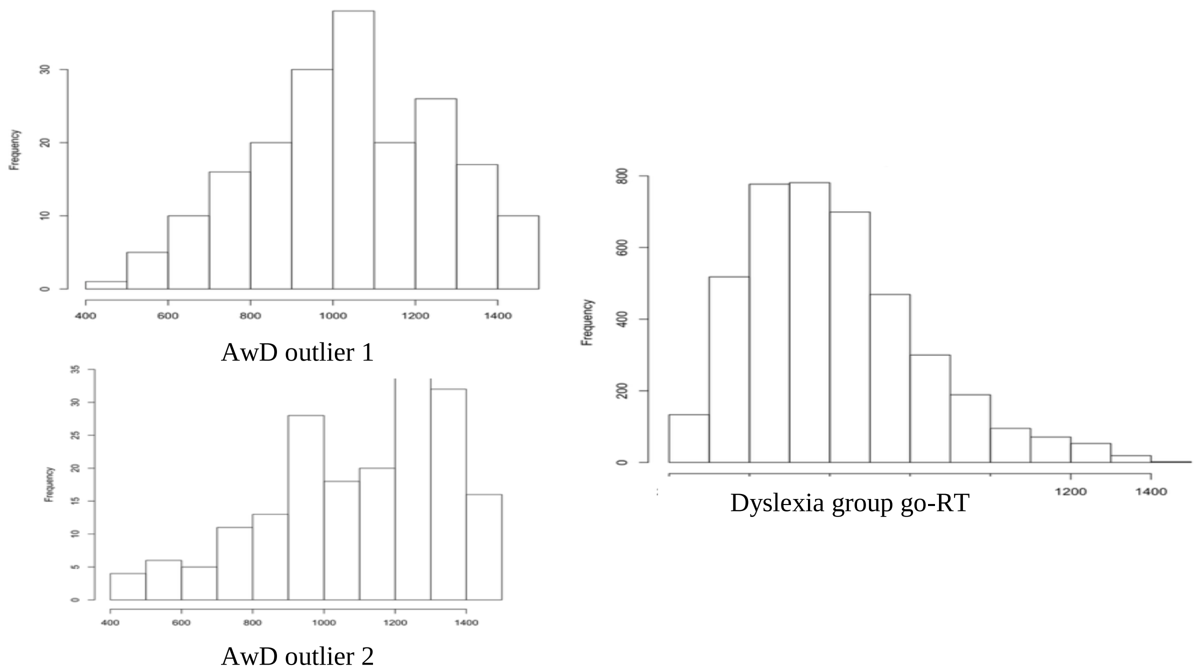


Figure 4-8 a) go-RT distribution of the control outlier compared to the distribution for the rest of the control group. The RT distribution for the outlier is shifted to the right with considerably more slow RTs than the fast RTs. b) go-RT distribution of 1st and 2nd AwD outliers compared to the rest of the dyslexia group. Leotti and Wager,(2010) argues that these types of SST distributions are a clear indicator of strategies in the stop signal task.

In addition, the visual condition of AwD outlier 2 is close to the margin of the strategy criterion. The same participant had two conditions removed based on the strategy criterion. Even though the visual condition does not technically meet the criterion, the overall pattern indicates the use of strategies across the experiment. I removed this participant altogether.

After the exclusion criteria, the final analysis included data from thirty –four controls and twenty-two AwD in the visual condition; thirty –three controls and twenty AwD in the auditory condition and thirty controls and twenty-one AwD in the mixed condition. For data overview see Table 4-5.

Table 4-5 Overview of the number of subjects after exclusion criteria; probability of responding on a valid –signal trials[p(respond)], average of the stop-signal delay(SSD) and stop-signal RT(SSRT) in the second Stop-signal experiment.

Group	N	*p*(respond|signal)		SSD		SSRT	
		M	SD	M	SD	M	SD
Controls							
Visual	34	.50	.03	369	188	199	23
Auditory	33	.49	.03	436	183	148	35
Mixed	30	.49	.02	391	185	161	55
AwD							
Visual	22	.49	.03	448	188	208	28
Auditory	20	.48	.03	553	210	160	40
Mixed	21	.49	.03	388	141	206	83

4.3.2.3 Data analysis.

Here, as in the first experiment I derived Stop-signal RTs in all three conditions using the *integration method* (Verbruggen et al., 2013) which gives an unbiased estimate (Band et al., 2003; Verbruggen et al., 2013). The integration method assumes that the finishing time of the stop process corresponds to the number of RTs in the response time distribution (nthRT) multiplied by the overall *p*(respond|signal) (Logan, 1981).

All measures were analysed with mixed effect models employing the lmer function of the lme4 package (Bates et al., 2013) using R version 3.5.1 (R Development Core Team, 2009). For accuracy I used logistic regression. Step-wise reduction was applied to determine the significance of interactions and the main effects, using Chi-square comparisons (Bates et al., 2013).

Response times and SSRT were analysed with linear mixed effect models. To obtain p-values and degrees of freedom, the “Satterthwaite” approximation was used with the lmerTest package (Kuznetsova et al., 2016). The procedure for reducing the fixed effect and random effect structures was the same as in the previous chapters (see Chapter 2 for more details).

4.3.3 Results

4.3.3.1 Double-response task.

4.3.3.1.1 Accuracy.

Accuracy of the no-signal trials in the double-response task accounted for 3.8% of all go-responses. I started the model fitting analysis with a model with Accuracy as the dependent variable, Group (Control and AwD) and Condition (Visual, Auditory and Mixed) and their interaction as fixed factors. The stepwise reduction of the final Random effect structure led to the random intercept for Subject and random slopes for Condition.

I found no significant Group by Condition interaction ($\chi2$=2.65; df=2; *p*= .262). The main effects of Group ($\chi2$=0.35; df=1; *p* =.555) and Condition were not significant ($\chi2$=4.09; df=2; *p*=.129), with no difference in the accuracy performance for the different groups or in the different conditions.

4.3.3.1.2 Double -signal reaction time (DSRT).

I fitted a full mixed effect model with double-SRT as the Dependent Variable, Group (Control versus AwD) and Condition (Visual, Mixed and Auditory) and their interaction as fixed factors. The random structure included random intercepts for subjects. The data included in the analysis was from the same participants and conditions as in the stop-signal RT analysis.

Table 4-6 shows the dependent variable Response times in the congruent and incongruent conditions for the group with dyslexia and controls.

Table 4-6 Mean and SDs for each of the conditions in the Double-response task.

Response times	*Visual*	*Auditory*	*Mixed*
Control group	605 ms (217)	616 ms (213)	680 ms (261)
AwD group	655 ms (182)	672 ms (214)	743 ms (187)

The Group by Condition interaction was not significant ($\chi2$=0.31; df= 2; *p*= .858). There was no significant main effect of Group ($\chi2$=2.3; df= 1; *p*= .127). The main effect of condition was also not significant ($\chi2$=4.78; df= 2; *p*= .092), showing no difference between the conditions. Results show that AwD did not differ in terms of their double-signal RT (see figure 4-9).

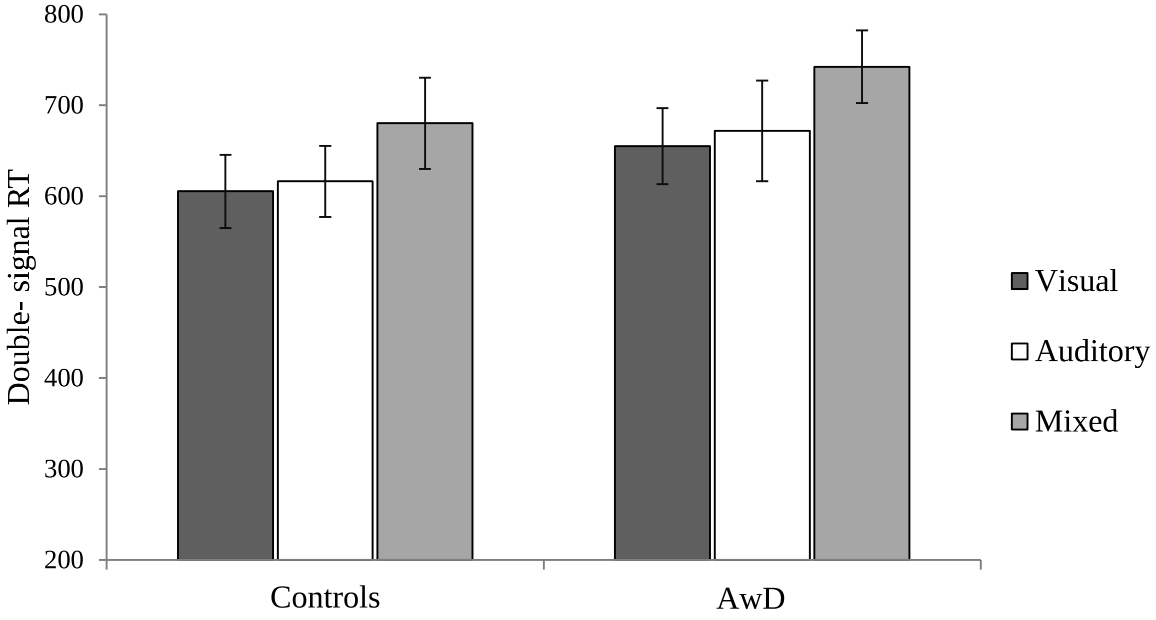


Figure 4-9 Averaged Double-signal RT across conditions, for each of the two groups. Error bars represent standard errors.

4.3.3.1.3 Go-Response times.

Response time outliers in the double-response task accounted for 2.3% of the total responses (N=34,560). The total number of trials after removing the outliers and the incorrect responses was 32,457. I fitted a full model with Response time as the dependent variable, Group (Control and AwD) and Condition (Visual, Auditory and Mixed) and their interaction as fixed factors. The random effect structure of the final model included random intercept for Subject and random slopes for Condition. The Group by Condition interaction was not significant ($\chi2$ =0.22; df= 2; p=.896). The main effect of Group was significant ($\chi2$=12.32; df=1; $p < .001$) with AwD being overall slower compared to controls. The main effect of Condition was also significant ($\chi2$=30.85; df=2; $p < .001$) with visual condition being the slowest and auditory condition being the fastest. Response time results are shown in Figure 4-10.

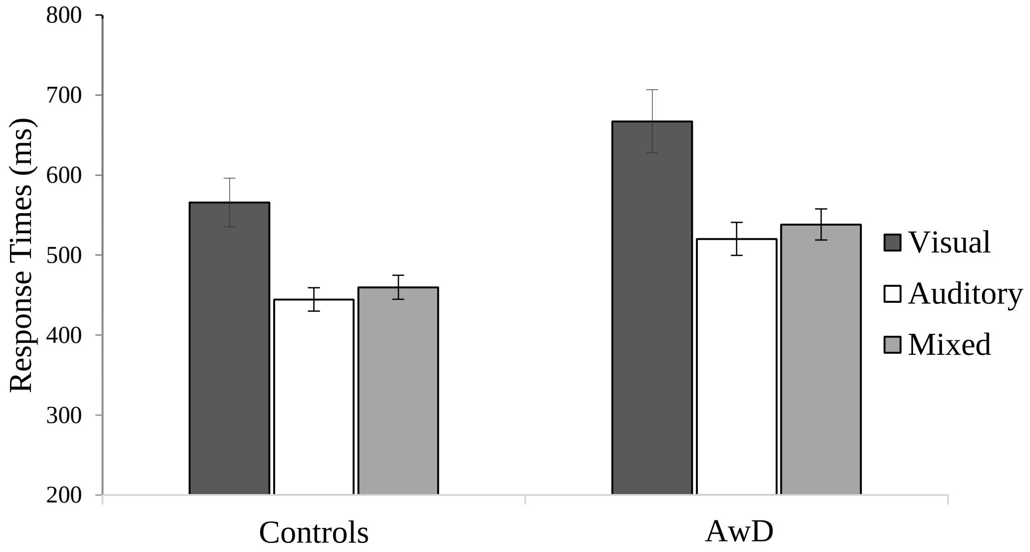


Figure 4-10 Represents the primary go-RTs in the three condition for the two groups, with AwD being overall slower compared to the controls.

In the Double-task, I found no evidence for a group differences in accuracy or in the dual-signal measure, which required the second response. However, I found group effect of *go*-RTs, with AwD responses being overall slower compared to the controls. Therefore, in the next analysis dual tasking could explain only the potential group effects.

4.3.3.2 Stop-signal task.

4.3.3.2.1 Accuracy.

Errors on the go trials of the Stop-signal task accounted for 4.1% of all responses. The initial model included Accuracy as the dependent variable, Group (Control and AwD) and Condition (Visual, Auditory and Mixed) and their interaction as fixed factors. Step-wise reduction for the Random effect structure (see sub-section *2.3.3* in Chapter 2) led to random intercepts for Participants and random slopes for Condition.

The accuracy results are shown in Figure 4-11. I found significant Group by Condition interaction ($\chi2$=12.65; df=2; *p*= .002). I also found a main effect of Group ($\chi2$=5.38; df=1; *p* =.020), with the AwD being less accurate compared to controls. The main effect of Condition was not significant ($\chi2$=3.42; df=2; *p*=.180). Post-hoc tests showed that the two groups did not differ in accuracy in the visual condition ($\chi2$=0.135; df= 1; *p*=.713). There was a trend for a group difference in the auditory condition ($\chi2$=2.94; df= 1; *p*=.086) and in the mixed condition both groups were significantly different ($\chi2$=10.23; df= 1; *p*=.001), with AwD being less accurate than the controls.

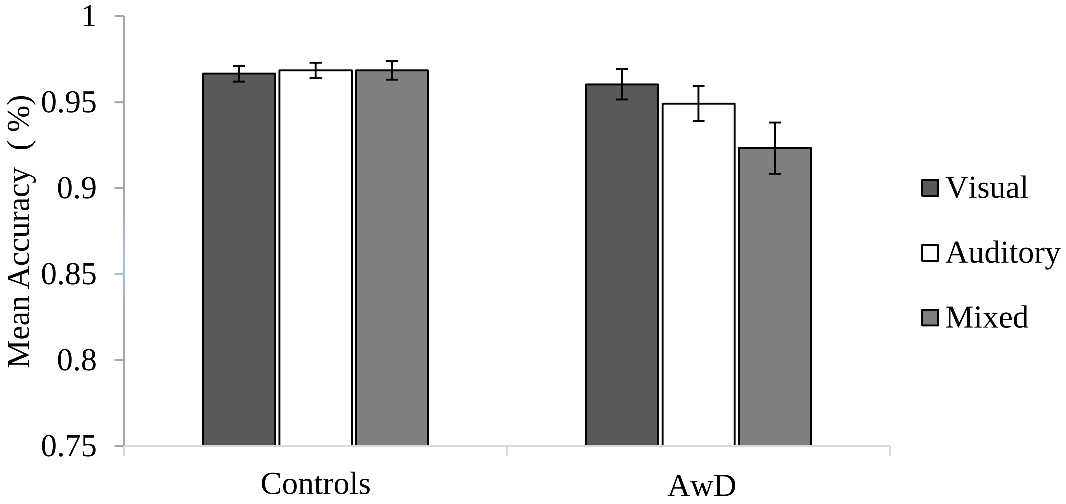


Figure 4-11 Mean accuracy performance by condition for each group. Error bars represent standard errors.

The accuracy performance in the *go-rt* is formed by errors during response selection (pressing left arrow for “square” instead of pressing right arrow) and omission errors (not executing a response on a go trial). In order to suppress successfully the response in the signal condition AwD could improve their performance by waiting for the stop signal, and, as a result, make more omission errors on go-trials. In order to see if individuals with dyslexia were making more omission errors compared to the controls, I performed additional analysis.

I fitted a model with Omission errors as the dependent variable, Group (Control and AwD) and Condition (Visual, Auditory and Mixed) and their interaction as fixed factors. The best random structure included random intercepts for Participants.

I found a significant Group by Condition interaction ($\chi2$=9.23; df=2; *p*= .009) and a significant main effect of Condition ($\chi2$=12.78; df=2; *p*=.002), with the auditory condition producing the most omission errors, followed by mixed and visual conditions. There was no effect of Group ($\chi2$=0.01;df=1; *p* =.909). Post-hoc tests showed that the two groups did not differ in the number of omission errors in either the visual ($\chi2$=0.967; df= 1;*p*=.323) or auditory ($\chi2$=1.64; df= 1;*p*=.200) conditions. In the mixed condition there was a trend toward a group difference ($\chi2$=3.09; df= 1;*p*=.078), with AwD producing *fewer* omission errors compared to the controls. The significant interaction was driven by the reversal in the mixed condition, where controls made more omission errors compared to the participants with dyslexia. The proportion of omission errors are displayed in Figure 4-12. Across conditions, there was no indication that participants with dyslexia made more omission errors than controls. AwD were less accurate than controls mainly in the mixed condition and to lesser extend in the auditory condition, but not because they made more omission errors.

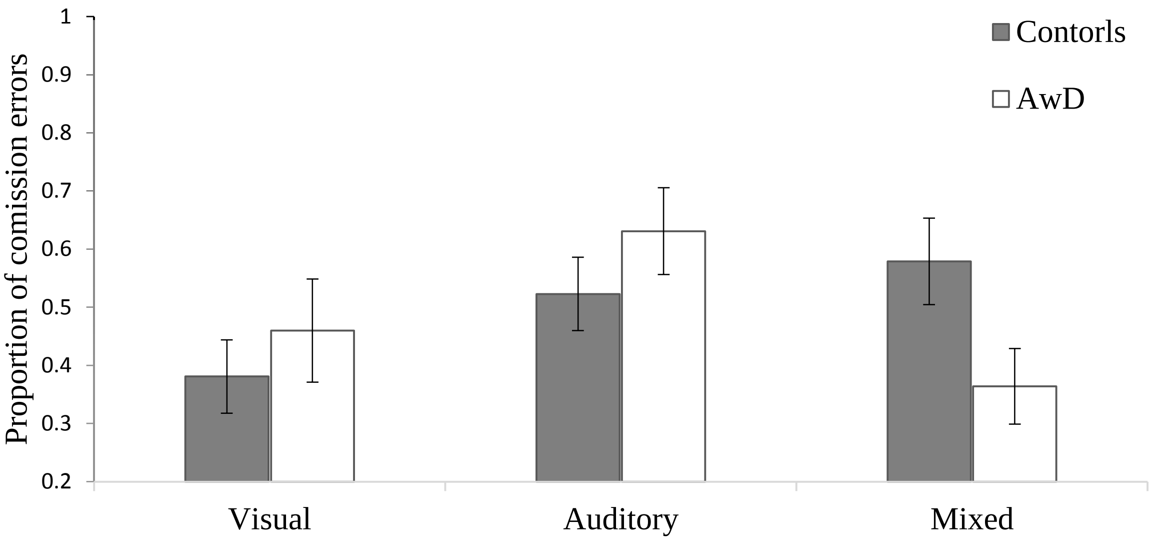


Figure 4-12 Proportion of missing responses for each condition in both groups. The opposite pattern of proportion of missing errors in the mixed condition is driving the interaction.

4.3.3.2.2 Stop-signal response times (SSRT).

I fitted a mixed effect model with SSRT as the Dependent Variable, Group (Control versus AwD) and Condition (visual, mixed and auditory) and their interactions as fixed factors. The random structure included random intercepts for participants.

The SSRT results are shown in Figure 4-13. I found a significant main effect of Group (χ2=6.91; df= 1; *p*= .009) with SSRT longer in the dyslexia group compared to the control group irrespective of the conditions. The main effect of condition was also significant (χ2=31.27; df= 2; *p*<.001) with visual conditions having the longest SSRT and auditory having the shortest SSRT. Interestingly, I found a trend toward a Group by Condition interaction (χ2=4.92; df= 2; *p*= .085). Post-hoc tests showed that the two groups did not differ in their SSRT measure in the visual (χ2=1.78; df= 1; *p*=.187) and in the auditory (χ2=1.22; df= 1;*p*=.274) conditions. The only significant group difference was in the mixed condition

($\chi 2=5.48$; df= 1;$p=.023$), with AwD having longer SSRTs compared to the controls. This finding is also in line with the results from the first experiment, where significant group differences for SSRT were also present.

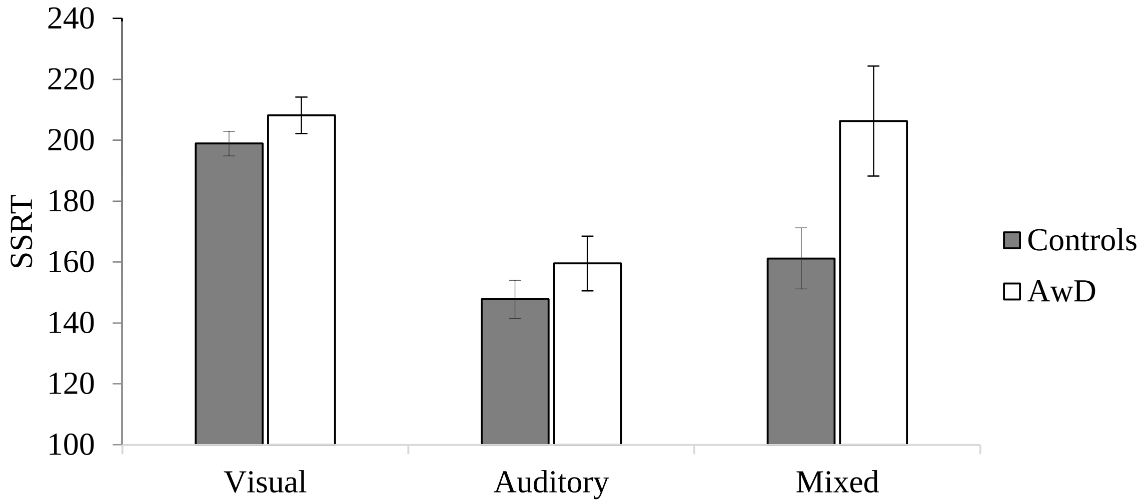


Figure 4-13 Averaged Stop signal RT across conditions, for each of the two groups. Error bars represent standard errors.

4.3.3.2.3 Go-Response times.

Response time outliers in the go responses of the Stop signal task accounted for 1.8% of total responses (N=35,640). The total number of trials after removing the outliers and the incorrect responses was 33,476. I fitted a model with go response time as the dependent variable, Group (Control and AwD) and Condition (visual, auditory and mixed) and their interactions as fixed factors. The random effect structure of the final model included random intercepts for Participants and random slopes for Condition.

There was a significant Group by Condition interaction (χ^2 =6.43; df= 2; *p*=.040). The main effect of Group was not significant (χ2=2.64; df=1; *p*=.104). The main effect of Condition was significant (χ2=12.87; df=2; *p*=.002), with the auditory condition showing the slowest RTs. Response time results are shown in Figure 4-14.

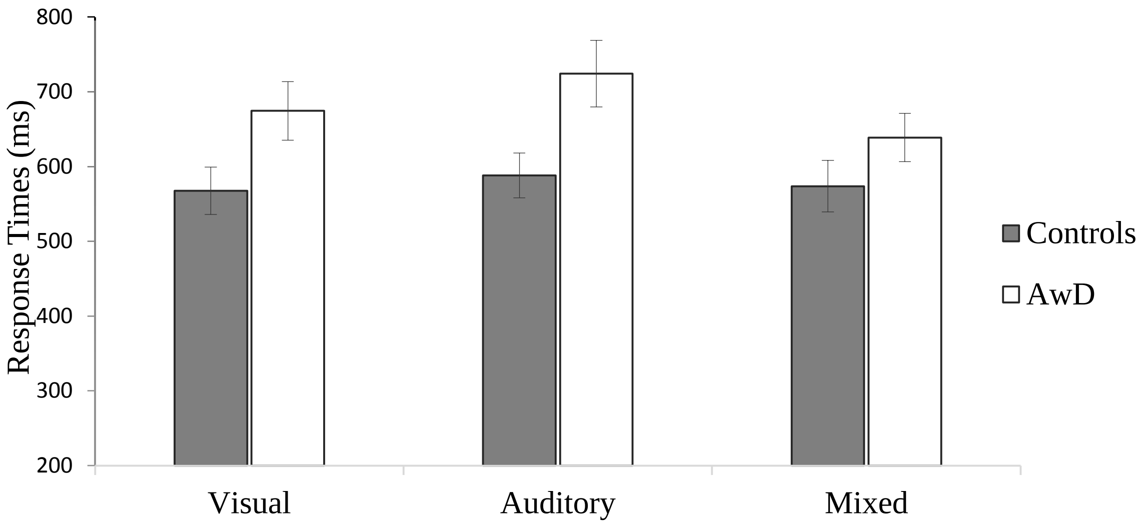


Figure 4-14 Go-RTs in both auditory and visual conditions are showing significant group difference. RTs from the mixed condition are not different between the two groups. Error bars represent standard errors.

To explore the significant interaction, I performed three post-hoc tests, with go RTs as dependent variable and Group as a factor. I included random intercepts for Participants. The analyses showed that the two groups were significantly different in their response times in the auditory condition (χ2=6.97; df= 1; *p*=.008), with individuals with dyslexia being slower when responding to the go-trials compared to controls. There was only a trend toward a group difference in the visual condition (χ2=3.59; df= 1;*p*=.057), and there was no significant group difference in the mixed condition ($\chi2$=1.15; df= 1; *p*=.283). These results suggest for particularly poor dyslexia performance in the auditory condition and for some weak evidence for a difference in the visual condition.

In addition, I conducted a within subject analysis for all three conditions with go-RT and stop-RT latencies as within subject factors, to confirm that data does not violates the assumptions of the Independent Race-model (if response latencies in the stop signal are significantly slower than response latencies in go trials). To check that I fitted a linear model with RTs as dependent variable, Signal (signal and no-signal trials) and Condition (visual, auditory and mixed) and their interaction as fixed factors. The Signal and Condition interaction was significant ($\chi2$=17.9; df= 1;*p*<.001).The main effect of Signal was significant ($\chi2$=15782; df= 1;*p*<.001), with response times in Stop-signal RT being faster than the Go-rt trials. This means that the data does not violates the assumptions, meaning that SSRT was a reliable measure of response inhibition in all three-stop signal conditions (Verbruggen, Chambers & Logan, 2013).

4.3.3.3 Correlations between task performance and the language assessments

4.3.3.3.1 Principal component analysis.

Here, as in experiment one I wanted to correlate the estimate dyslexia severity with the response suppression. I found in the previous stop signal experiment relation between lexical skills and SSRT in the control participants, so it will be interesting to see if the pattern remains the same in the followed-up study. To do so, I ran three Principle component factor analyses similar to Chapter 2 for the dyslexia and the control group separately. I grouped participants' measures for sight word and irregular word reading scores, rapid letter naming and the Gray silent reading test scores in a factor named "Lexical skills". For the second PCA analysis, I entered non-word repetition and memory for digits subtests used to measure

Phonological short-term memory, so I named the second factor “Phonological STM”. With the third PCA analysis, I extracted factor “Phonological manipulation” measured with Elision, Phoneme reversal and non-word reading. I used principal component extraction and one factor for each of the analysis. In the dyslexia group the “Lexical skills” factor accounted for 45% of the variance with loadings from sight word reading =-.81, irregular word reading=.25, rapid letter naming=.93 and Grey silent reading test=.46. For the control group “Lexical skills” accounted for 45% of the variance, with loadings from sight word reading =.81, irregular word reading=.75, rapid letter naming=-.73 and Grey silent reading test=.26.

For the factor “Phonological STM” loadings memory for digits=.80 and non-word repetition=.80 accounted for 63% of the variance in the dyslexia group. In the control group the variance was 76% with loadings memory for digits=.87 and non-word repetition=.87. Finally, the third factor “Phonological manipulation” accounted for 67% of the variance in the dyslexia group with factor loading of phoneme-reversal=.72, elision=.86 and non-word reading=.86. For the control group the variance was 47% with factor loading of phoneme-reversal=.86, elision=.35 and non-word reading=.75. I used the factor loadings derived via Barlett method and correlated the results with the experimental measures showing suppression deficit, cognitive load deficit and general cognitive abilities.

4.3.3.3.2 Correlations between the Principle component factors and experimental measures.

In experiment 1, I found that the Stop-signal deficits in individuals with dyslexia were not related to their lexical and sub-lexical skills, but in the controls, SSRT was related to the lexical skills. Here, I want to see if I can replicate this finding. I correlated all measures where group differences were found with the factors of the PCA. Refer to Table 4-7, for the significant relationships.

Table 4-7 Correlations in the AwD group, controls and the whole groups for the lexical skills factor and the mixed SSRT and double-task mean RTs.

		Lexical Skills	
		r	*p*
Control group			
	Mixed SSRT	**-.31**	*.096*
	Double-task MRT	**.37**	*.029*
AwD group			
	Mixed SSRT|	**-.22**	*.346*
	Double-task MRT	**.37**	*.074*
Whole group			
	Mixed SSRT	**-.26**	*.064*
	Double-task MRT	**.35**	*.007***

It is important to note that the Phonological STM and Phonological manipulation factors from the PCA are not included in Table 4-7 because they were not significant. This lack of relationship shows a nice replication of the pattern reported in the previous analyses, with a second and independent participant sample. There was a trend for correlation in the dyslexia group between the RTs in the Double–response task and the factor Lexical skills. For the controls, the same correlation reached significance. However, when examined in detail in Figure 4-15 it was evident that the relationship in both groups was mainly driven by two outliers, one in each group.

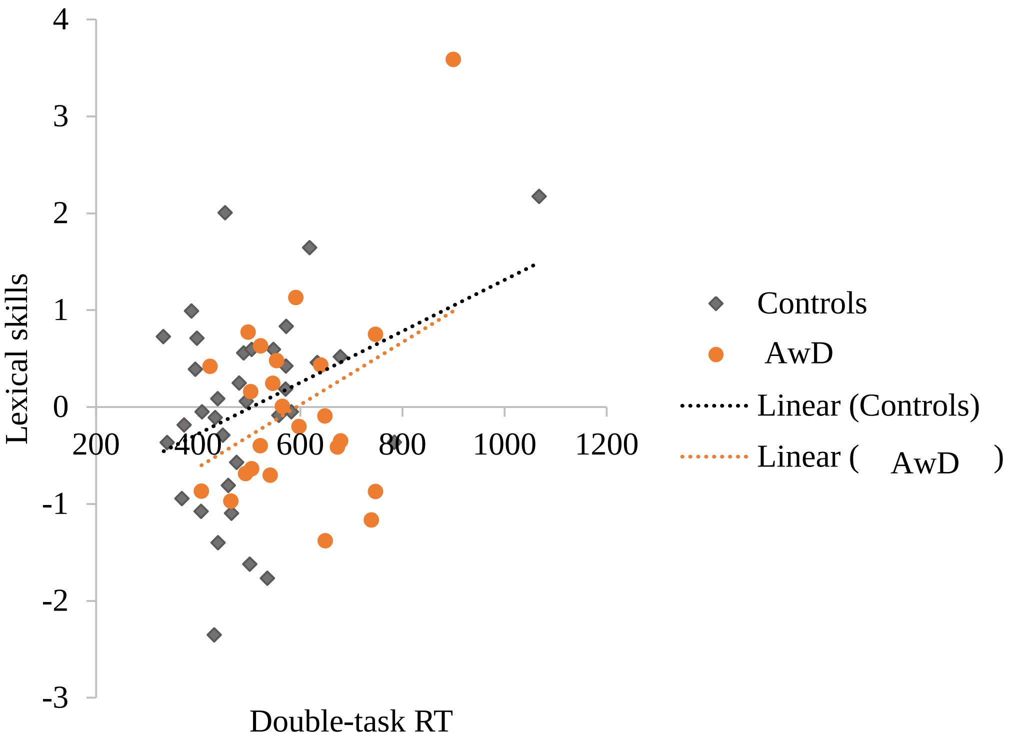


Figure 4-15 The go- RT in the Double-task is correlated with Lexical skills for both groups.

Once the outliers were removed the correlation was not significant in both the controls (r=.16;*p*=.376) and AwD (-.10;*p*=.684). See Figure 4-16 more details.

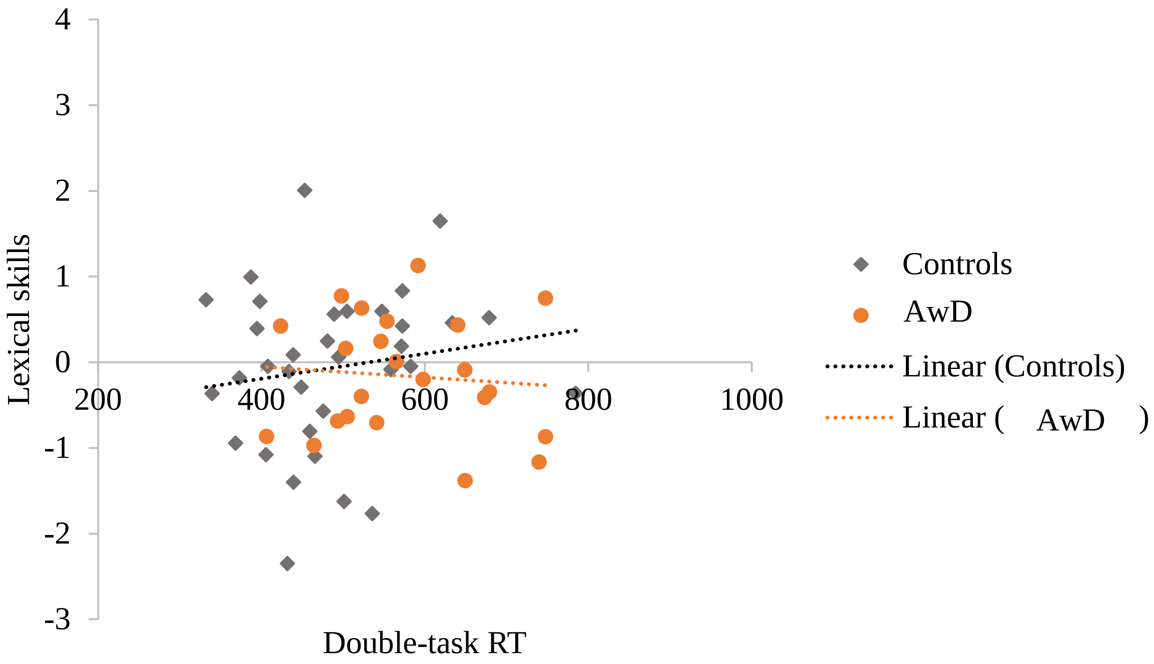


Figure 4-16 The correlation between the go-RT and SSRT is no longer significant once the outliers were removed.

For the control group I found a possible indication for a relationship between the SSRT in the mixed condition and the factor Lexical skills. Even though not significant, the direction of the relationship is in line with, the experiment 1 results. The lack of significant relationship in the second experiment could be as a result of power issues or/and noisier data. In order to investigate the relationship between the SSRT and lexical skills in a wider population of participants I combined the data from experiment one and two in both the dyslexia and control groups. The results are displayed in Table 4-8.

Table 4-8 Correlations for the lexical skills factor and the mixed SSRT for the controls and AwD in both experiments.

		Lexical Skills	
		r	p
Control group			
	Mixed SSRT	-.39	.002**
AwD group			
	Mixed SSRT|	-.04	.793

I found a moderate relationship between the response inhibition in SST and the lexical skills only for the control group (see Figure 4-17). The result confirms my initial hypothesis that there are some general mechanisms operating in the lexicon. However, these mechanisms are not evident in the dyslexia group.

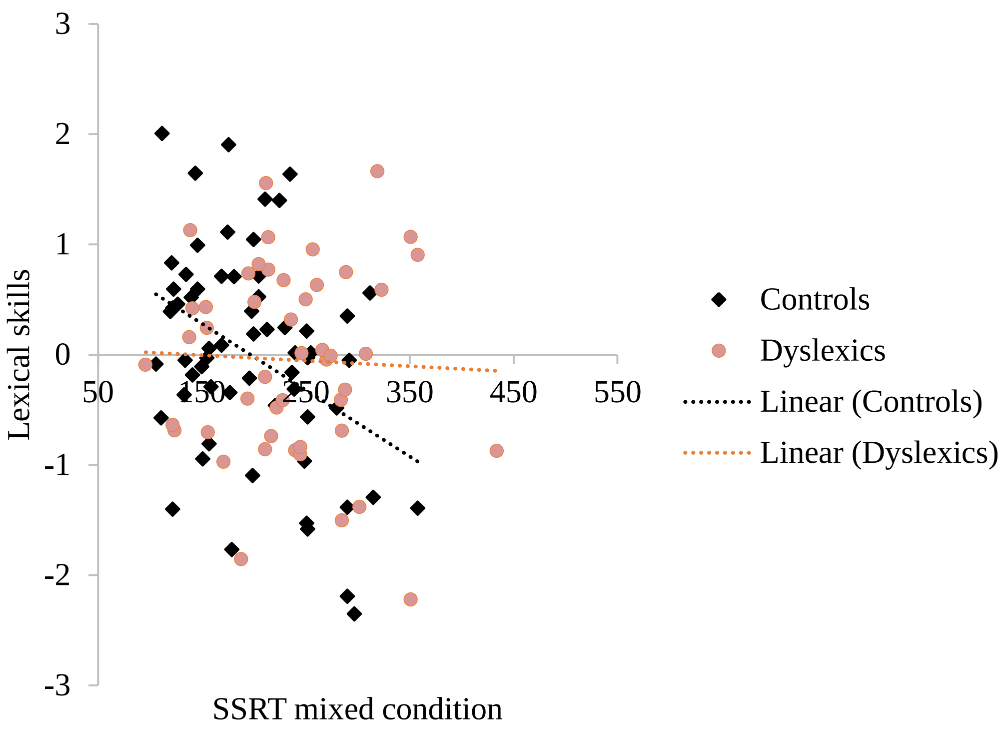


Figure 4-17 Lexical skills factor was correlated with the SSRT only for the control group, in both of the Stop-signal experiments.

4.4 General Discussion

The goal of the second experiment was to explore if AwD response suppression deficit found in the first Stop-signal experiment is due to the domain-general suppression mechanisms, auditory processing, cross-modal integration or to more general processing deficits. Thus, I used a modified version of the Stop-signal task, in order to address the open questions left unanswered from the first experiment. In the second Stop-signal task, I looked at suppression and dual-task processing mechanisms not only in mixed modality but also in uni-modal auditory and visual conditions. I found group differences in the response suppression irrespective of the modalities, with AwD having poorer response suppression in comparison to controls. However, I also found group difference in the go- RTs in the double task, which implies that the general suppression mechanism could be also due to dual-task processing difficulties rather than a general suppression deficit in individuals with dyslexia.

I also found group differences mainly in the auditory and mixed conditions of the Stop-signal task that could not be accounted for by the dual-task processing. When the results from each condition was individually analysed, it was discovered that the visual condition was the least affected in participants with dyslexia, showing only weak evidence for a go-RT group difference. In contrast, in auditory and mixed conditions AwD consistently reported poor performance. The mixed SSRT showed the biggest group difference, with AwD showing poor response inhibition performance. However, I also found evidences of AwD experiencing slower go-RT and less accuracy in the auditory condition. Based on these findings I can argue that the poorer performance of the participants with dyslexia in SST was a result of dyslexia deficits in the auditory system that also affected the cross-modal communication resulting in poor suppression. Similarly, to Experiment 1, there was not any evident relationship between dyslexia suppression deficits and any of the lexical or sub-lexical factors, which confirms the previous observation that different mechanisms are involved in response suppression and dyslexia language deficits. In the remaining of this section, I compare the present findings to those already reported in the literature.

The results of the second experiment were in line with those form first experiment, which affirms once more that the response suppression deficits are evident in highly functioning AwD. The current findings about the group effect of SSRT are supported by the observations in the literature that reports on response inhibition deficit in children with dyslexia (De Jong et al., 2009; Purvis & Tannock, 2000; Van der Schoot & de Sergeant, 2000; Van der Schoot et al., 2002; Willcutt et al., 2005). Nevertheless, the findings of the present study also differ from those in the literature. In particular, I argue that the suppression deficits in individuals with dyslexia are not general as reported in the literature (e.g., De Jong et al., 2009) but specific to cross-modal situations where auditory signal need to be suppressed, potentially due to a specific deficit with auditory processing. The lack of suppression deficit in the visual condition is in agreement with Roe et al. (2018) study, where authors found that children who struggled with fluency and reading comprehension experienced no response suppression deficits in a visual Stop-signal task. Thus, my work further extends the Roe et al. (2018) findings to AwD.

Another key finding of the second experiment relates to the question of whether AwD's SSRT deficits are result of the limited cognitive load. The main effect of group in the go-RTs, with slower RTs for the AwD, in the double-task suggested that participants with dyslexia experienced difficulties with more demanding cognitive load and these deficits could explain the group effect in SSRT. Nevertheless, the lack of group difference in the Double-task conditions advocates that AwD cross-modal SSRT deficits and the poor performance in the auditory condition were not due to the increased cognitive load.

One of the open research questions I addressed in the second experiment relates to whether the suppression deficits observed in first experiment could be explained with deficits in the processing of the auditory signal. The current results confirmed that hypothesis. Despite the fact that individuals with dyslexia showed good ability to learn discriminating the low and high frequency tones, their performance was poorer than those of the controls, in the primary go-RT task. Specifically, I found that participants with dyslexia had slower RTs and were less accurate in the auditory conditions of the Stop-signal tasks, which suggests that AwD needed more time to discriminate if the auditory signal was low or high. The strategy use would have been another plausible explanation for such behaviour, but since no correlation was found between the response suppression and go-RT in the auditory condition ($r=-.25$; $p=.284$), this possibility was considered unlikely. These results showed evidences that AwD had slower discrimination of auditory tones presented in close sequences in the sample with dyslexia. This finding in accordance with the observations of previous studies where auditory processing deficits were reported (e.g. Ahissar, Protopapas, Reid, & Merzenich, 2000; Paula Tallal, 1980; Wijnen, Kappers, Vlutters, & Winkel, 2012).

Another dyslexia deficit that could have had an effect on inhibition performance is the existence of wider temporal-window as a result of poor multi-sensory integration (Francisco et al., 2017; Hairston et al., 2005; Kast et al., 2011). Such deficit was expected to manifest itself only in the mixed condition where poor binding of auditory-visual information will result in more time for the processing of the signal and subsequently failing to suppress it. However, such integration difficulty by itself could not explain the dyslexia performance in the auditory condition. Therefore, it is unlikely that multi-modal integration on it is own could explain the suppression deficit in the participants with dyslexia. The more likely explanation is that the auditory deficits in AwD interrupt the cross-modal communication leading to suppression deficits only in the mixed condition.

4.5 Overall Conclusion

Several findings from the present study have important implications for understanding the response suppression in AwD measured with the Stop-signal task. Firstly, I was able to replicate previous stop-signal studies where response inhibition deficits were reported in children with dyslexia. Moreover, by using highly function AwD, I was able to show for the first time that suppression deficits are not linked with developmental delay. Secondly, I wanted to isolate the potential influence of sensory and/or more general processing deficits in individuals with dyslexia on SSRT performance by testing response suppression within the visual and auditory domains. These findings suggest that AwD do not have difficulty suppressing response in general, but only in situations where the cross-modal communication was more difficult due to the auditory processing deficits in the dyslexia sample. Thirdly, I found no relationship between AwD' lexical and sub-lexical deficits and their SSRT deficits, confirming previous hypothesis that suppression deficits are not the primary cause of dyslexia reading difficulties.

CHAPTER 5

Conflict resolution in Flanker task: Assessing the time course of distractor processing in adults with developmental dyslexia.

5.1 Abstract

Previous studies reported conflict resolution deficits in AwD using the Flanker task. The locus of the increased conflict in individuals with dyslexia was previously linked to the increased conflict at the response selection stage or to a deficit with early stimuli processing. In Chapter 3, I found that the dyslexia deficit in flanker task is not due to a domain-general response resolution deficit. Therefore, the question arises if individuals with dyslexia have deficits as a result of poor stimuli processing. To answer this question, I administered and adapted version of the Flanker task called the Mutation paradigm. This paradigm allows detecting the critical time window at which the distractors are processed. In this task, the flankers mutated once per trial, in different times during the initial 100 ms following the onset. The task consisted of three types of trials incongruent (i.e. disruptive) mutated to neutral distractors, neutral that mutated to incongruent distractors and the control condition where neutral distractor mutated to a different neutral distractor. In their previous study, Max and Tsal (2015) found that the first 50ms were critical for the stimuli processing. Contrary to my hypothesis, I found no evidence for different stimuli processing between the two groups. However, I also found no group difference in the classical version of the flanker task. The later finding is not in line with my previous study. Possible study implications were discussed in detail.

5.2 Introduction

In Chapter 3, I found a larger flanker effect in the sample with dyslexia compared to the control sample. These findings are in line with previous studies which reported poorer performance by CwD (Bednarek et al., 2004; Buchholz & Davies, 2005; Facoetti & Molteni, 2000; Facoetti et al., 2000; Facoetti & Turatto, 2000) and adults (Goldfarb & Shaul, 2013; Mahé et al., 2014) in various versions of the Flanker paradigm. The CwD poorer performance in these studies was attributed to various mechanisms from deficits in resolving the conflict at a response stage, to attentional deficits and/or to difficulties to suppress the interference of the flanker stimuli. In Chapter 3, I investigated some of these mechanisms, and found that the dyslexia deficit in flanker effect does not seem to be due to domain-general deficits in resolving response conflict because of a lack of an interference effect in the Simon task. I also found no evidence for general attentional deficits in the sample with dyslexia, evident from their normal performance in the Visual search task. In addition, the lack of task relationship between the Flanker effect and the response conflict Simon effect in the dyslexia group and a weak relationship for the control group suggested that the mechanisms driving the conflict effect in the two tasks are different. I proposed that an early conflict resolution- processing deficit could offer a plausible explanation for the increased Flanker effect size in individuals with dyslexia.

According to some models (Miller, 1991; Yantis & Johnston, 1990), the closely positioned stimuli in the Flanker task creates increased conflict that could be resolved by early suppression of the distractors and/or by boosting the target. Several hypotheses have been proposed for this early conflict mechanism. Some of these argue that the conflict is a result of attentional modulation in a form of attentional leakage to distractors (Yantis & Johnston, 1990), which is reduced when spatial attention is focussed on the target. Similarly, Lachter et al., (2004) proposes that AwD might show attentional slippage to the distractors as result of poor control of attention. However, I believe that the poor flanker performance in AwD could not be explained with poor control of attention. As I already mentioned in Chapter 3, the Visual search task part of the Preview-search requires control of attention for its successful execution. I found that the AwD have similar to the controls performance in this task, suggesting that poor control of attention could not explain the deficits observed in Flanker task. Others like Miller (1991) explains the effect as being due to the inability to discriminate the target because of the damaging effect of the spatially adjacent flankers, effect known as crowding. Others have argued that the suppression of distractors occurs at an even earlier stage, namely before the attentional mechanisms have started. Max and Tsal (2015) suggest that interference in the Flanker task is resolved during the collection of perceptual information. They therefore proposed suppression mechanisms are involved in the interference resolution at the perceptual level. Given the possibility of these early suppression mechanisms in the Flanker task, I will investigate in this chapter whether AwD deficit in the Flanker task might be due to a deficit of early distractor suppression mechanisms. I will do this with means of a modified version of the Eriksen Flanker task, namely the Flanker Mutation paradigm (Max & Tsal, 2015).

5.2.1 Flanker Mutation paradigm

The Flanker mutation paradigm, developed by Max and Tsal (2015), assesses the disruptive effect that distractors have at different time points over the course of the processing of a Flanker trial. In the mutation paradigm, stimuli were the similar as in the original Flanker task by Eriksen and Eriksen (1974), with a central target letter being surrounded with distractors, one on each side. Three different types of distractors formed three conditions: distractors identical to the target formed a congruent condition (i.e. Z Z Z); distractors similar to the target formed an incongruent condition (i.e. Z X Z); and distractors that shared no similarities with the target formed a neutral condition (i.e. P Z P). In contrast to the variant of the Flanker paradigm of chapter 3, the distractors mutated once per trial, with the target remaining the same for the whole trial. Manipulating the mutations led to three mutation conditions (See Figure 5-1 in the method section): a mutation from *incongruent to neutral distractors*, a mutation from *neutral to incongruent distractors*, and a *baseline* condition of neutral distractors that mutated again to neutral distractors. To find the time window at which distractors are having effect on the target response, Max and Tsal (2015) manipulated the time of the mutation. They used 11 time points, starting from 17 ms until 187 ms and increased the mutation points in a staircase way every 17 ms. They compared both the *incongruent to neutral* condition and the *neutral to incongruent* condition to the *baseline condition* (neutral to neutral distractors). By comparing the *incongruent to neutral* condition to the *baseline* condition for each mutation time point, it was found that incongruent distractors impaired performance irrespective of the length of time they were presented. This was true even when distractors were presented for only 17 ms before changing into neutral distractors. However, it is also important to note that even though the incongruent to neutral condition was significantly different from the baseline for all mutation time points, the accumulation of interference stopped increasing after the 50 ms mutation time point, suggesting no influence of the distractors after this time point. The *neutral to incongruent* condition delayed responses compared to the *baseline* condition, but only if the mutation happened within the first 50 ms, after which the presentation of incongruent distractors did not have any sufficient effect on the response times. Max and Tsal (2015) interpreted these findings as evidence that perception of distractors happens during the initial 50 ms of the stimuli presentation, after which the flankers stop having an effect on the performance.

In this experiment I used Flanker Mutation paradigm to addressed if AwD’s increased Flanker effect observed in Chapter 3 and in previous studies (e.g., Buchholz & Davies, 2005; Facoetti & Molteni, 2000; Facoetti et al., 2000 in children and Goldfarb & Shaul, 2013 in adults) might be due to deficits in collection of perceptual information. Since Max and Tsal (2015) had found that participants were affected by incongruent distractors only during the first 50ms of stimulus presentation, I specifically tested whether AwD might have a deficit in suppressing distractors during these first 50ms. In the *neutral to incongruent* mutation, typical population experienced delayed responses compared to the *baseline* condition, only if the mutation happened within the first 50 ms, after which the presentation of incongruent distractors did not have any sufficient effect on the response times. If AwD have potential perceptual deficit this would be evident in particular slowness to respond when neutral distractors change to incongruent ones, which would affect the time window later than 50ms. Similarly, deficits in collection of perceptual information would also be evident in the *incongruent to neutral* condition when compared to the *baseline* condition for as early as 17ms. For the typical population the difference between these two conditions results in a big interference effect, while in AwD lesser or no difference should be observed. In addition, while controls have been shown to not be affected by a change of incongruent distractors to neutral distractors after 50ms of stimuli presentation, participants with dyslexia might still benefit from such a change.

5.3 Method

5.3.1 Participants

I recruited 40 participants with dyslexia and 40 controls. All participants were recruited through study-specific recruitment posters displayed around the University of Birmingham campus and through the School of Psychology research participation scheme. The inclusion criteria were identic al to the ones used in the experiments of the previous chapters: Participants were only monolingual English speakers with normal or corrected-to-normal vision, with no history of a neurological condition, or any other disability (e.g. Autistic Spectrum Disorder). Participants must have completed the whole experiment in order to be included into any further analysis. Based on this requirement, I excluded two participants with dyslexia. This resulted in 38 individuals with dyslexia (8 of whom also participated in the second Stop-signal experiment) and 40 control participants included in the dyslexia assessment analysis.

The majority of the participants with dyslexia in this study suffered from both reading and phonology segmentation and retention difficulties. Participants were categorised as having dyslexia:

- they had a formal dyslexia diagnosis,
- had no history of psychological and/or neurological problems,
- they scored at least 2 SDs below the mean of the control group on at least two tests of a series of dyslexia measures (e.g. word/non-word reading, phonological processing subtests, reading measures; for details of tests see below).
- they scored no less than 2SDs or more below the control mean on both a non-verbal IQ measure (Wechsler Adult Intelligence Scale-Fourth edition (Wechsler, 2008)) and a Visual spatial working memory test - Corsi-block test (PEBL software; Mueller, 2011).

Similar criteria were applied for the control participants. They were expected to have:

- no history of psychological and/or neurological problems
- scored no less than 2SDs below the group mean on both the non-verbal IQ measure and the Visual spatial working memory test,

- did not score more than 2 SDs below the mean of the control group on more than one test of the dyslexia measures.

Using the criteria five participants were excluded from the control group: four were excluded for scoring 2 SDs below the mean of the control group on two or more of the language subtests, and one participant was excluded for scores of 2SDs below the group's mean on both IQ score and visual spatial memory. The same stringent criterion for participants with dyslexia resulted in six participants formerly diagnosed as having dyslexia being excluded from the analyses, with having scores similar to the control group on the language assessment subtests. This resulted in 32 participants with dyslexia (mean age 20.1 SD = 2.3, 11 male) and 35 controls (mean age 18.8, SD = 0 .7, 8 male) participants being included in the analyses.

Participants were either paid £20 compensation or given course credits. All participants gave written consent for their data to be used in the analysis. Apart from the Flanker Mutation task, participants completed the same tasks as in the previous chapters. They were tested individually in a quiet testing room at the University of Birmingham over two sessions carried out on two different days, no more than seven days apart. In session one, they completed the Flanker Mutation task and were assessed on two of the dyslexia tests: Gray Silent Reading Test (GSRT; Wiederholt & Blalock, 2000) and the Corsi-block tapping test. In session two, participants completed the rest of the dyslexia tests, the Comprehensive Test of Phonological Processing (CTOPP; Wagner et al., 1999), the Test of Word Reading Efficiency (Torgesen et al., 1999), the Irregular Word Reading Efficiency test (Reynolds & Kamphaus, 2007) and the Perceptual Reasoning Index Scale and The Processing Speed Index Scale from the Wechsler Adult Intelligent Scale (WAIS-IV).

5.3.1.1 Assessment tasks of dyslexia defining characteristics.

5.3.1.1.1 General cognitive ability.

Non-verbal IQ - WAIS-IV. For measuring non-verbal IQ, both the Perceptual Reasoning Index Scale and the Processing Speed Index Scale of the WAIS-IV (Wechsler, 2008) were used. Administration and scoring were applied according to the standardised instructions.

Non-verbal working memory - Corsi-block tapping test. As in the previous chapters, a computerised version of the Corsi-block tapping test was used as a measure of visual-spatial working memory. The measure entered into analyses was the memory span.

5.3.1.1.2 Literacy.

Reading comprehension. I administered the Gray Silent Reading test (GSRT; Wiederholt & Blalock, 2000) in order to measure participants' reading comprehension. The raw scores of the test were used for the group comparison analysis.

Phonological processing. The Comprehensive Test of Phonological Processing (CTOPP; Wagner et al., 1999) was used to assess phonological awareness, phonological memory and rapid naming. For detailed description, for each of the subtests used refer to section 2.2.3 of Chapter 2. Raw scores of these measures were entered into the analyses.

Single word and non-word reading. Word and non-word reading were assessed with the TOWRE-2 test (Torgesen et al., 1999). Irregular word reading was assessed with the TIWRE (Reynolds & Kamphaus, 2007). In all tests the scores were the number of words pronounced correctly. For a more detailed description see sub-section *2.3.1.1.2.3* of Chapter 2.

5.3.1.2 Assessments Group comparison.

Table 5-1 provides an overview of the participants' demographic data and their performance on the dyslexia assessment tests (non-verbal IQ, visual-spatial memory, various orthographic skills (reading comprehension, word and non-word reading) and sub-lexical phonology (phonological short-term memory; phonological awareness)). For the non-verbal IQ measure, the standardised test score was used (*scaled score*). For all the other assessment tasks, participants were compared using their raw scores.

Table 5-1 Means and SDs for age, scores on standardised tests of literacy, and general cognitive abilities for both dyslexia and control group, as well as comparative statistics.

		AwD				**CONTROLS**				**COMPARISON**	
		Min.	**Max.**	**Mean**	**SD**	**Min.**	**Max.**	**Mean**	**SD**	**Test significance**	**Value**
Gender	Male:female			10:22				8:27		$\chi 2$= .59	.309
Age	Years	18	29	20.1	2.35	18	20	18.8	.72	F= 10.5	.002
Non-verbal tasks											
WAIS Non-verbal IQ	Scaled score	90	130	108.3	9.9	87	122	103.9	8.6	F= 3.8	.054
Spatial memory (corsi-blocks)	N of correct	4	8	5.8	1	4.5	7.5	6.0	.7	F= 1.2	.271
Reading											
Reading Comprehension	Time (sec.)	455	2160	1053	356	218	1620	972	329	F=.94	.335
Reading Comprehension	N correct	41	63	54	5.8	36	64	55.5	7.3	F= .89	.348
TOWRE word reading	N correct	61	105	80.9	10.3	79	107	97.1	5.1	F= 68.1	$\leq$ .001

TOWRE nonword reading	N correct	13	56	44.6	8.4	46	66	59.3	5.6	F= 71.9	$\leq$ .001
TIWRE word reading	N correct	40	49	44.3	2.3	43	50	47.3	1.6	F= 43.3	$\leq$ .001
Phonological STM											
Memory for digits	N correct	9	20	15.4	2.8	13	20	16.8	1.8	F= 6.20	.015
Non-word repetition	N correct	7	17	12.5	2.7	12	18	15.4	1.7	F= 25.6	$\leq$ .001
Phonological awareness											
Elision	N correct	7	20	16.7	2.6	17	20	18.4	.9	F= 14.1	$\leq$ .001
Phoneme reversal	N correct	4	16	10.4	3.0	8	17	12.8	2.3	F= 12.74	$\leq$ .001
Naming speed											
Rapid Letter Naming	Time (sec.)	21	39	29.3	5.0	17	29	22.8	2.9	F= 42.4	$\leq$ .001

The comparison of the two participant groups shows the same pattern as for the participants in the previous chapters. The two groups differed significantly in terms of age, with group of dyslexia being on average about a year older. As expected, the group if dyslexia did not differ from the control group in terms of gender, non-verbal IQ (WAIS-IV), and non-verbal spatial memory (Corsi-block test). The two groups did not differ in their text reading comprehension scores and text reading times either. This lack of deficit in reading times is likely due to the highly functioning dyslexia population found at university. As expected, individuals with dyslexia showed severe impairments on the word and non-word reading, naming speed and sub-lexical phonology measures compared to the control group. This pattern of impairments is in line with what has been reported in the literature and with the formal diagnosis of developmental dyslexia.

5.3.2 Flanker Mutation task

5.3.2.1 Material and Procedure.

I used Max and Tsal (2015) Mutation paradigm, a modified version of the Flanker task. Participants were instructed to respond as quickly and as accurately as possible to the direction of a central target, by pressing the *z* and *m* key for left and right respectively. The target (i.e. "/ "or "\") was always flanked by two identical distractors, one on each side. There were three types of distractors: neutral distractors (" ‿ "), which were not related to the target, congruent distractors, which were identical to the target, and incongruent distractors (same as the target, but pointing into the opposite direction, i.e. "/ "or "\"). The stimuli type in the current experiment was different from the first Flanker task. Even though this could be a confounding variable, it was a necessary step to assure Mutation effect replicability.

In 89 % of the trials both of the flankers mutated once during the course of the trial presentation, while the target remained unchanged. In the other, 11 % of the trials, no mutation took place, meaning both the flankers and the target remained unchanged for the whole trial duration. Together with the non-mutation conditions, this led to six conditions: three no-mutations *neutral, incongruent* and *congruent* conditions and three mutations *neutral to neutral*, *incongruent to neutral* and *neutral to incongruent* conditions. There were six different time points at which flankers could mutate. The mutations appeared between 17ms and 100ms after stimulus onset, thus creating six possible mutation times 17ms, 33ms, 50ms, 67ms, 83ms and 100ms.

Each participant started with a practice block of 30 trials. This was followed by eight experimental blocks, with 250 trials each. Each trial started with a fixation cross presented for 150ms, followed by a blank screen presented for 50ms, and a stimulus presented until response (maximum RTs warning appear after 800ms). The post-response interval was 250ms.

Stimuli were presented on a 24-inch LED monitor (60Hz). The stimuli were black and were presented on a white background. The stimulus width, height and inter-stimulus distance were set on 1°. The experimental task was created by Max and Tsal (2015) using the Matlab Psychophysics Toolbox.

To make sure that the participants are having the expected performance warnings were generated after RTs were slower than 800ms and when more than six errors were executed for 20trilas.

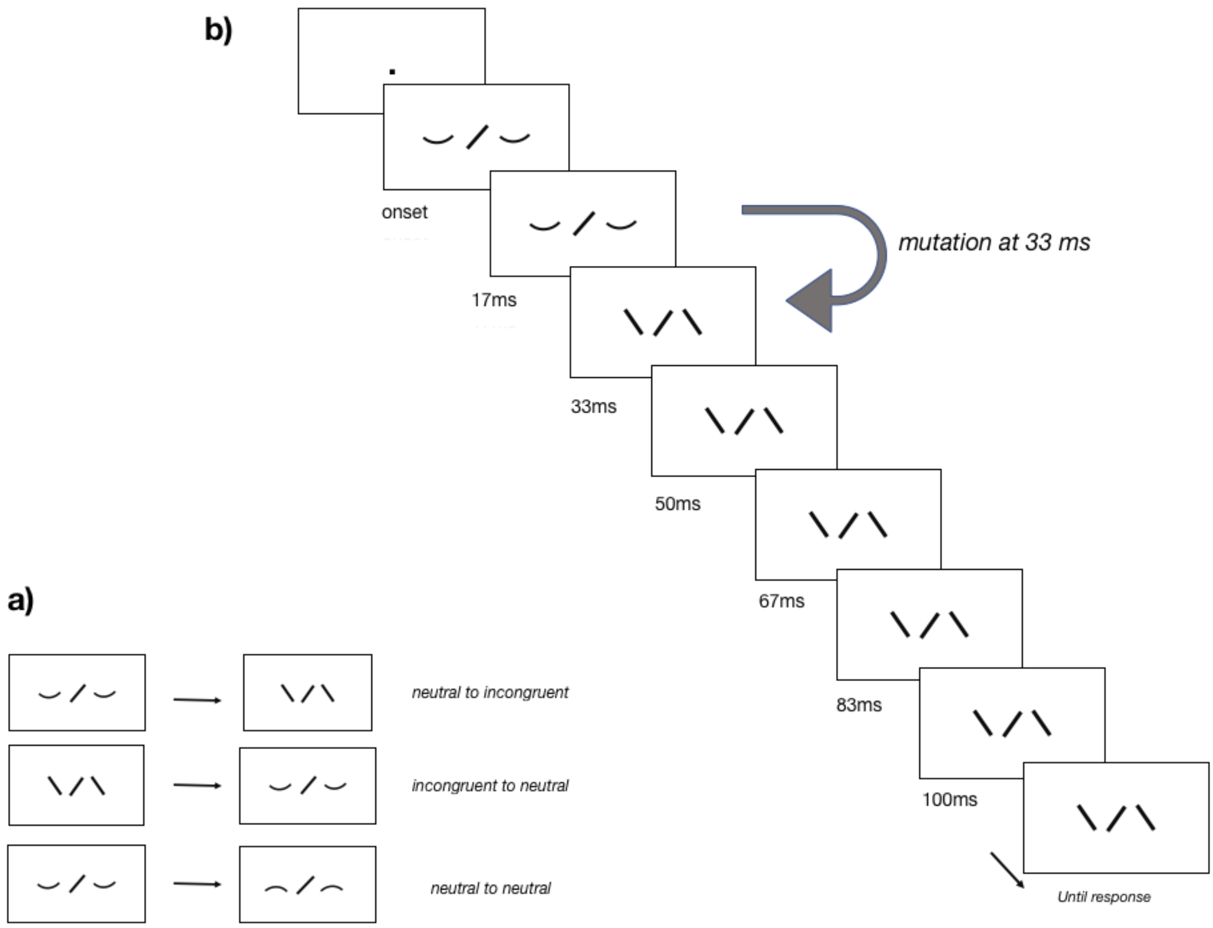


Figure 5-1 The Flanker Mutation paradigm. Panel a) shows the four types of stimulus mutations. Distracters mutate once per trial at one of six different time points, while the target remains unchanged. Panel b) shows an example of a mutation from neutral to incongruent distractors at 33ms.

5.3.3 Data analysis.

I analysed the no-mutation and mutations conditions separately. By analysing the no-mutation conditions, I was able to see whether I replicated the finding of a dyslexia deficit of processing incongruent flankers of Chapter 3. I will present analyses of both accuracy and RTs. Importantly, the mutation conditions allowed us to test whether the window of distractor processing differs for participants with dyslexia and controls, that is whether this window might be shorter for controls than AwD. More specifically, I was able to test whether the appearance of incongruent distractors would affect target recognition at a later time point in AwD than in controls by comparing the neutral-to-incongruent mutation condition to the neutral-to-neutral mutation condition. In addition, by comparing the incongruent-to-neutral mutation condition against the neutral-to-neutral mutation condition, I was able to see whether incongruent distractors affect the target processing for longer times in participants with dyslexia. I used the same analysis procedure as in previous chapters (see Data analysis sub-section 2.2.3 in Chapter 2 for more information). Response times were analysed with linear mixed effect models employing the lmer function of the lme4 package, and accuracy measures were analysed with generalised linear models (GLM), using a binomial link function. To determine whether a model was the best fitting model, I used the Akiake's Information Criterion (AIC) (Sakamoto et al., 1986).

5.4 Results

For RTs analyses, I removed all errors and outlier responses from the total responses (N=133,440). The errors accounted for 6.2% of the overall data. As in the previous chapters, outliers were defined as response times at least 2.5SDs above the mean RT of each participant. Outliers accounted for 2.3 % of the overall data. The number of trials left in the analysis was 122,337.

5.4.1 No-mutation Flanker conditions

5.4.1.1 Accuracy.

For the no-mutation Flanker conditions, I started the model fitting analysis with a general linear model with Accuracy as the dependent variable, Group (Control and AwD) and Condition (Neutral, Congruent, Incongruent) as fixed factors. The random effect structure included random intercept for Subjects.

The accuracy results are shown in Figure 5-2. I found no significant Group by Condition interaction ($\chi2$=3.09; df=2; p= .222). There was a significant main effect of Group ($\chi2$=4.25; df=1; p= .039), with AwD being overall less accurate than the controls. The main effect of Condition was also significant ($\chi2$=19.06; df=2; p< .001), with responses in the incongruent condition being less accurate compared to the congruent ($\chi2$=15.71; df=1; p< .001) and neutral conditions ($\chi2$=11.5; df=1; p< .001) and with no difference between the neutral and congruent conditions ($\chi2$=0.6; df=1; p= .471).

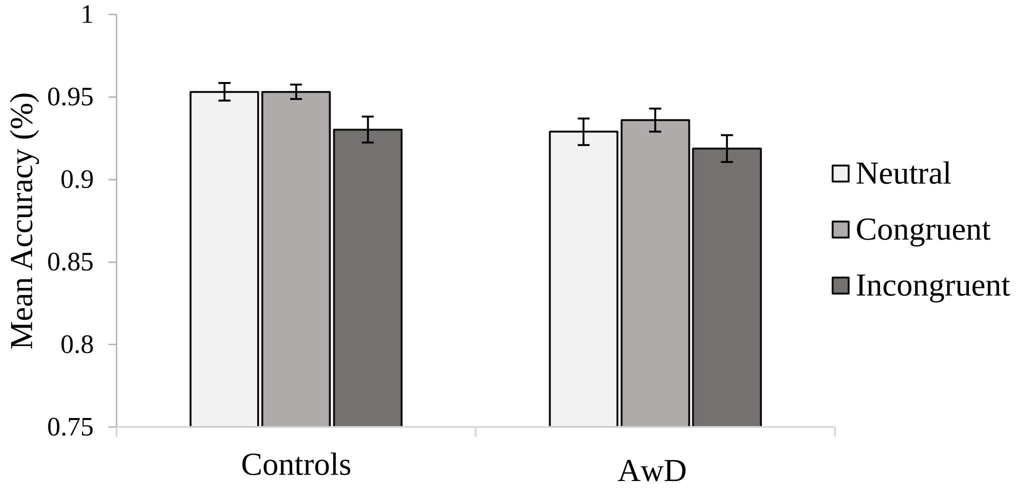


Figure 5-2 Mean accuracy for the no mutation conditions and both participant groups. Error bars represent standard errors.

5.4.1.2 Response times.

I fitted a full model with Response time as the dependent variable, Group (Control and AwD) and Condition (Neutral, Congruent and Incongruent) and their interaction as fixed factors. The random effect structure of the final model included random intercept for Subject and random intercept for Condition. Response time results of the no-mutation conditions are shown in Figure 5-3.

There was no significant Group by Condition interaction (χ^2 =1.11; df= 2; *p*=.572) and no main effect of Group (χ2=0.08; df=1; *p*=.779). The main effect of Condition was significant (χ2=8.58; df=2; *p*=.013), with the neutral condition showing faster RTs compared to the incongruent (χ2=35.3; df=1; *p*<.001) and congruent conditions (χ2=15.4; df=1; *p*<.001). There was only a trend for a difference between incongruent and the congruent conditions (χ2=3.27; df=1; *p*=.073), with incongruent condition being slower. Thus, I did not replicate the findings from the flanker experiment in Chapter 3, where I found an increased flanker effect for the dyslexia sample, with AwD being particularly slow in the incongruent condition.

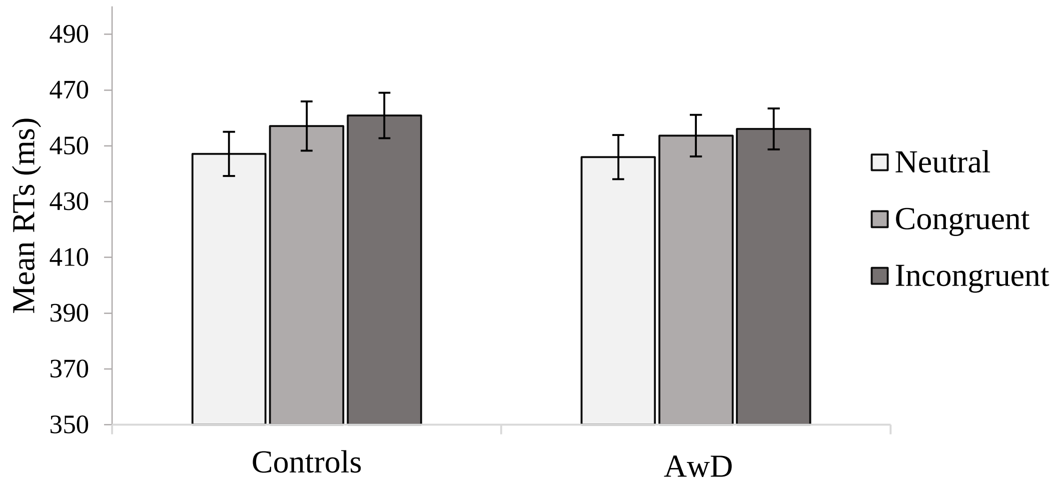


Figure 5-3 Mean Response times for the no mutation conditions in both group of participants. Error bars represent standard errors.

5.4.2 Mutation flanker conditions

5.4.2.1 Analysis of Accuracy.

For the mutation conditions, accuracy was analysed with *glm* rather than *glmer* due to convergence problems with the random structures. Neither the analysis comparing the neutral-to-incongruent condition to the neutral-to-neutral condition nor the analysis comparing the incongruent-to-neutral condition to the neutral-to-neutral condition showed any significant interactions with Group (for all interactions $\chi2 < 1$ and $p > .05$). However, I found main effects of Group across all conditions ($\chi2= 214$; df=1; $p<.001$), with AwD being less accurate than the controls.

5.4.2.2 Time Course of Incongruent Flanker Appearance Effect

Figure 5-4 shows the response times for all three-mutation conditions and for both participants groups. Comparing the neutral-to-incongruent condition with the neutral-to-neutral condition suggests that the appearance of incongruent flankers stops to slow down response times at 33ms for both participant groups. I therefore tested this effect across the first three time points and fitted a full model with RT as the dependent variable and Group (Control and AwD), Condition (neutral-incongruent and neutral-neutral) and Mutation Time (17ms, 33ms, and 50ms) and their interaction as fixed factors. To capture the parabolic shape (refer to the Figure 5-4) of the two conditions I fitted both a linear model and a quadratic model/curvilinear regression model. For the latter I used mutation time squared instead of mutation time. The random effect structure of the final model included random intercepts for Subject. Table 4-2 shows the dependent variable RTs for each of the mutation times in the three mutation conditions for the group with dyslexia and controls.

Table 5-2 Mean and SDs for each of the mutation times for the *neutral to incongruent; incongruent to neutral* and *neutral-to-neutral* mutation conditions.

Response times	*17ms*	*33ms*	*50ms*	*(17-50) Overall*	*67ms*	*83ms*	*100ms*	*(63-100) Overall*
Control								

group								
Neutral-incongruent	465ms(105)	452ms(93)	456ms(101)	458(99)	456ms(95)	460ms(101)	460ms(103)	459(100)
Incongruent-neutral	455(97)	462(96)	462(97)	460(97)	467(97)	468(98)	466(103)	467(100)
Neutral-neutral	451ms(92)	459ms(94)	451ms(95)	454(94)	454ms(100)	451ms(95)	454ms(94)	453(96)
AwD group								
Neutral-incongruent	454ms(95)	448ms(92)	449ms(97)	451(95)	454ms(96)	452ms(101)	454ms(103)	453(100)
Incongruent-neutral	451(98)	461(102)	460(97)	458(99)	466(101)	464(101)	460(99)	463(100)
Neutral-neutral	445ms(92)	457ms(102)	451ms(99)	451(98)	449ms(95)	450ms(103)	447ms(92)	449(97)

In all of the analysis, I am mainly interested in the interactions with group. Before examining the interaction, I first tested if a quadratic model in time was a better fit for the data by comparing it to a linear model. I found that the quadratic model was a better fit for the data ($\chi2$=47.2; df=4; *p*<.001)[15]. I then proceeded with testing the three-way interaction of the quadratic model. I found no significant Group by Condition by Mutation Time interaction ($\chi2$=0.4; df=2; *p*=.805). There was also no significant Group by Mutation interaction ($\chi2$=4.17; df=2; *p*=.124). The timing of the mutations affected the response times of both groups very similarly. The Condition by Mutation Time interaction, however, was significant ($\chi2$=57.65; df=2; *p*<.001). The performance differences between the two conditions changed across the mutation time points. The Group by Condition ($\chi2$=6.43; df=1; *p*=.011) interaction

[15] Note that the results are the same for a linear model.

was also significant. Comparing the two conditions for each group (collapsing over time points) shows that AwD show no effect of Condition ($\chi 2=0.06$; df=1; $p=.800$), while controls do ($\chi 2=7.04$; df=1; $p=.008$). This could suggest that, overall individuals with dyslexia were less affected by the appearance of incongruent distractors than controls. However, the interaction was driven by larger variability in the group of dyslexia. Some participants with dyslexia had slower RTs in the neutral-neutral condition than the neutral to incongruent condition (see Figure A2 in the Appendix 2), and others had effects in the opposite direction, while controls were more consistently slower in the neutral-incongruent condition.

Based on these findings I can conclude that AwD were suppressing the distractors at the same time point as the controls (by ~ 33ms), but they were also more variable in their response to incongruent distractors, which goes against my prediction that the neutral-incongruent condition would be more disruptive for AwD. It was not.

In order to investigate whether the appearance of distractors affected responses at later time points, I performed the same analysis as above for the mutation points between 50 and 100ms. There were no significant interactions with Group, meaning that there was no evidence that at later time points individuals with dyslexia were affected by the appearance of distractors differently than controls (Group by Condition interaction: $\chi 2=0.14$; df=1; $p=.703$; Group by Mutation time interaction: $\chi 2=1.43$; df=2; $p=.487$).

5.4.2.3 Time course of Incongruent Flanker Disappearance Effect

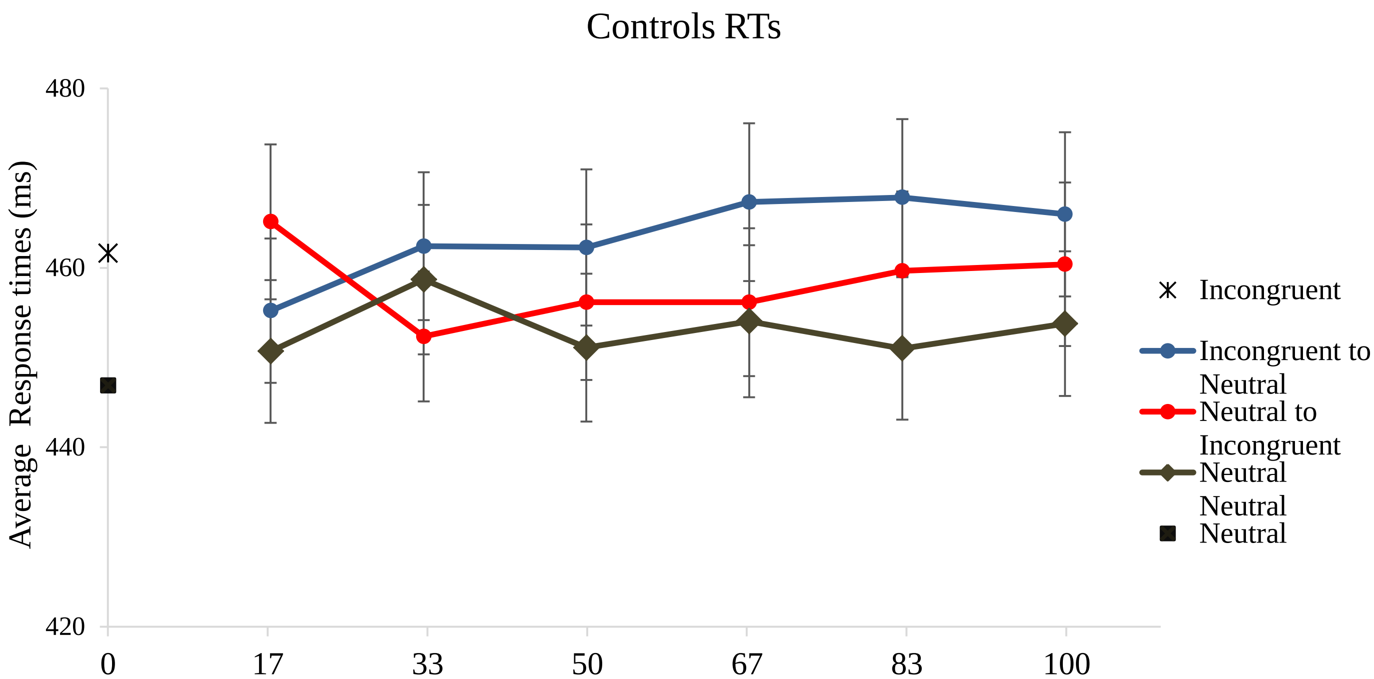
Response time results are shown in Figure 5-4. In order to investigate the length of time that incongruent distractors affect AwD performance I looked for group differences in performance when incongruent distractors changed into neutral ones for mutation time points up to 50ms and for the last three mutations from 67ms to 100ms. Refer to Table 4-2 for the

RTs for each of the mutation times in the 67 to 100ms mutation conditions for the group with dyslexia and controls.

For the mutations up to 50ms, I fitted a full model with Response time as the dependent variable, Group (Control and AwD), Condition (incongruent- neutral and neutral-neutral) and mutation times (17ms, 33ms and 50ms) and their interaction as fixed factors. The random effect structure of the final model included random intercept for Subject and random intercept for mutation times. I found no significant Group by Condition by Mutation Time interaction ($\chi 2=0$; df=1; p=.941). There was also no significant Group by Mutation Time ($\chi 2=2.18$; df=1; p=.139) or Group by Condition ($\chi 2=0$; df=1; p=.967) interaction. The only significant interaction was the Condition by Mutation Time interaction ($\chi 2=4.39$; df=1; p=.035), with a change of incongruent distractors to neutral distractors leading to increased RTs at17ms ($\chi 2=6.7$; df=1; p=.009) and 50ms ($\chi 2=25.8$; df=1; p<.001) for both participant groups. For the 33ms ($\chi 2=3.13$; df=1; p=.076) there was a trend for RTs increase.

For mutations between 50 and 100ms, I found a trend for a Group by Mutation Time interaction ($\chi 2=3.72$; df=1; p=.054). Follow-up analyses showed the RTs of the groups only differed at 100ms ($\chi 2=11.2$; df=1; p<.001), with AwD being faster at this time point (independent of condition). This result is difficult to interpret.

a



b

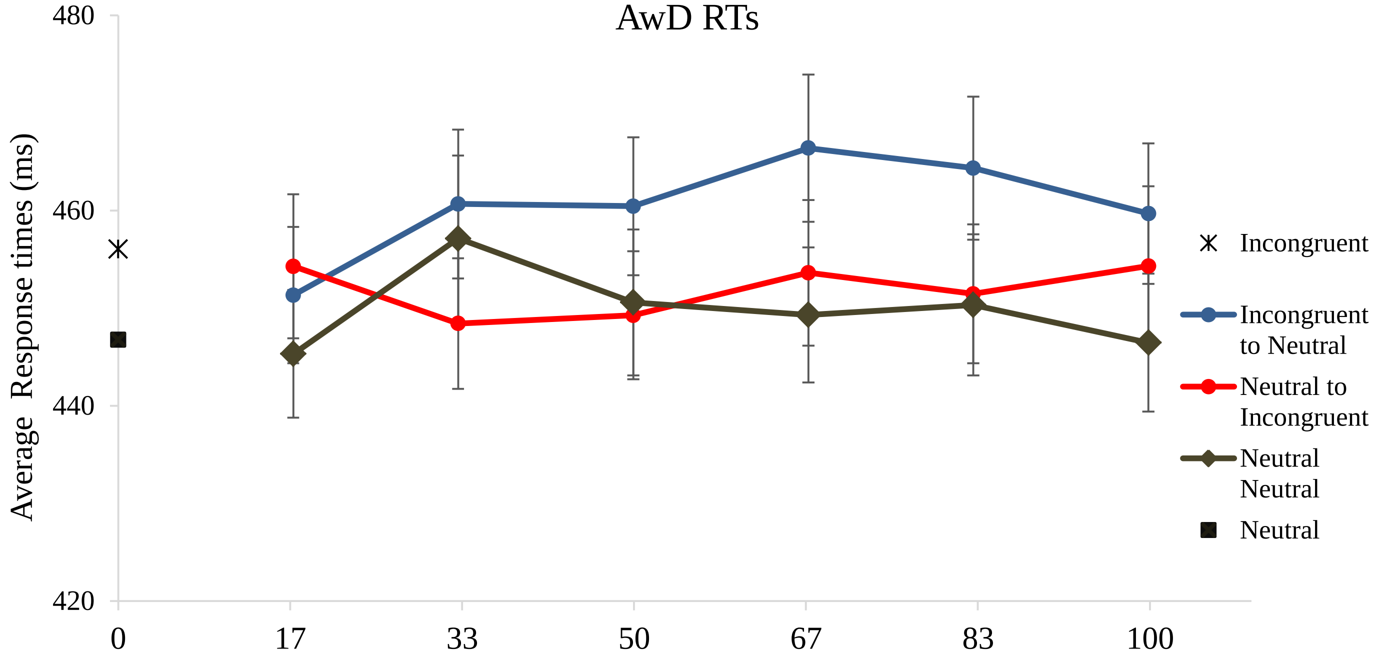


Figure 5-4 Mean reaction times by mutation times for the three mutation conditions as well as for the (no mutation) incongruent and neutral conditions for the control (a) and AwD (b) participants. Error rates represent standard errors.

5.5 Discussion

In Chapter 3, I found that the performance of AwD in the Flanker task was significantly worse than that of control participants. More precisely, they showed difficulties in the conflict conditions. Since their performance was not related to their verbal suppression skills (their lexical and sub-lexical skills), I concluded that their deficit was particularly related to demands of the Flanker task. The aim of this chapter was to explore if AwD's poor performance in the Flanker task was a result of suppression or attention deficit during early perceptual levels. In other words, do participants with dyslexia show a deficit in focussing on the target during early perceptual processing of stimuli in the Flanker task? I addressed this question by means of the Flanker Mutation paradigm, which has been used previously to investigate the time-course of distractor perception in flanker task I found that AwD were suppressing the distractors within same time window as controls. I also found that AwD did not differ in the flanker disappearance effect in either early or later time widows. I found some group differences, but these were not related to the suppression of the flankers. Together the result show that AwD performed very similarly to controls in the Flanker Mutation paradigm. These findings have several implications. In what follows, I will first discuss how current results relate to the existing literature. I then discuss the difference between the two flanker paradigms used in the current thesis and how these differences explain the different findings. Finally, I will discuss possible study limitations and suggestions for future studies.

Contrary to my hypothesis, I found no evidence that participants with dyslexia and controls differ in their perception of distractors in the Flanker Mutation task. Specifically, I found that both groups are supressing the distractors within the first 50ms of the stimuli presentation. This finding points to no deficits in the temporal suppression of the distractors. However, despite very similar overall reaction times in both groups, I also found that individuals with dyslexia were generally less affected than controls when neutral distractors turned into incongruent distractors at very early time points. I already mentioned that the source of this difference was a small group of dyslexia who had poorer performance on the neutral-neutral condition compared to the neutral to incongruent condition in the first three mutation points. Form the current experiment it is not clear why some AwD experienced difficulties with the mutation of neutral to neutral distractors. However, I should also note that the dyslexia sample was not different from the controls in the no-mutation condition where there was no change of the flankers. This finding is not in line with my previous experiment (see Chapter 3) or with previous dyslexia studies (Bednarek et al., 2004; Buchholz & Davies, 2005; Facoetti & Molteni, 2000; Facoetti et al., 2000; Goldfarb & Shaul, 2013; Mahé et al., 2014). Different study results could be due to differences in the dyslexia sample or the experimental design. I used the same inclusion criteria for the dyslexia participants across the two experiments. But the samples might have been slightly different. However, I suspect that the different results are rather due to differences in stimuli.

There were several differences between the stimuli in the Flanker task of Chapter 3 and in the current Flanker Mutation version: the length of the stimuli, the distance of symbols within stimuli, the type of stimuli, the predictability of the presentation position and the congruency ratio. The first difference was the length of the stimuli, with the targets in the version in chapter 3 being flanked by four distractors compared to only two distractors in the current experiment. It has previously been found that the length of letter strings has an effect on processing in individuals with dyslexia. De Luca, Burani, Paizi, and Spinelli (2010) found that participants with dyslexia had slower response naming times compared to skilled readers when reading long word and non-word letter strings. The authors proposed that letter strings of four or more letters have significant influence on dyslexics' performance and they suggested a visual processing deficit as one root of the problem. Even though the strings used were not letter strings, but symbols, it is possible that the short symbol string was not processed differently by the individuals with dyslexia due to its shortness.

In addition to the length effect, differences in crowding of the stimuli might have led to different performance in the dyslexia sample. The distance between symbols in the experiment of Chapter 3 was 0.06 degrees visual angle compared to 1 degree in the current experiment. The larger symbol distance might have resulted in less stimulus crowding. Decreased crowding makes it easier to identify a target (Bouma, 1973; Bouma & Legein, 1977; Martelli, Di Filippo, Spinelli, & Zoccolotti, 2009; Pernet, Andersson, Paulesu, & Demonet, 2009). The effect of crowding has been shown for participants with dyslexia in terms of improved reading performance when spacing between letters was increased (Perea, Panadero, Moret-Tatay, & Gómez, 2012; Zorzi et al., 2012). This finding links crowding to object identification (Levi, Hariharan, & Klein, 2002). Crowding has also been shown to interact with stimulus length, with larger effects of crowding in dyslexia population for longer stimuli (Atkinson, 1991; Martelli et al., 2009; O'Brien, Mansfield, & Legge, 2005; Spinelli et al., 2002). It is therefore possible that the combination of less crowding and shorter stimulus length in the current experiment made the AwD performance and target identification more similar to that of controls.

Third, the first experiment used left and right pointing arrows, while in the second experiment I used left and right tilted lines. Such difference could have had an effect on the speed of response activation, with left pointing arrow bound to the direction of the left-hand response position, resulted in fast automatic perceptual response activation. It is possible in the cases of the tilted lines the direction requires to first associate the stimuli with the response direction and then to bound the stimuli-response together. Since dyslexia is characterised with learning difficulty the to be learned stimuli association could offer a plausible interpretation of the overall accuracy effect in which AwD were found to be less accurate in their responses regardless of the condition. However, since I do not have a task measuring dyslexia learning abilities this hypothesis is speculative.

To date, I am the first study to investigate AwD's conflict effect in flanker task with larger inter-stimuli distance (more than half a degree of visual angle) in stimulus strings of three symbols. Taking both current and previous experiments together, it appears that participants with dyslexia do not have a deficit in suppressing distractors / attending to targets per se, but the suppression deficits seem to only occur for crowded and long stimulus strings.

Another, difference between the flanker paradigms used in the thesis is the predictability of the position of the stimuli and thus of the target. The position was completely predictably occurring in the centre of the screen in the mutation paradigm, while in the experiment of Chapter 3 stimuli appeared randomly above and below the centre of the screen. In addition, a fixation point appeared at the exact same location before the target in the mutation experiment, potentially allowing participants to direct their attention more easily to the target location. This argumentation fits with earlier findings that individuals with dyslexia can use cues to orient and constrain their attention (Moores et al., 2015). Although, using the fixation point as a cue to improve performance would offer a plausible explanation for the finding that AwD were less affected by the appearance of incongruent distractors than controls in the early time windows. However, the lack of similarly good performance in the incongruent to neutral condition in dyslexia sample could be problematic for this explanation.

Finally, there was a difference in the congruent display ratio in both tasks. In the Mutation paradigm, I followed the Max and Tsal (2015) design where the trial ratio was the same for the different mutation conditions. However, in the Flanker task used in Chapter 3 I used the 75% congruent displays. This difference between the two tasks outline a possible differentiation between the processes used in the two tasks. For example, it is possible that in the current Flanker task AwD used predominantly proactive control mode to compensate for their potential reactive control difficulties. However, to date deficit in reactive control in AwD has not been reported in the literature.

5.6 Conclusion

The aim of this chapter was to explore if AwD' poor performance found in the Flanker task of Chapter 3 was a result of a suppression deficit during early perceptual stimulus processing. Contrary to my expectations, I found no group difference in distractor perception during an early processing time window, suggesting that early visual suppression mechanisms in AwD are similar those of controls. However, the fact that I found no group difference in the no-mutation conditions of the paradigm suggests that this result might be due to stimulus features such as a short length and the absence of crowding as well as due to the way stimuli were presented. A future study should therefore use a mutation paradigm with a larger number of distractors that are positioned closer together and/or where the location of the target cannot be predicted. Previous studies on visual attention suggest that AwD' early visual suppression deficits might only be evident in situations that are more demanding on the attentional system.

CHAPTER 6

GENERAL DISCUSSION

The aim of this thesis was to explore how individuals with dyslexia resolve competitive situations in various verbal and non-verbal experimental tasks.

In Chapter 2, I explored whether AwD have lexical-semantic retrieval deficits with regards to the resolution of lexical competition. I tested this hypothesis with two paradigms previously used for measuring competition during lexical retrieval, including the blocked cyclic naming task (Belke, Meyer, et al., 2005) and the Hayling task (Burgess & Shallice, 1996). The results showed that competitive semantic context was more pronounced in participants with dyslexia than controls. More specifically, AwD performed less accurately than controls in the competitive condition of the blocked cyclic task exhibiting more semantic errors. Furthermore, AwD were also less accurate in the inhibition condition of the Hayling task and experienced more semantically related (partial inhibition) errors compared to controls. Importantly, the number of semantically related errors in the blocked cyclic naming task was associated with the partial failures in the Halying task in both groups. The increased number of semantically related errors in AwD and the positive relationship between the semantic errors in both tasks confirm the prediction that lexical retrieval deficits were observed in AwD, specifically, in conditions where lexical-semantic competition was increased.

In Chapter 3, I followed up on the findings of Chapter 2 investigating if the mechanisms for resolving competition in the verbal tasks originated from an underlying more general suppression mechanism. I re-tested the participants from Chapter 2 with a set of non-verbal tasks involving resolution of competition in situations of increased conflict and in situation without a conflict. Two tasks were used to test how AwD' resolved competition in increased conflict situations, the Flanker task and the Simon task. I used the preview-search task to study the resolution of competition in situations with no response conflict. Results showed group differences only in the Flanker task, with AwD experiencing a larger interference effect in comparison to the controls. I found no evidence for group differences in the Simon and Preview-search tasks. To address whether a domain general suppression mechanism is operating in individuals with dyslexia, I correlated the Flanker effect with the non-verbal tasks from Chapter 2. The results showed no evidence of shared suppression mechanisms in AwD. I also found no evidence of a relationship between language skills of AwD and their performance in the Flanker task, suggesting that the deficit was not related to their language difficulties.

In Chapter 4, I investigated a more global form of suppression used to withhold the execution of an ongoing response in order to gain a complete understanding if the competition in the lexicon is resolved by domain general mechanism. In the first experiment of Chapter 4, I re-tested the sample of participants used in the previous two chapters with the Stop-signal task. Participants' had to respond to visual stimuli as fast as possible. Occasionally an auditory signal was presented, and participants had to suppress their response. I found that individuals with dyslexia experience suppression deficits characterised by a difficulty to stop a response. I correlated participants' performance on the Stop-signal task with the verbal tasks from Chapter 2 and found correlations only for the controls, but not for the participants with dyslexia. This suggested that AwD were using different mechanisms than the controls either in one or in both of the two tasks. But, since dyslexia is characterised by low-level perceptual deficits in the visual and auditory domains as well as deficits in integrating multi-modal information, this could have had an influence on the Stop-signal task performance.

In the second experiment of Chapter 4, I extended the results by studying the suppression mechanism in three types of Stop-signal conditions: a uni-modal visual condition where the signal and the stimuli were visual, uni-modal auditory condition and a cross-modal condition identical to experiment one. I also performed the same conditions with a different task requirement. Instead of suppressing their response, participants executed two consecutive responses (the primary go response and an additional response to indicate if a stop signal has occurred; dual-task condition). I found group differences in the overall response suppression, with AwD having poorer response suppression in comparison to controls. There was a group difference in the main go-RT in the double-response task, suggesting that the group effect of SSRT could be a result of dual-task processing difficulties rather than a general suppression deficit in AwD. Additionally, I also found differences mainly in the auditory and mixed conditions of the Stop-signal task that could not be accounted for by dual-task processing. The mixed SSRT showed the biggest group difference, with group of dyslexia showing poor response inhibition in cross-modal processing, replicating the experiment 1 findings of larger SSRT. I also found auditory group differences in the go-RT, with group of dyslexia being slower and less accurate than the controls. Based on these findings I concluded that AwD poorer performance in SST was a result of specific dyslexia deficits with auditory processing that also impair the cross-modal communication.

Chapter 5 focussed on the increased Flanker effect in AwD found in Chapter 3. More specifically, I investigated if individuals with dyslexia have deficits that affect the time course for resolving interference at an early perceptual level. I used a modified version of the Flanker task, called the Mutation paradigm (Max &Tsal, 2015). In this task the flankers mutated once per trial from *neutral-to incongruent* distractors or from *incongruent-to neutral* distractors in various time points from as early as 17ms to 100ms. I also included no mutation trials to compare the AwD performance to that of Chapter 3. The results from the mutation conditions showed that both groups of participants resolved the distractor interference at around the same time (~33ms). Nevertheless, I did not find group differences in the classical (no-mutation) flanker trials. Therefore, the finding that AwD resolve the distractor interference at around the same time as controls is only a tentative conclusion. The difference in the group performance in the Flanker task reported in Chapter 2 and the task reported in Chapter 4 could have been a result of the different stimuli representations i.e., fewer distractors, increased inter-stimulus spacing or to the different characters used in the second experiment.

How thesis findings fit in the theoretical models of dyslexia?

The individuals with dyslexia used in the thesis had poor phonological representations and struggle to segment, manipulate, store and retrieve phonemes, pattern of impairments in line with the phonological deficit theory (Snowling, 1981, 2001). However, I also had individual with dyslexia with severe deficits in word reading and naming speed, in addition, or in isolation to the participants' phonological deficits. These non-phonological deficits are problematic for the phonological theory, but are explained with the orthographic learning account of dyslexia (e.g. Blau et al., 2010). According to this account, reading difficulties in dyslexia are not due to underlying phonological deficits, but result from poor learning of the grapheme to phoneme mappings, which leads to the inability to develop fluent reading (Aravena et al., 2013). Importantly, both of these models argue that the deficits in dyslexia are as a result of language specific deficit.

In my thesis, I found no evidence for a strong relationship between the sub-lexical skills and the suppression ability in individuals with dyslexia. This finding is in line with the view that dyslexia deficits are language specific. However, I found that AwD experienced a larger interference effect in Flanker task and evidences for auditory processing deficits in

SST. Therefore, the view that dyslexia is characterised solely by the sub-lexical deficits is not fully in line with the current findings.

The overall deficit pattern observed in the group with dyslexia is in line with the multiple-deficit account. According to this account children with multiple cognitive difficulties were most likely to develop and suffer from a severe type of dyslexia (e.g. Pennington, 2006; Peterson & Pennington, 2015). This perfectly fits the heterogeneous deficits evident in the participants used in throughout the thesis. However, it should be kept in mind that the AwD tested here are all university students who continued into higher education despite their persistent dyslexia deficits. Suggesting the use of possible strategic behaviour necessary to compensate for their severe difficulties. This could have had some influence on the AwD task performance where the employment of strategies could potentially mask or lessen their deficits. Thus, limiting the possible factors contributed to their reading deficits.

6.1 Towards a better understanding of the competitive resolution in audults with dyslexia

Previous studies using picture naming have found that AwD name the pictures slower (e.g., for results in children see Katz, 1986; Swan & Goswami, 1997; for a review see Nation, 2005; in adults see Raman, 2011) and make picture errors semantically related to the target (Nation et al., 2001). Individuals with dyslexia were also found to have an enhanced Stroop effect when compared to controls (see Chapter 2, sub-section 2.2.1). I found evidence that these previously reported naming deficits might be attributed to a specific lexical retrieval deficit in AwD during the heightened demand of lexical-semantic competition. In addition, I also investigated if the increased lexical competition in dyslexia was part of a domain-general cognitive control deficit or if it was due to a language specific competition deficit. My results showed no relationship between the non-verbal tasks from Chapter 3 and 4 where group differences were found and the language tasks in Chapter 2. This was evidence against the domain-general suppression deficit in the dyslexia sample. This conclusion was further supported with the results from the inhibition errors in the Hayling task in which AwD did not differ from the controls. These types of inhibition errors included the suppression of a proponent response and the lack of group provided further evidence against a domain general inhibition deficit.

The current findings for the increased lexical-competition in AwD could be explained with two plausible interpretations. According to the first one, the increased competition was a result of an underlying language-specific deficit either due to insufficient lateral inhibition or due to insufficient lexical facilitation; depending on the lexical production model specifications i.e., for lateral inhibition see Howard et al., 2006; McClelland & Rumelhart, 1981 or for facilitation see Levelt et al., 1999. The insufficient lateral inhibition would result in less inhibition applied to the co-activated competitors, subsequently leading to increased activation of the target name and its semantic competitors (note that increased activation would also be evident with insufficient lexical facilitation). This increased activation in AwD would result in overly competitive lexical-semantic network, where the chance of producing the incorrect semantic competitor is increased. The second interpretation is that instead of underlying deficit a reading-related compensation strategy could be the source of the increased competition. For example, to compensate for their reading deficits AwD rely on the sentence context to improve their reading (Helenius, Salmelin, Service, & Connolly, 1999). Since the strategy would rely on reading via meaning this could potentially result in increased semantic activation in the lexicon. The trend I found in the relationship between the accuracy effect in the cyclic blocking task and the factor lexical skills favours the hypothesis of a language-specific deficit. People with poorer lexical skills struggled more to resolve the competition between lexical items in the homogeneous condition. This trend was observed in both groups of participants, suggesting that the role of strategic behaviour in AwD as a source of the increased competition is the less likely option. However, it should be noted that the trend between the accuracy effect and lexical skills disappears after correcting for multi-collinearity. Therefore, the role of strategic behaviour in AwD increased lexical competition could not be ruled out completely.

There was a clear difference in the pattern of findings between participants with dyslexia and controls. More specifically, I found that the poor accuracy of controls in the competitive condition of the blocked cyclic naming task was correlated with poor response inhibition in the Stop-signal task. This finding indicates a possible existence of general cognitive processes that operate in the lexicon, which were not evident in the dyslexia sample. This is also supported by the correlation between the response inhibition measure of the Stop-signal task and the controls' lexical skill, found in both Stop-signal experiments. This relationship was found only in the control group could be interpreted in two ways. First, it is possible that participants with dyslexia were performing the Stop-signal task in a different way in comparison to the controls, possibly as a result of their auditory processing deficits. Secondly, since AwD have poorer response suppression, it is possible that they used a different mechanism for resolving competition within the lexicon. However, determining the origin of such compensatory mechanism is beyond the scope of this thesis.

6.2 Key Findings

The main aim of the thesis was to explore if developmental dyslexia is characterised by a domain general suppression deficit. In order to achieve the thesis aim, I tested AwD on several language and non-language tasks where increased competition had to be resolved. I found that individuals with dyslexia experience deficits in the blocked cyclic naming and Hayling language tasks and in some of the non-language tasks, like Stop-signal and Flanker tasks. These make it possible that there is a general suppression deficit in dyslexia population. However, when I correlated the tasks that exhibited group differences, I found no evidence for such a relationship, making an overall suppression deficit unlikely.

It should be kept in mind that there is an impurity in the tasks measuring inhibition, with other executive functions also influencing performance (Hasher & Zacks, 1988).In addition, in the dyslexia literature evidence for strategies (i.e., good visual WM) have been linked to reading difficulty compensation. Therefore, the correlations between tasks could have been mediated by other EFs and/or dyslexia strategies. Even though tentative this hypothesis is also likely.

6.3 Future directions

There were some questions left unanswered in the current thesis. For example, future studies should investigate more thoroughly the cause of the increased flanker effect in AwD. In Chapter 5, I tried to replicate current flanker results from Chapter 3, by investigating if the locus of the AwD deficits was in the early processing of the distractors. However, I could not replicate the increased flanker effect in the dyslexia sample found in Chapter 3, possibly due to the stimuli differences between the two-flanker task experiments.

Future studies should aim to replicate my experimental findings but using a modified version of the Mutation paradigm. Such a task should address the stimulus limitations by increasing the number of the distractors and decreasing the within-stimulus distance. I am aware that other stimuli differences would be more difficult to address, such as reducing the target predictability. In the Mutation paradigm target stimulus was always stable, this high predictability allowed the participant to zoom in on the fixed position easily. However, in the first flanker experiment the stimuli appeared in a random order below and above the fixation point. Making the target unpredictable requires participants to refocus on the target on every trial, making the target recognition more demanding. Changing the mutating stimulus to an unpredictable target might not control very well for when the mutation occurs in comparison to when the target was acquired, due to the different times in which the participants will focus on the target. This will result in increased interference from the mutation appearance, aborting completely the effect of the different conditions i.e., the post-mutations in each condition (and possibly time point) would be equally problematic for the participant. Nevertheless, addressing this issue is not impossible. In particular, this could be achieving by using eye-tracking technology that could detect if the participant is focused at the target and only then to trigger the mutation of the distractors. Previous studies investigating sentence reading have used eye tracking in a similar way (i.e., after focus onset the word is masked) (e.g., Blythe, Liversedge, Joseph, White, & Rayner, 2009).

The second question that was left unanswered was the type of mechanism that individuals with dyslexia used to resolve lexical competition. I found a relationship between the response inhibition measure and lexical competition and lexical skills in controls. This finding raised two possibilities. One plausible explanation was that individuals with dyslexia are performing the Stop-signal task in a different manner in comparison to controls because of poor auditory processing. The other possibility is that individuals with dyslexia were using different mechanism for resolving competition within the lexicon. Another way to capture if the group of dyslexia used different mechanisms from the control group in the Stop-signal task would be by expanding the experimental techniques to include measures of brain activation during task performance. Previous studies have already established different ERP components in successful and unsuccessful stop trials in the Stop-signal task (Kok, Ramautar, De Ruiter, Band, & Ridderinkhof, 2004; Ramautar, Kok, & Ridderinkhof, 2006). This could reveal the underlying mechanism behind the groups' different behaviour.

6.4 Envoi

A full account of developmental dyslexia cannot be developed without taking into consideration the additional non-language related cognitive deficits. In this thesis, I was particularly interested if AwD have difficulties in resolving increased competition in language and non-language related tasks and the relationship between these tasks. Previous studies have reported that individuals with dyslexia have deficits in situations of increased conflict (e.g., Bednarek et al., 2004; Goldfarb & Shaul, 2013). In this thesis, I was specifically interested to see if dyslexics' difficulties in resolving competition were part of a domain general control deficit that could account for some of their language deficits. The current findings provide evidence for increased lexical competition in AwD, potentially due to weaker language specific suppression. The poorer performance in situations with increased conflict was not limited to language-specific tasks but was extended to the non-verbal domains. However, there was no relationship between the performance in the language and non-language tasks, suggesting that AwD have task specific not domain general deficits. Further studies of the specific task-related deficits are needed to understand dyslexia better as a broader syndrome.

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APPENDIX 1

Language tasks stimuli sets

a) Picture stimuli used in the Semantic blocking task.

Animals	Furniture	Tools	Clothing
Duck	Desk	Brush	Coat
Snake	Lamp	Drill	Skirt
Fish	Bed	Saw	Tie
Mouse	Chair	Rake	Boot

b) Sentence stimuli used in Hayling task

List 1

1 The lecture should last about one HOUR.
2 Water and sunshine help plants GROW
3 You can't buy anything for a PENNY.
4 The academic year began in September.
5 The dispute was settled by a third PARTY.
6 They went as far as they COULD.
7 John swept the floor with a BROOM.
8 When you go to bed turn off the LIGHT.
9 The train was still on TIME.
10 It's hard to admit when one is WRONG.
11 We sometimes forget that golf is just a GAME.
12 The wealthy child attended a private SCHOOL.
13 Most cats see very well at night.
14 Jack bet all he had on the last RACE.
15 He liked milk and sugar in his TEA.
16 He posted the letter without a STAMP.
17 It's easy to get lost without a MAP.
18 The pizza was too hot to EAT.
19 The bill was due at the end of the MONTH
20 The game was called off when it started to RAIN.
21 Her job was easy most of the TIME.
22 The captain wanted to stay with the sinking boat.
23 The children went outside to PLAY.
24 Jack tried to squeeze in but there was no room.
25 Bill jumped in the lake and made a big SPLASH.
26 The better students thought the test was too EASY
27 The rude waiter was not given a TIP.
28 The baby cried and upset her MOTHER.
29 This man has travelled everywhere around the world.
30 The winter was very harsh this YEAR.
31 Water and sunshine help plants GROW
32 The pizza was too hot to EAT.
33 He liked milk and sugar in his TEA.
34 When you go to bed turn off the LIGHT.
35 They went as far as they COULD.
36 The captain wanted to stay with the sinking boat.
37 The lecture should last about one HOUR.
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51 The train was still on TIME.
52 This man has travelled everywhere around the world.
53 The baby cried and upset her MOTHER.
54 We sometimes forget that golf is just a GAME.
55 The rude waiter was not given a TIP.
56 Her job was easy most of the TIME.
57 Most cats see very well at night.
58 The bill was due at the end of the MONTH
59 The game was called off when it started to RAIN.
60 The better students thought the test was too EASY

List 2

1 Water and sunshine help plants GROW

2 The pizza was too hot to EAT.

3 He liked milk and sugar in his TEA.

4 When you go to bed turn off the LIGHT.

5 They went as far as they COULD.

6 The captain wanted to stay with the sinking boat.

7 The lecture should last about one HOUR.

8 You can't buy anything for a PENNY.

9 He posted the letter without a STAMP.

10 The academic year began in September.

11 It's easy to get lost without a MAP.

12 Bill jumped in the lake and made a big SPLASH.

13 Jack tried to squeeze in but there was no room.

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15 The wealthy child attended a private SCHOOL.

16 The winter was very harsh this YEAR.

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35 The dispute was settled by a third PARTY.

36 They went as far as they COULD.

37 John swept the floor with a BROOM.

38 When you go to bed turn off the LIGHT.

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APPENDIX 2

Mutation paradigm

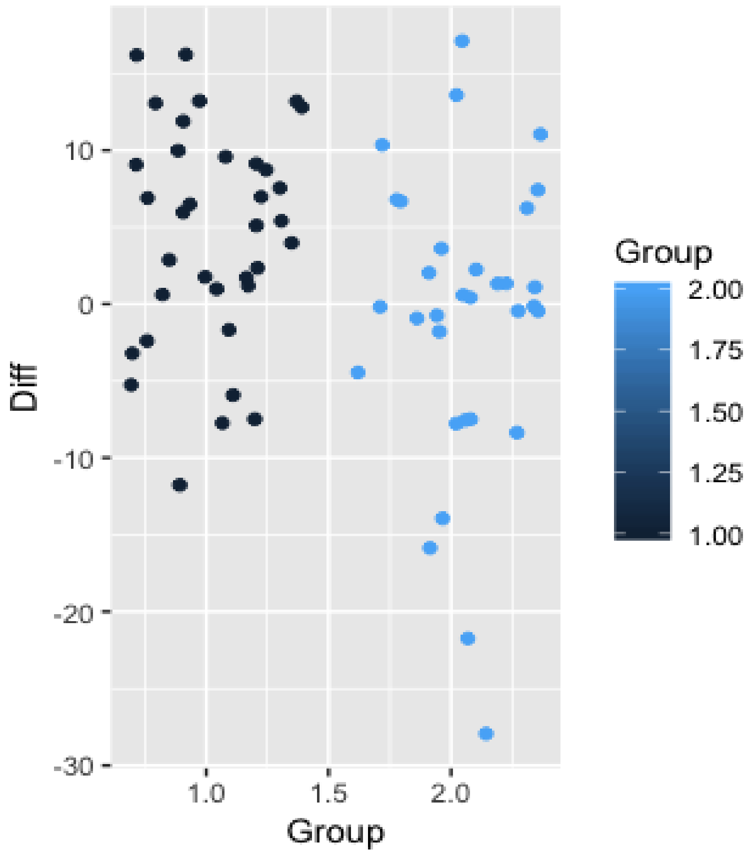

Figure A2. The figure shows the *neutral to incongruent* effect size (*neutral to incongruent - neutral to neutral condition)*. Group 1 are controls and Group 2 AwD. It is evident from the plot that a group of the participants with dyslexia were having negative effect size, driven by the slower *neutral to neutral* RTs.