EXECUTIVE FUNCTIONS, TIME PERCEPTION AND PROSPECTIVE MEMORY IN ADULTS WITH DYSLEXIA

CHARLES A MENSAH

A thesis submitted in accordance with the conditions of London South Bank University for the degree of Doctor of Philosophy

November 2021

Dedicated to my wife Denise and my children Casey and Havanah

Acknowledgements

I am grateful to God for granting me the strength and focus to successfully complete this thesis. I would like to extend my gratitude to my wife and daughter who always encouraged me throughout the different phases of the thesis through to its completion. I acknowledge their patience, understanding and support over the last five years. I would like to acknowledge my fellow PhD students who welcomed me into the research community and were always there to support me whenever I needed advice and guidance. Finally, I am extremely appreciative of my director of studies Dr James Smith-Spark and my second supervisor Dr Alexander Marchant, whose expert direction, knowledge and support contributed to the successful completion of this research project.

Abstract

Dyslexia-related difficulties have been reported in prospective memory, executive functions and time perception in both children and adults. With evidence of problems in these areas shown to persevere into adulthood, the extent of their presence was investigated in adults with and without dyslexia. Using a wide-range of experimental laboratory-based and semi-naturalistic and naturalistic tasks, prospective memory, executive functions and time perception were investigated in the two groups of university students with and without dyslexia. The two groups were matched for age and IQ and differed on spelling and reading tests. The results indicated prospective memory problems in adults with dyslexia when prospective memory performance relied on time-cues rather than on environmental cues and when time-cues were one-off rather than repetitive. Furthermore, adults with dyslexia showed problems in a range of executive functions related to set-shifting, dual-task performance and planning. There was no evidence of dyslexia-related difficulties in time perception tasks in both short duration (milliseconds range) and long duration (minutes range). The findings in this work point to several dyslexia-related problems that fall within the cognitive functioning range. Interpretations of the findings can be explained from the perspective of the dyslexia automatization deficit hypothesis and the supervisory attentional system rather than merely from the point of view of the phonological deficit hypothesis.

Key thesis chapters

Chapter 1 Dyslexia…...…………………………………………………………...16

Chapter 2 General method and structure of test sessions..……………………..…..37

Chapter 3 Prospective memory………………………………………………………...45

Chapter 4 Executive functions…………………………………………………..107

Chapter 5 Time perception……………………….………………………….…...147

Chapter 6 General conclusion…..…………………………………………….....193

Contents

Key thesis chapters 5

Chapter 1.0 Dyslexia 16

1.1 Definition 16

1.2 Theoretical models of dyslexia 17

1.2.1 Single deficit approaches 17

1.2.2 Multiple deficit approaches 26

1.3 Broader issues with cognition in dyslexia 28

1.4 Persistence of dyslexia-related deficits 35

1.5 Conclusion 36

Chapter 2.0 General method, sampling, screening tasks and structure of each test session 37

2.0.1 Overview of chapter 37

2.1 General method 37

2.1.1 Introduction - Screening Measures 37

2.1.2 Methodology and design 38

2.1.3 Screening Measures 40

2.1.3.1 Intelligence quotient measure; Wechsler Adults Intelligence Scale; WAIS-IV (2010) 40

2.1.3.2 Reading assessment: The DAST nonsense word passage (Fawcett & Nicolson, 1998) 40

2.1.3.3 Spelling assessment: WORD spelling test (Wechsler, 2010) 41

2.1.3.4 Results 42

2.1.3.5 Conclusion 42

2.2 Structure of each test session 43

Chapter 3.0 Prospective Memory 45

3.1 Overview of chapter 45

3.2 Definition and key concepts 45

3.2.1 Prospective memory tasks 46

3.2.2 Processes and strategies involved in PM 48

3.3 Prospective memory theories 49

3.4 Prospective Memory problems and dyslexia 52

3.4.1 Possible explanations of PM difficulties in dyslexia 57

3.4.1.2 Problems with the retrospective component of PM as an explanation of dyslexia-related PM deficits 57

3.4.1.3 Prospective component of PM as an explanation of dyslexia-related PM deficits 59

3.4.1.4 Time perception as an explanation of dyslexia-related PM problems 61

3.5 Rationale for including multiple measures to explain PM failure in dyslexia 63

3.6 Materials for PM tasks 64

3.7 Design for PM tasks 65

3.8 Study 1: Laboratory-based EBPM and TBPM measures 65

3.9 Task 1: Rationale and hypotheses for computerized EBPM task 65

3.10.1 Task 1: Computerized EBPM task 66

3.10.2 Design, method and procedure - laboratory-based computerized EBPM task 66

3.10.3 Results..67

3.10.3.1 Results: between-group comparison on EBPM task performance..67

3.10.3.2 Results: Between-group comparison on ongoing-task performance 68

3.10.3.3 Results: Between-group comparison on RT on ongoing-task performance 68

3.10.4 Discussion...69

3.11 Task 2: Rationale and hypotheses for a computerized TBPM task laboratory-based task 70

3.11.1 Design, method and procedure for the computerized TBPM Task 71

3.11.2 Results..72

3.11.2.1 Results: Between-group comparison on TBPM task performance..72

3.11.2.2 Results: Between-group comparison on clock checking tendencies 72

3.11.2.3 Results: Between-group comparison on reaction times to ongoing task.......................................73

3.11.3 Discussion...74

3.12 Task 3: The Rivermead Behavioural Memory Test (Wilson, et al. 2008) – An everyday memory laboratory-based task...76

3.12.1 Rationale and hypotheses for the inclusion of the RMBT-III 77

3.12.2 Design, method and procedure for the Rivermead Behavioural Memory Test version III 78

3.12.3 Results..79

3.12.3.1 Results: MANOVA analyses: Main effects and interaction effects between task type, participant group and time of testing 79

3.12.3.2 MANOVA analyses: Within-subjects time of testing performance 80

3.12.3.4 Results: Independent-samples t-tests for between-group performance analyses related to first and second names recall, appointments after a delayed period recall, combined indices of immediate versus delayed recall and overall summary performance. 80

3.12.4 Discussion 82

3.13 Study 2 Laboratory-Based Meal Preparation Simulation Task 84

3.13.1 Task 1: The Dresden Breakfast Task 84

3.13.2 Rationale and hypotheses for inclusion of Dresden Breakfast task 84

3.13.3 Design, method and procedure for the Dresden Breakfast task 86

3.13.4 Results 88

3.13.4.1 Results: 2-Way ANOVA PM task type within-group performance 88

3.13.4.2 Results: 2-Way ANOVA PM task type performance between-groups 89

3.13.4.3 Results: 2-Way ANOVA Ongoing Breakfast Task performance between-group 90

3.13.5 Discussion 91

3.14 Study 3 Naturalistic TBPM task 93

3.14.1 Task 1 Naturalistic TBPM task over longer intervals 93

3.14.2 Rationale and hypotheses for using a Naturalistic TBPM task - longer interval 94

3.14.3 Design, method and procedure 94

3.14.4 Results 95

3.14.4.1 Results: 2 x 2 Chi Squared Test of Association on the likelihood of the successful performance of naturalistic TBPM task........95

3.14.4.2 Results: 2 x 2 Chi Squared Test of Association on the use of mental strategies between-groups........96

3.14.4.3 Results: Independent-samples t-test on the length of gap between the given instruction and expected response between-groups........97

3.14.5 Discussion........97

3.15 General Discussion........99

Chapter 4.0 Executive functioning........107

4.0.1 Executive summary........107

4.1 General definition and chapter overview........107

4.2 Executive functioning framework........108

4.3 Core EFs........109

4.3.1 Inhibitory Control........109

4.3.2 Updating working-memory........110

4.3.3 Set shifting........110

4.3.4 Verbal fluency (Phonemic Fluency)........111

4.5 Core EF problems in dyslexia........112

4.5.1 Supervisory attentional system dysfunction hypothesis........112

4.6 Study rationale for Core EF's and hypotheses........114

4.7 Method........117

4.7.1 Participants 117

4.7.2 Materials 118

4.7.3 Design and procedures for core EF measures 118

4.7.4 Inhibition (Go/No Go Task) 118

4.7.5 Updating working-memory (AOSPAN Task; e.g., Unsworth, Heitz, Schrock, & Engle, 2005) 119

4.7.6 Set Shifting (Plus/Minus Task; e.g., Jersild, 1927) 119

4.7.7 Phonemic fluency 120

4.8 Results for Core EFs 121

4.8.1 Inhibition 121

4.8.1.1 Independent-samples t-test - Habituation phase 121

4.8.1.2 Independent-samples t-test - Inhibition phase 121

4.8.2 Updating working-memory 122

4.8.3 Set Shifting (Plus / Minus Task) 122

4.8.3.1 2x3 Repeated measures ANOVA main and interaction effects operation mode 122

4.8.3.2 Independent-samples t-test – Between-group cost of switching 122

4.8.4 Phonemic Fluency 123

4.8.4.1 Independent-samples t-test – Between-group word production 123

4.9 Discussion of core EFs 123

4.10 Broader EFs 125

4.10.1 Definition 125

4.10.2 Dual Task Performance 125

4.10.3 Planning 127

4.11 Dyslexia and broader EFs 128

4.12 Study Rationale for Broader EFs and related hypotheses 131

4.13 Method 132

4.13.1 Participants 132

4.13.2 Design and Procedures for broader EF measures 133

4.13.3 Dual-task performance 133

4.13.4 Planning (Trail Making Test) 135

4.13.5 Results for broader EFs 136

4.13.5.1 Dual-task Performance 136

4.13.5.2 Two-way repeated measures ANOVA Between-group task performance 136

4.13.5.3 Independent-samples t-test between-group performance on independent task-mode 137

4.13.5.4 Independent-samples t-test between-group performance on dual-task mode 137

4.14 Planning 139

4.14.1 Two-way repeated measures ANOVA performance 139

4.14.2 Independent-samples t-test: Between-group performance: Cost of switching 139

4.15 Discussion of broader EFs 140

4.16 General discussion 142

Chapter 5.0 Time perception 147

5.0.1 Executive summary......147
5.1 Overview of chapter......147
5.2 Definition of time perception......148
5.3 Theoretical models of time perception......149
5.4 Types of tasks used in assessing short duration time perception......154
5.4.1 Temporal generalization task......154
5.4.2 Bisection task......155
5.4.3 The verbal estimation task......157
5.5 Time perception in dyslexia......158
5.6 Study 1 Rationale......162
5.7 Method......163
5.7.1 Participants......163
5.7.2 Materials......163
5.7.3 Study 1 – General temporal Generation Task......164
5.7.3.1 Design......164
5.7.4 Study 1: Task design and procedures......164
5.7.4.1 The temporal generalization task......164
5.7.4.2 Results......165
5.7.4.2.1 Two-way repeated measures ANOVA between-group performance......165
5.7.4.3 Discussion......167

5.8 The Bisection Task 168

5.8.1 Results 169

5.8.1.1 Two-way repeated measures ANOVA on task performance 169

5.8.1.2 Discussion 172

5.9 The verbal estimation task design and procedure 173

5.9.1 Results 174

5.9.1.1 Two-way repeated measures ANOVA on task performance 174

5.9.1.2 Discussion 177

5.10 Study 2: Introduction – Longer durations - Prospective and Retrospective time perception 178

5.11 Study 2 Rationale - short duration minutes interval measures 181

5.12 Retrospective and prospective time perception measures design and procedures 183

5.13 Retrospective time perception measure design and procedure 183

5.13.1 Results 183

5.13.1.2 Discussion 184

5.14 Prospective time perception Longer interval design and procedure 185

5.14.1 Results 186

5.14.1.2 Discussion 186

5.15 General discussion for shorter and longer time perception durations. 186

Chapter 6.0 General conclusions 193

6.0.1 Overview of the concluding chapter 193

6.0.1.2 Outline of overall findings 193

6.0.1.3 Prospective memory: summary of findings......194

6.0.1.4 Executive functions: summary of findings......195

6.0.1.5 Time Perception: summary of findings 196

Chapter 6.1 Correlations between measures of dyslexia severity and scores on the PM, EF and TP tasks 197

6.1.1 Pearson correlations of the performance between the scores on the cognitive tasks and the spelling, reading and IQ abilities of the whole sample 199

6.1.2 Pearson correlations of the performance between the scores on the cognitive tasks and the spelling, reading and IQ abilities of the dyslexia only......202

6.1.3 Discussion......203

6.2 An overview of a dimensional view of profiles of strengths and weaknesses in dyslexia versus non-dyslexia PM and EF task performance 205

6.2.1 Linking the findings to previous research and theory 205

6.3 Conclusion 213

Chapter 1.0 Dyslexia

1.1 Definition

Dyslexia is the most frequently occurring developmental condition (e.g., Lyon, 1996; Shaywitz, 1998; Shaywitz & Shaywitz, 2003) with documented occurrences reported as being between 5 and 17% in the Western population (e.g., Badian, 1984; Jones, Kuipers, & Thierry, 2016; Katusic, Colligan, Barbaresi, Schaid, & Jacobsen, 2001; Shaywitz, 1998; Shaywitz, Shaywitz, Fletcher, & Escobar, 1990). This wide-ranging estimate of incidences is a consequence of the diversity of definitions and diagnostic criteria developed in studying dyslexia (e.g., Elliot & Grigorenko, 2014). Dyslexia has been defined as a particular learning difficulty that is characterized by enduring problems in the ability to accurately and fluently read, spell or both (e.g., World Health Organisation, 2011). Reading and spelling difficulties in people with dyslexia may be experienced when converting written symbols into sound (reading) and/or when articulating words into written symbols (spelling and writing; World Federation of Neurology, 1968). These difficulties may adversely influence an individual's capacity to make sense of written materials such as academic textbooks or employment application forms. It is widely acknowledged that in most people with dyslexia, a difficulty in the decoding of the written word to sound is linked to deficits in speech sound manipulations rather than deficiency in identification of visual symbols (e.g., Ahissar, 2007). Reading and spelling difficulties are specific and may arise in dyslexia despite adequate levels of intelligence and learning abilities. This is what differentiates the individual with dyslexia from the "garden-variety" poor readers (e.g., Orton Dyslexia Society Research Committee, 1994). Fisher and DeFries (2002) indicated that dyslexia is highly inheritable, with a reported proportion of between 30 to 50% likelihood of being genetically transmitted from parent to child. In contrast to single deficit approaches (e.g., phonological deficit hypothesis (Snowling, 1987; Velutino, 1979) which present core deficit explanations of dyslexia see Section 1.2.1), multiple deficit approaches (e.g., Pennington, 2006) point to the multiple comorbidity of neuropsychological profiles that share risk factors pertaining to genetic, environmental, neurobiology, cognition and an interaction between these (see Section 1.2.2). Given that textbook resources are accessed through reading, problems with reading may be a challenging issue in practically all of a child's educational learning experiences. Brunswick et al. (2010) have indicated that the frequency of the occurrence of dyslexia is marginally lower in other languages and writing systems than it is in English. The greater challenge in English reading fluency has been attributed to the presence of deep orthography wherein the representation between word and sound may not correspond directly or consistently (e.g., Richlan, 2014). Dyslexia's underlying cognitive explanations are still passionately debated and have generated divergent theories in explaining the basis of its occurrence (Ramus, 2003). Research suggests that reading and spelling problems in dyslexia do not occur independently (e.g., Brosnan et al., 2002; McLean, Stuart, Coltheart & Castles, 2011; Fawcett & Nicolson, 1999; Wang & Gathercole, 2013).

Dyslexia is commonly indicated to co-occur with poor verbal working memory (e.g., Snowling, 2000). Commonly, dyslexia is characterized by deficits in language processing (e.g., Rosen, 2003), visual processing, phonological awareness (e.g., Snowling, 1987; Vellutino, 1979), verbal processing speed (e.g., Valdois, Lassus-Sangosse, & Lobier, 2012), verbal memory (e.g., Kramer, Knee & Delis, 2000), as well as focused, switching and sustained attention (e.g., Moores, Nicolson & Fawcett, 2003). An important argument to consider relates to whether reading and spelling deficits are limited to language (i.e., they are domain- specific) or whether they are extensive and relate to both processing of verbal and non-verbal stimuli (i.e., they are domain-general). Theoretical models from which dyslexia is explained will be considered in the next section.

1.2 Theoretical models of dyslexia

1.2.1 Single deficit approaches

Theoretical models and empirical studies have largely explained reading and spelling problems in dyslexia through the phonological deficit hypothesis

(Snowling, 1987; Velutino, 1979; see also Vellutino et al., 2004). According to this theory, the difficulties experienced by people with dyslexia when decoding written words into sound are a consequence of a domain-specific deficit limited to a particular facet of language area - that is phonemes. A phoneme is the smallest part of a word that differentiates any individual word sound (e.g., “r” in rig) from another word (e.g., “p” in pig) within any language system. The phonological deficit hypothesis argues that impaired awareness of, access to, or inadequate representations of rudimentary speech sounds account for poor decoding of phonemes (Bradley & Bryant, 1983). A shortcoming of the phonological deficit hypothesis is that it overlooks manifestations of motor and sensory deficits in dyslexia (e.g., Ramus et al., 2003). Additionally, the theory fails to explain spatial working memory deficits (e.g., Smith-Spark, Fisk, Fawcett & Nicolson, 2003; Smith-Spark & Fisk, 2007). Even so, phonological hypothesis theorists have argued that sensory and motor deficits are not core characteristics of dyslexia and have merely stipulated their concurrence with phonemic deficits as conceivable indicators of dyslexia (e.g., Snowling, 2000). Moreover, the theory accounts for verbal working memory problems in dyslexia through deficient access to phonological representations (e.g., Isaki, Spaulding, & Plante, 2008). The central tenet that supports the association of impaired access to phonological representations and poor verbal working memory ability is grounded in Baddeley’s (1986) model of working memory. Baddeley’s working memory model postulates that an activated stimulus in working memory is preserved for two to three seconds and requires repetition for preservations beyond this interval. Dyslexia-related verbal working memory problems have been linked to poor access to phonological representations (e.g., Snowling, 2000; Mann & Liberman, 1984). The function of impaired access to phonological representations is considered to weaken working memory capacity in dyslexia.

An alternative line of reasoning underscores impaired working memory as the core deficit – and attributes this deficit to people with dyslexia’s impaired phonemic awareness (e.g., Gathercole & Baddeley, 1990). Given that phonological awareness tasks characteristically involve manipulations and recall of series of speech sounds, Landerl and Wimmer (2000) have argued that the complexity envisaged in executing such tasks is likely to hinder performance even in instances where phonemic awareness proficiency is considered as being at a satisfactory level. Although a fundamental assumption of the phonological deficit hypothesis advocates a domain specific difficulty in accounting for reading and spelling problems in dyslexia, individuals with these problems typically have extensive cognitive problems which involve other verbal abilities (e.g., Bishop & Snowling, 2004), poorer attentional capabilities (e.g., Kadesjo & Gillberg, 2001), and weaker abilities in an array of tasks including simple visual tasks (e.g., Ramus et al., 2003; Talcott et al., 2003) and simple auditory tasks (e.g., Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Ahissar, Protopapas, Reid, & Merzenich, 2000). Dawes et al. (2009) have argued that since cognitive deficits and reading and spelling difficulties co-occur in dyslexia, the phonological deficit hypothesis would therefore have to consider the concurrence as being of no functional significance in incidences of dyslexia. Studies such as those of Ahissar, Lubin, Putter-Katz, Banai, (2006), and Banai and Ahissar (2006, 2009) have endorsed Dawes et al.'s assumption that the extent of deficiencies in dyslexia extends to broad cognitive and perceptual domains (i.e., it is domain-general) as opposed to domain-specific.

A different interpretation of reading and spelling difficulties in dyslexia shifted the focus from a linguistic to a non-linguistic paradigm. An earlier model grounded in the non-linguistic assumption is the auditory temporal processing deficit hypothesis by Tallal (1980). Tallal posited that dyslexia-related phonological problems are a consequence of low-level auditory processing deficiencies that interrupt one's sensitivity in distinguishing auditory features that are exemplified by short durations or rapid variations. Consistent with this outlook, a rudimentary deficiency in temporal processing induces difficulties in assimilating rapid succession sensory information coming into the central nervous system. As indicated in Tallal, Miller and Fitch (1993), this creates a series of consequences that begins with interference of typical development of the phonological system and, following this difficulty in attaining typical reading ability.

The auditory temporal processing deficit hypothesis suggests that impaired reading and spelling difficulties in dyslexia occur as a result of problems in processing brief sounds in the range of 20-30 Hertz. Tallal (1980) proposed that this deficit negatively influences awareness of speech sounds which in turn leads to ambiguous acquisition of phonemic representations. Scrutiny of the model's predictions has yielded contrasting conclusions (e.g., Amitay et al., 2002; compared with Groth, Lachmann, Riecker, Muthmann, & Steinbrink, 2011); Lehongre, Ramus, Villiermet, Schwartz, & Giraud, 2011). Tallal's model has been assessed with non-linguistic stimuli to explore temporal processing. Linguistic stimuli have also been used to study phonological processing. In Bretherton and Holmes, (2003) and Nittrouer, (1999), it was reported that there was no correlation between temporal processing impairments and phonological processing problems. In studies such as those of Boets, Wouters, van Wieringen, and Ghesquiere, (2007) and White et al. (2006) it was reported that phonological difficulties can arise in the absence of temporal processing problems - which provides support for the phonological deficit hypothesis of dyslexia and argues against a temporal processing problem being at the core of dyslexia.

On the other hand, the cerebellar deficit hypothesis proposes that dyslexia occur as a result of deficiencies in the cerebellum, and that this is largely related to difficulty in skill automatization (e.g., Nicolson, Fawcett & Dean, 2001). The theory posits that the onset of dyslexia commences from structural defects in the cerebellar lobes. The defects are said to cause problems in motor movement and implicit learning (the procedure through which our skills attain automaticity; Doyle, 2017). Whereas motor deficiency is associated with motor control problems which impede writing ability (e.g., Nicolson, Fawcett & Dean, 2001), implicit learning deficits impedes the ability to attain skill automaticity. Difficulty in automatization in dyslexia can impede conversions from grapheme-phoneme. Grapheme-to-phoneme conversion refers to the process of articulating words from their written arrangement (grapheme) system into their sound sequence (phonemes). The consequence of this, according to the cerebellar deficit theory, can manifest into reading and spelling deficits in dyslexia. Evidence in support of the cerebellar deficit hypothesis can be found at the neural and behavioural levels. At the neural level, evidence suggests that deficiencies located in the right cerebellar lobe (Eckert et al., 2003) including biochemical variances are suggestive of lower cell concentration of choline - containing compounds – a marker of overall cellular density (Rae et al., 1998). Furthermore, Kibby, Fancher, Markanen, and Hynd (2008) have reported that the presence of dyslexia is signified by atypical irregularity of the cerebellar lobes. Nevertheless, some individuals with dyslexia show typical symmetry and functioning of the cerebellar lobe - suggesting that not all instances of dyslexia can be explained by the cerebellar deficit theory. At the behavioural level, evidence of motor deficits in dyslexia have been linked to the cerebellar deficit theory. Such evidence points to motor deficits in dyslexia that are comparable to those indicated in cerebellar lesion patients (Fawcett & Nicolson, 1999; Fawcett et al., 1996).

Other studies that have reported impaired automaticity in individuals with dyslexia include, for example Henderson & Warmington (2017), and Nicolson and Fawcett, (1990), with the latter discussed at length as an example. In Nicolson and Fawcett (1990), the performance of 23 13-year-old children with dyslexia were compared with age-matched controls on a series of motor balance assessments. A dual-task paradigm was employed. The participants carried out all tasks two times - which entailed performing each task once independently, and once in dual task mode simultaneously with a secondary task. Two alternative secondary tasks were employed. They consisted of a classic counting-backwards task and an auditory choice reaction task. In order to ensure that participant performance matched a pre-specified benchmark, the tasks were standardized for each participant. The results showed that in the single-task condition, there was no group difference. Conversely, in 19 out of the 20 tasks carried out in the dual-task condition, the group with dyslexia was found to be significantly impaired. In comparison, the performance of the group without dyslexia was superior as they did not show any deficits. The only discrepancy as reported by Nicolson and Fawcett was that the group with dyslexia did not show impairments in the easiest balance condition with the choice reaction task. In the dual-task conditions, the group with dyslexia performed significantly less well on the secondary task in comparison with the control participants. Nicolson and Fawcett explained their results by asserting that, unlike children without dyslexia, those with dyslexia must dedicate substantial conscious resources in order to monitor balance. The cost of this consequence negatively impacts on a secondary task which functions as an interference of attention on the primary task. Nicolson and Fawcett's work demonstrated that in children with dyslexia, when the need for conscious compensation arises, motor balance skill is weakly automatized. Nicolson and Fawcett thus argued that numerous reading problems found in children with dyslexia are just indications stemming from a more domain-general learning deficit that hinders the achievement of full-automatized skill.

Conversely, the magnocellular theory attributes the occurrence of dyslexia to low-level sensory processing deficits (Stein, 2001) owing to deficient magnocellular cells in the brain (Livingstone, Rosen, Drislane, & Galaburda, 1991). Magnocellular deficiencies impede the ability to detect rapid brief visual or auditory stimuli. Moreover, Stein and Walsh (1997) and Stein (2001) have argued that this in turn leads to difficulty in visuo-motor and binocular control (synchronizing and integration of eyes) by means of connections located between the magnocellular cells in the lateral geniculate nucleus and the posterior parietal cortex (Stein, 2001; Stein & Walsh, 1997). According to this theory, dyslexia-related difficulties in reading are due to weak perceptual control which result in distortion and letter movements and are attributed to deficiencies in visuo-motor and binocular fixations (Stein, 2001). Furthermore, the magnocellular theory suggests that phonological deficits in dyslexia are a result of atypical magnocellular cells which create difficulties in detecting rapid transient auditory stimuli. As a consequence of this, the magnocellular theory posits that the acquisition of phonological proficiency required for reading is problematic in dyslexia (Stein, 2001). Criticisms of the magnocellular theory derives from studies that have reported dyslexia-related reading and phonological deficits without underlying atypical magnocellular functioning (Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Kronbichler, Hutzler, & Wimmer, 2002). This implies that magnocellular deficits are not the central contributory factor to the occurrence of dyslexia. Moreover, although magnocellular activity is linked to reading proficiency, the link may not be causative as demonstrated by non-readers who showed variations in pre-post variances in the magnocellular layers subsequent to learning to read (e.g., Olulade, Napoliello, & Eden, 2013). Magnocellular deficits could thus be resultant as opposed to the basis of poor reading proficiency.

Alternatively, the anchoring deficit hypothesis (Ahissar, 2007; Ahissar et al., 2006) also based on a non-linguistic principle has presented an explanation for reading and spelling deficiencies in dyslexia through the dynamics of perception. The model argues that difficulties in the processing of auditory stimuli negatively impacts on short-term memory which in turn influences a wide range of problems in dyslexia. Evidence in support of the anchoring deficit hypothesis has shown that people without dyslexia rapidly and involuntarily anchor to incoming stimuli and perform quicker with greater levels of accuracy when subsequently re-presented with the stimuli. In contrast, the evidence points out that people with dyslexia are disadvantaged in processing of repeated presentations of specific stimuli due to their faster decay of implicit memory of previously presented stimuli. The anchoring deficit hypothesis advocates that an anchoring deficiency in dyslexia can account for phonological, working memory, visual, auditory problems, and greater sensitivity to external noise.

On the other hand, the cross-modal processing deficit hypothesis (Warmington & Hulme, 2012) posits that reading and spelling difficulties in dyslexia stem from cross-modal letter-to-speech sound integration discrepancy. Research in this area has indicated that proficiency in learning arbitrary pairings of visual stimuli and phonological labels is a robust indicator of reading capability (e.g., Warmington & Hulme, 2012). In demonstrating support for the cross-modal account, Warmington and Hulme (2012) reported that visual to verbal paired-associate learning rather than phoneme recognition predicted word recognition - whereas visual to verbal paired-associate learning and phoneme awareness were predictors of non-word reading. What is more, Jones et al. (2013) reported that reading difficulties in adults with dyslexia can be predicted by cross-modal binding deficits at early stages of word learning. Cross-modal binding can be referred to as the capacity to form a perception that involves interaction between two or more disparate sensory modalities. In this regard, the cross-modal or binding effect relates to visual to phoneme associations as a predictor of word reading. In Jones et al's work, a visual-phonological binding association effect was found to be a predictor of word reading. For supplementary reviews on binding association effects, see Blau et al. (2010), Blomert, (2011), and Dehaene et al. (2010).

An integrative theory proposed by Szmalec, Loncke, Page, and Duyck (2011) has argued that both linguistic and non-linguistic deficits related to learning and memory in individuals with dyslexia derive from memory deficiency for serial-order information recall. This relates to the uniformity of the sequence in which stimuli are presented. Learning based on sequence is the procedure in which one can develop sensitivity to serial-order consistencies in presented sequences of information (Berry & Dienes, 1993). According to Conway and Christiansen (2001), sequence learning is key in language acquisition. Studies such as those of Hepper, Scott and Shahidullah (1993), and Saffran, Aslin and Newport (1996) have shown that, our ability to acquire distributional phonological awareness stems from the stage of infancy where sensitivity towards sequential consistencies in our native language. Studies (e.g., Bogaerts, Szmalec, Hachmann, Page & Duyck, 2015a; Szmalec et al., 2011) have reported a deficiency in the sensitivity to regularities of sequential information in adults with dyslexia. Szmalec et al's integrative theory was founded on deficits in adults with dyslexia in relation to their performance on recall for repeated sequence of spatial and verbal stimuli for the duration of an immediate serial recall task (Hebb, 1961). Experimental evidence shows that Hebb repetition learning can be regarded as a laboratory equivalent of lexical acquisition. Page and Norris, (2008, 2009) have asserted that laboratory alternatives that are equivalent to lexical learning of a novel word (e.g., ‘’beejayeffemmelle’’) is comparable to acquiring a sequence of letters (e.g., B J F M L) in a process of repeated presentations. Bogaerts, Szmalec, Hachmann, Page, and Duyck (2015a) have reported a direct link between deficits in Hebbian learning of verbal serial information and problems related to the acquisition of novel word representations in dyslexia. Moreover, problems related to short-term memory for order (recall sequential positions of a stimulus in a list) has been reported in adults and children; but to a lesser degree for item information (Hachmann et al., 2014; Martinez Perez, Majerus, & Poncelet, 2013; Perez, Majerus, Mahot, & Poncelet, 2012). Serial order deficits appear to manifest in both verbal and non-verbal processing.

Although there is ample theoretical and empirical evidence to substantiate the phonological deficit hypothesis, a core deficit model, the occurrence of dyslexia cannot fully be explained by one core underlying shortfall. By and large, empirical research that have explored cognitive indicators of reading attainment have found effects that stem beyond that of phonological discrepancy in explaining the extent of reading proficiency (e.g., Catts, Nielsen, Bridges, & Bontempo, 2015; McGrath et al., 2011; van Bergen, de Jong, Regtvoort, Oort, van Otterloo, & van der Leij, 2011). A potential difficulty for the phonological core deficit hypothesis pertains to the observation that not all individuals who have difficulty in phonological awareness do exhibit the typical difficulties in word reading that are characteristic of dyslexia (e.g., Pennington et al., 2012; Snowling, 2008).

For instance, Pennington et al. (2012) employed two large groups of children and revealed that whilst many of the children exhibited substantial phonological processing difficulty, those children did not present any problems in word reading. Additionally, in Moll, Loff, and Snowling, (2013), it was reported that typically-developed siblings from families who have historical occurrences of phonological problems did not always exhibit word reading problems. The presented empirical evidence does not rebut the function of dyslexia-related phonological problems.

Rather, such evidence is suggestive of other problems that coexist with phonological awareness difficulties. Thus, multiple deficit models of dyslexia have been explored (e.g., Catts & Adlof, 2011; Pennington, 2006; Snowling, 2008; Torppa, Parrila, Niemi, Lerkkanen, Poikkeus, & Nurmi, 2013; van Bergen, de Jong, Maassen, & vander Leij, 2014). These are discussed in the next section.

1.2.2 Multiple deficit approaches

Pennington (2006) has maintained that the occurrence of complicated disorders such as dyslexia is implicated in multiple factors and their interactivity with several risk factors. Multiple deficit approaches such as Pennington's model propose that deficits in phonological awareness may be the chief underlying factor, although this would be exhibited together with additional biological and/or environmental risk factors. The multiple deficit approaches of dyslexia propose that the risk factors function by way of probability - such that they either amplify or weaken the prospects of the occurrence of dyslexia. For example, Snowling et al. (2003) purported that oral language problems may be a fundamental contributory factor in dyslexia. Snowling et al. proposed that the semantic element of word reading may augment the likelihood of reading problems in children who have phonological awareness difficulties. On the other hand, sufficient language abilities or semantic proficiency can function as protective mechanism for children with a phonological awareness difficulty.

Evidence for the aforementioned was demonstrated by Snowling et al. (2003) and showed that though affected and non-affected siblings with a familial record of dyslexia can have phonological awareness difficulty, those affected had a greater likelihood of exhibiting language problems in preschool and early school assessments. Furthermore, Moll et al. (2013) revealed in children who had a family history of dyslexia that siblings unaffected showed enhanced comprehensive language abilities compared with siblings who were affected. Peterson, Pennington, Shriberg, and Boada (2009) revealed that children who had a speech sound condition with phonological processing problems generally did not have dyslexia, except for cases in which the children additionally have a language difficulty. Additionally, studies (e.g., Snowling, 2008) has revealed that dyslexia in children are frequently accompanied with oral language difficulties and that the occurrence of dyslexia is often characterised with comorbid specific language impairment (e.g., Bishop, McDonald, Bird, & Hayiou-Thomas, 2009).

Rapid automatized naming is considered to play a function in multi deficit models. For example, investigations (e.g., Denckla & Rudel, 1976; Wolf & Bowers, 1999) reported evidence of problems in rapid automatized naming tasks in children with dyslexia. In such tasks, participants are asked to swiftly retrieve names of numbers, colours, and letters as well as objects that are shown on a stimulus card. Previously, a problem with rapid automatization naming was understood from the double deficit framework (Wolf & Bowers, 1999) as a distinct problem. Nonetheless, it was observed that children with phonological processing problems and rapid automatized naming generally exhibited greater difficulties in word reading. For instance, Bishop et al. (2009) revealed that children with language problems, who either exhibited or did not exhibit problems in word reading varied in rapid naming but not in phonological processing. Van Bergen et al. (2014) revealed in their dyslexia familial study that children who had the condition rather than those who did not, exhibited problems in rapid automatized naming. Furthermore, it was reported that the parents of children with dyslexia performed weaker than parents whose children did not have the condition. The presented evidence above indicates that problems in rapid naming may play a moderating role in dyslexia.

Pennington et al. (2012) explored the abovementioned factors in numerous dyslexia case studies. They identified children who had one or more problems in phonemic awareness, oral language, and/or rapid naming in kindergarten and linked the incidence of these difficulties with word reading results at the end of first grade. Single deficit and multiple deficit models were assessed. The results showed that a similar number of cases were linked to a single deficit as with a multiple deficit; a phonological processing deficit was found to be the most dominant problem in the two instances. Based on the presented evidence for multiple deficits in dyslexia, it is clear that the single deficit hypothesis is inadequate to account for all cases of dyslexia. Other cognitive problems that coexist with dyslexia are considered next.

1.3 Broader issues with cognition in dyslexia

By and large, reading and spelling difficulties in dyslexia typically co-occur with wide-ranging cognitive and perceptual deficits such as auditory short-term memory (e.g., Richardson et al, 2011); impaired automaticity (e.g., Henderson & Warmington, 2017; Nicolson & Fawcett, 1990), and short-term memory (e.g., Jorm, 1983; Fischbach, Könen, Rietz & Hasselhorn, 2014). There is evidence to suggest that memory processes involved in reading acquisition is related to long-term memory (e.g., Menghini, Carlesimo, Marotta, Finzi, & Vicari, 2010). Menghini et al. investigated whether the learning problems in dyslexia was limited to the verbal aspect of long-term memory abilities or whether learning problems in individuals with dyslexia were also negatively impacted on in visual-object and visual-spatial domain. Another of their aims was to explore the predictive ability of non-verbal long-term memory abilities in relation to word and non-word reading in children with dyslexia. The participants, both children with dyslexia and age-matched typical readers were assessed on verbal, visual-spatial and visual-object tasks. The results showed generic problems with episodic long-term memory abilities in the children with dyslexia. Additionally, individual differences found in the non-verbal long-term memory tasks were predictive of dyslexia-related reading problems. Menghini et al.'s study indicate that dyslexia-related long-term memory problems is not restricted to problems related to phonological components but additionally, that visual-object and visual-spatial aspect are also intricated. This thus indicates that dyslexia is linked to a compound of cognitive deficits.

In dyslexia, the contribution of memory processes in the acquisition of reading and its relatedness to long-term memory has been explained in terms of particular difficulty during encoding and storing of oral information in working memory (e.g., Bogaerts et al., 2015; Menghini, Finzi, Carlesimo, & Vicari, 2011; Palmer, 2000; Smith-Spark, Fisk, Fawcett & Nicolson, 2003; Smith-Spark & Fisk, 2007). Menghini et al. (2010) assessed children with dyslexia (age range: 8.4-17.6 years) and age-matched normal readers (age range: 8.1-15.7 years) on verbal, visual-spatial and visual-object tasks. Menghini et al. reported a comprehensive long-term memory deficit in children with dyslexia. They reported that there was diminished verbal, and visuo-spatial long-term memory abilities in children with dyslexia compared with an age-matched group of normal readers. Decreased abilities in verbal long-term memory frequently reported in dyslexia are commonly understood as being the result of phonological coding problems. Besides verbal assessments, individual differences in non-verbal long-term memory tasks were found to reliably predict reading problems in dyslexia. Menghini et al. showed that dyslexia-related long-term memory problems are not restricted to deficiencies related to phonological factors – but that they also contribute in the visual-object and visual-spatial domains. This suggests that the occurrence of dyslexia is linked to a range of cognitive problems. Other cognitive difficulties include short-term memory problems which have been reported in dyslexia (e.g., Fischbach, Könen, Rietz & Hasselhorn, 2014; Hachmann, et al., 2014; Perez, Majerus, Mahot, & Poncelet, 2012; Jorm, 1983).

Perez et al. (2012) reported a specific deficit of serial order short-term memory in dyslexia. Perez et al. used the distinction between item and serial order retention abilities to further the understanding of verbal short-term memory deficits in developmental dyslexia. Children with developmental dyslexia and chronological age-matched controls and reading-age-matched controls were tested. A serial order short-term memory task measured recall of sequential order information through reconstruction. In the task, auditory presentation of sequences of familiar animal names were played at one item per second (e.g., cat, dog, lion, wolf, monkey). Each trial was presented with an increasing list length. After each trial, participants were given cards in alphabetical order to represent the exact animals presented to them in the trial and had to rearrange them based on order of presentation. In another task, a short-term memory task assessed item information (an adaptation of the delayed item repetition task; Leclercq & Majerus, 2010). Stimuli included single nonwords and were presented individually to the participants. After each stimulus presentation, the participants were required to repeat each nonword and immediately had to count in steps of two during a six-seconds epoch. It was reported that the group with dyslexia performed significantly less well in their item short-term memory ability and in their serial order short-term memory compared with the controls in the chronological age group. In the group with dyslexia, item weaker recall ability was expected on the basis that item short-term memory is contingent on the recruitment of phonological processes – and these have been shown to be deficient in dyslexia. Perez et al.'s findings provide evidence that demonstrate an acute deficit in short-term memory for serial order information in dyslexia which cannot be attributed to a phonological processing deficit.

Auditory processing deficits have been reported to co-occur with reading problems in dyslexia (e.g., Law, Vandermosten, Ghesquiere, & Wouters, 2014; Ramus et al., 2003). For instance, Law et al. investigated whether auditory, speech perception, and phonological skills were strongly correlated or whether they independently contributed to reading in adults with dyslexia versus age-matched typical reading adults. The assessment of phonological skills comprised of rapid automatic naming, verbal short-term memory and phonological awareness tasks. Dynamic auditory processing skills were measured through a frequency modulation and an amplitude rise time. An intensity discrimination task was employed as a measure of a non-dynamic control task. Speech perception was measured by way of sentences and words-in-noise tasks. The results showed that there were significant group variances in the auditory tasks (i.e., amplitude rise time and intensity discrimination) as well as in the phonological processing tasks. However, no group difference was reported for the speech perception task performance. A correlation was found between performance of amplitude rise time task and reading. Although the association was mediated by phonological processing and not by speech-in-noise. Examination of individual scores showed that the group with dyslexia had a larger percentage of participants on the slow-dynamic auditory and phonological tasks, even though every participant with dyslexia did not demonstrate an obvious pattern of problems across the processing skills. Law et al. concluded that although the findings provide support of phonological and slow-rate dynamic auditory problems which is linked to literacy; they argued that at the individual level, dyslexia-related reading and writing difficulties cannot be accounted for by the auditory processing theory. Instead, Law et al. suggested that adults with dyslexia differ significantly according to the degree to which each auditory and phonological factor is conveyed and interact with environmental and higher-order cognitive influences. Visual processing deficits have been shown to occur with reading problems in dyslexia (e.g., Lobier, & Valdois, 2015; Prado, Dubois, & Valdois, 2007). In Prado et al.'s study as an example, the eye movements of children with dyslexia were shown to have a reduced visual attention span versus typical children without dyslexia. All participants were assessed with two tasks comprising of text reading and visual search. It was reported that the group with dyslexia showed higher numbers of rightward fixations but only during the reading. It was reported that the group with dyslexia concurrently processed similarly low numbers of letters during both tasks. In comparison, the group without dyslexia processed significantly more letters during reading. A key finding was that the children's visual attention span capacities correlated with the number of letters that were concurrently processed during reading. Prado et al. concluded that the irregular eye movements shown in some individuals with dyslexia when reading, seems to suggest problems in enhancing their visual attention span in accordance with the task demands.

Working memory difficulties have been reported extensively in dyslexia (e.g., Menghini, Finzi, Carlesimo, & Vicari, 2011; Smith-Spark & Fisk, 2007). In Smith-Spark and Fisk (2007), the performance of adults with dyslexia was compared with age and IQ-matched adults without dyslexia. The participants were requested to perform verbal and visuospatial working memory tasks. Participant performance was compared on assessments of simple span, complex span (involving both storage and processing), and dynamic memory updating in the two domains. The results showed significant lower spans in the group with dyslexia in comparison to the control group on all the verbal tasks, comprising simple and complex, as well as on the spatial complex span assessments. It was found that deficits persisted even after controlling for simple span performance. Smith-Spark and Fisk suggested a dyslexia-related central executive deficiency. In comparison to the control group, in the group with dyslexia, it was reported that the novelty of task demands on the initial trials of the spatial updating task additionally showed additional difficulties. In the spatial updating task, participants were shown a pattern comprised of blank squares. Some of the blank squares were filled with “X” sequentially - but varied by the number of squares filled. The participants were forewarned on each trial how many would be highlighted (i.e., four, six, eight or ten). The task required participants to memorise the location of each cell highlighted on the screen. At the end of each trial, the participants were required to write down the location the last four cells appeared in order. Smith-Spark and Fisk proposed the likelihood of dyslexia-related difficulty in the supervisory attentional system of Norman and Shallice (1986). Furthermore, it was demonstrated that the working memory problems can affect functioning in both the phonological and visuospatial modalities, and implicate central executive dysfunction, in addition to problems with storage.

Cross-modal integration problems have been revealed in dyslexia and it has been shown that the capacity to learn visual to phonological associations can predict word learning. For example, in Jones, Branigan, Parra, and Logie (2013), learning of visual-phonological cross-modal associations or binding ability was investigated by comparing the performance of adults with dyslexia versus adults without dyslexia. Their participants were shown a single exposure of pairs of visual and phonological attributes. This represented cross-modal learning at the initial phases of binding. In two experiments, a detection task was performed by the group with dyslexia and those without dyslexia. The task assessed participants ability to differentiate between the similarity of the currently presented stimuli and those shown to them earlier at the learning stage. In Jones et al.’s first experiment, the learning phase comprised of the participants initially being presented with a learning variety of objects that were differentiated by visual features (shape), phonological attributes (phonology), and feature bindings (visual-phonological). During the test phase, the participants were presented with an alternative assortment of objects that comprised of the precise identical phonological features, visual features, or visual-phonological feature bindings, or those that varied in terms of feature or feature bindings. Jones et al. structured presentations such that the presentation of features/feature bindings were differed in terms of location during the learning phase in comparison to the test phase. In Jones et al.'s second experiment, features/feature bindings were presented in identical location in both the test and learning assortments. A group difference was revealed in the performance of two change-detection tasks on cross-modal binding ability based on encoding of spatial location. Specifically, in experiment one, Jones et al. reported that adults with dyslexia did not differ from those without dyslexia in their performances when location of features/feature bindings were identical. In contrast, compared to adults without dyslexia, those with dyslexia demonstrated significantly poorer accuracy binding accuracy when location was a consistent cue. Jones et al. demonstrated dyslexia-related cross-modal binding problems based on location information.

Prospective memory (PM) is recognized as memory for delayed intentions (Winograd, 1998) and involves one's capacity to form an intention, retain the contents of the intention and carry out the related action(s) following a delayed interval. The intended action is executed at a later point in reaction to a time-based cue or an environmental cue. Consistently, dyslexia-related difficulties (see Figure 1.1) have been reported in PM (e.g., Smith-Spark, Ziecik et al., 2016a, b, 2017a, b). In this modest corpus of evidence, PM problems have been found in adults with dyslexia in these measures - self-report questionnaires, naturalistic conditions, including laboratory-based tasks. In dyslexia, PM problems have been reported in intentions that are triggered by time-based cues or those that require self-prompting for successful activation. With regards to intentions that are triggered by specific environmental cues, the evidence indicate that dyslexia-related difficulty is displayed (e.g., Smith-Spark, Ziecik et al., 2017a) when the delayed period between formation of an intention and the required future response is prolonged (see Section 3.4 for a wider discussion).

Executive function (EFs) means a group of complex cognitive capabilities that are called upon to allocate attention to be engaged in conscious intentions. Executive Function deficits have been shown in dyslexia (see Figure 1.1) These deficits have been found in inhibition (e.g., Wang, Tasi & Yang, 2012), set shifting (e.g., Poljac et al., 2010), updating working-memory (e.g., Bacon et al., 2013), and phonemic fluency (e.g., Smith-Spark, Henry et al., 2017), - these are commonly referred to as Core EFs (see Sections 4.3 and 4.5 for a wider discussion). These EF problems extend to abilities linked to organization (e.g., Levin, 1990), planning (Torgeson, 1977), and dual-task performance (e.g., Nicolson & Fawcett, 1990), - these types of EFs are referred to as broader EFs (see Sections 4.10 and 4.11 for a comprehensive discussion).

Time perception difficulties have also been reported in dyslexia (see Figure 1.1). These problems have been revealed in these areas: time estimation (e.g., Gooch, Snowling, & Hulme, 2011; Khan, Abdal-hay, Qazi, Calle & Castillo, 2014; Nicolson, Fawcett, & Dean, 1995), allocation of time (e.g., Bruno & Maguire, 1993), timing precision and rhythm (e.g., Wolff, 2002), and auditory time perception (e.g., Tallal, 1980). Time perception imply the awareness of the passage of time (see Section 5.0 and 5.5 for a broader discussion). In a small body of evidence which has been focused on the milliseconds timing range, discernment of pairs of stimuli pertaining to auditory or visual types when presented in a rapid sequence, as well as identifying the order in which a differing pair of stimuli appeared first were found to be problematic in participants with reading problems (e.g., Lovegrove, 1993; Tallal, Miller & Fitch, 1993).

Taken together, the review of the abovementioned studies indicate broader cognitive dyslexia-related problems co-occur with dyslexia, namely, auditory short-term memory (e.g., Richardson et al, 2011); automaticity (e.g., Henderson & Warmington, 2017; Nicolson & Fawcett, 1990), short-term memory (e.g., Perez, Majerus, Mahot, & Poncelet, 2012), long-term memory (e.g., Menghini, Carlesimo, Marotta, Finzi, & Vicari, 2010), auditory processing deficits (e.g., Law, Vandermosten, Ghesquiere, & Wouters, 2014), visual processing deficits (e.g., Lobier, & Valdois, 2015; Prado, Dubois, & Valdois, 2007), Working memory difficulties (e.g., Menghini, Finzi, Carlesimo, & Vicari, 2011; Smith-Spark & Fisk, 2007), cross-modal integration problems, (e.g., Jones, Branigan, Parra, & Logie, 2013), prospective memory (e.g., Smith-Spark, Ziecik et al., 2016a, 2016b, 2017a, 2017b), executive functions (e.g., (e.g., Bacon et al., 2013; McLean, Stuart, Coltheart & Castles, 2011; Smith-Spark & Fisk, 2007; Smith-Spark, Henry et al., 2017; Wang, Tasi & Yang, 2012), and time perception (e.g., Bruno & Maguire, 1993; Gooch, Snowling, & Hulme, 2011; Khan, Abdal-hay, Qazi, Calle & Castillo, 2014; Nicolson, Fawcett, & Dean, 1995; Tallal, 1980). The co-existence of dyslexia and a number of cognitive deficits inclines more towards the multiple deficit models rather than the single deficit approaches of dyslexia.

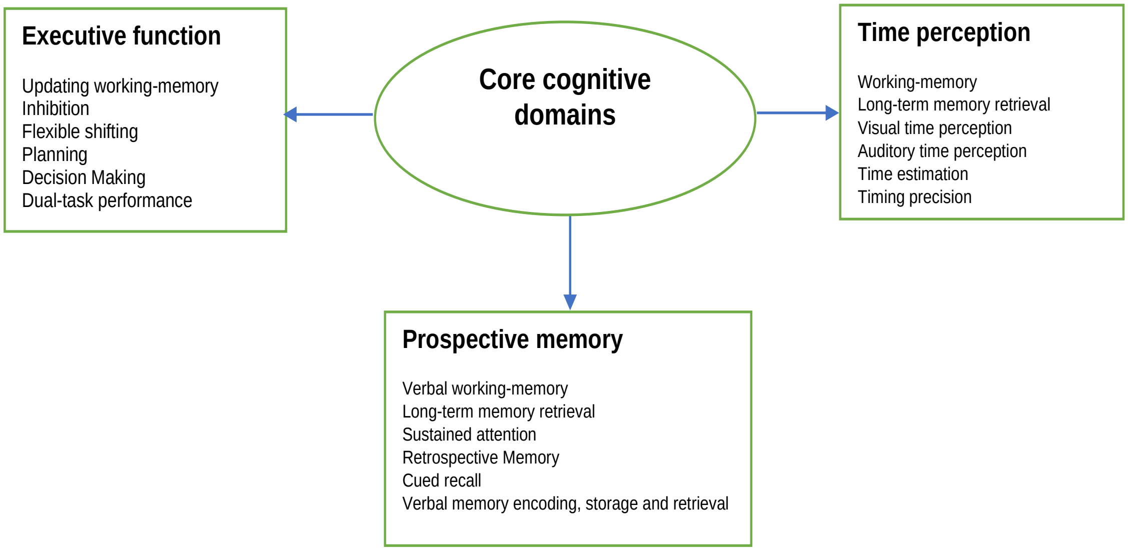

Figure 1.1 Core cognitive domains and dyslexia-related deficits

1.4 Persistence of dyslexia-related deficits

Dyslexia is considered as one of the most persistent developmental disorders (e.g., Badian, 1984). The occurrence of dyslexia has been reported to be two to three times greater in males compared with females (e.g., Rutter et al., 2004). However, in other languages and writing systems, this ratio has been found to be marginally lower (e.g., Brunswick, McDougall, & Davies, 2010). Studies have indicated that problems related to dyslexia endure from childhood into adulthood. These dyslexia-related problems have been reported in executive functions (e.g., Bacon Parmentier & Barr, 2013), working-memory (e.g., Nergård-Nilssen, & Hulme, 2014), verbal working-memory (e.g., Smith-Spark, Fawcett & Nicolson, 2003).

1.5 Conclusion

The effects of dyslexia therefore persist into adulthood. The effects may negatively impact on the everyday living experiences, learning abilities and employment opportunities of individuals with the condition. This thus highlights the importance of studying these dyslexia-related cognitive difficulties in adults in their own right as argued by McLoughlin, Fitzgibbon and Young (1994) and Fawcett (2014) and not just inferring them from children with dyslexia. Specifically, this thesis will explore three areas that are among the wide-ranging cognitive problems that occur in adults with dyslexia. These are PM, EF and TP (see Figure 1.1) and are discussed in Chapters 3, 4, and 5 respectively with empirical work being conducted on each aspect of cognition. The next chapter entails the general method, sampling and screening measures employed in the participant selection criteria.

Chapter 2.0 General method, sampling, screening tasks and structure of each test session

2.0.1 Overview of chapter

This chapter commences with the general method which entailed the screening measures that formed the preconditions for participant inclusion. A brief introduction and the purpose of the screening measures employed in the work is presented. This is followed by the methodology and design of the screening procedure including brief descriptions of each measure. Next the IQ, reading and spelling results are presented for adults with and without dyslexia.

2.1 General method

2.1.1 Introduction - Screening Measures

The present investigation involved assessing adults with dyslexia and those without dyslexia. As a prerequisite for research comparing cognitive abilities across groups, it is necessary to ensure that the two groups are age-matched and have similar cognitive abilities (e.g., Goswami, 2003). Goswami (2003) has argued that it is important to ensure that caution is used when matching the experimental versus the control groups. As suggested by Goswami, an extensive assessment of verbal and nonverbal IQ should be utilized – with variances between groups minimized to indicate similarity of IQ aptitude. Goswami has suggested that tests such as Raven’s Progressive Matrices (Raven, 2008) are unsuitable to employ in dyslexia-related research on the basis that they are the only assessment being used for determining between group IQ similarity. By definition, nonverbal tests are barely correlated with verbal skills (Goswami, 2003). When individuals with dyslexia are matched to those without dyslexia, there is evidence to indicate that significant variations can be found in verbal IQ (e.g., Stanovich, 2000). The Wechsler Adults Intelligence Scale - current UK version WAIS-IV (2010), is considered by Turner (1997) as a suitable IQ assessment tool to be used when matching participant groups with and without dyslexia. Turner has argued that there are specific subtests that are not sensitive to the presence of dyslexia – these are the subtests that have been used in the current work. Therefore, they provide a reliable confirmation of cognitive abilities that are independent of the effects of dyslexia. Accordingly, in the current research, participants were invited to undertake four subscale tests (consisting of Comprehension, Vocabulary, Block Design, and Picture Completion), performance on which Turner has identified as not being affected by dyslexia.

2.1.2 Methodology and design

Overall, 55 participants aged between 18 to 40 years old consisting of 28 adults with dyslexia (mean age = 23.30 years, *SD* = 3.01; 23 females, seven males) and 27 adults without dyslexia (mean age = 25.37 years, *SD* = 4.98; 23 females, four males) were recruited through University-based systems, and third-party dyslexia-support organization poster advertisements. The participants were matched for age and IQ. However, it should be noted that the lack of significant group difference on the IQ measures is not sufficient for ensuring that the groups were matched on IQ at the individual level. The two participant groups were differentiated on spelling and reading (literacy) tests (see Table 2.1 below for the related descriptive statistics). This was carried out by means of an unrelated t-test. Upon contacting the investigator, participants were sent information about the experiment at least one week prior to agreeing to take part. Subsequently a suitable appointment was arranged. Participants interested in taking part made an initial decision to give consent based on the information sheet sent to them via email prior to coming to the first session. At the beginning of the first of three sessions, the participants were briefed about the nature of the experiments and invited to read a consent form and advised to sign only if they were completely satisfied to take part. Participants were given one week's grace from being sent initial information about the experiment to think of any questions that may have arisen prior to signing a written consent. The investigator recruited individuals without dyslexia from undergraduate Psychology students. Psychology undergraduate participants were given course credits as an incentive to participate. Individuals with dyslexia can be difficult to recruit and thus it was deemed conceivable that some of the participants may be non-Psychology students and others were recruited from outside the University. Therefore, the participants with dyslexia were compensated with £20 in vouchers or course credits for their time and travel costs in attending three one-hour thirty minutes long test sessions.

Table 2.1 shows the descriptive statistics for the means and SDs for the IQ and literacy screening measures for the adults with and without dyslexia.

	Group with dyslexia			Group without dyslexia		
IQ Measures	N	Mean	*SD*	N	Mean	*SD*
Block design	28	47.07	12.33	29	44.03	11.92
Picture Naming	28	34.32	5.39	29	35.93	7.27
Comprehension	28	25.07	3.90	29	27.24	5.51
Vocabulary	28	13.14	3.44	29	14.48	3.87
Spelling Measure						
Spelling raw score	27	41.56	4.30	30	46.17	2.41
Spelling age	27	16.17	2.44	30	18.00	0.00
Reading Measure	27	76.61	15.95	30	95.83	4.37

2.1.3 Screening Measures

2.1.3.1 Intelligence quotient measure; Wechsler Adults Intelligence Scale; WAIS-IV (2010)

This IQ measure comprising subscales: (Vocabulary, Picture Completion, Block Design and Comprehension) were administered to the participants to calculate a short-form IQ using Turner's (1997) formula. The IQ measures were administered and scored with standardised procedures. This measure has been used previously in studies that required group intelligence comparisons (e.g., Cassim, Talcott, & Moores, 2014; Schiavone et al., 2014; Smith-Spark, Ziecik & Sterling, 2016 a, b). It was hypothesized that there would be no group performance-related variance between adults with dyslexia and those without on the short-form IQ test. This expectation was formed on the basis that, since, according to Turner (1997), the effects of dyslexia are not sensitive to measures of the short-form IQ test, adults with dyslexia would perform comparable to those without dyslexia.

2.1.3.2 Reading assessment: The DAST nonsense word passage (Fawcett & Nicolson, 1998)

The Nonsense Word Reading (NWR) Passage from the Dyslexia Adult Screening Test (DAST; Fawcett & Nicolson, 1998) is an established test that measures reading proficiency with standardized normative scores to indicate the presence of and severity of dyslexia. Nonword decoding ability has been found to be problematic for individuals with dyslexia in adulthood whose reading aptitude is satisfactory (Brachacki, Fawcett, & Nicolson, 1994). Nonword decoding ability has been suggested as a very strong predictor of dyslexia in adults with the condition (e.g., Snowling, Gallagher, & Frith, 2003). The literacy measure for reading was administered and scored with systematized protocols. Accuracy and reading speed were assessed by combining both aspects of performance to produce a single score of reading ability. In this task, participants were invited to read a passage of text containing both actual words and nonsense words in a timed performance. Prior to testing, the participants were presented with a sample of the passage consisting of one sentence which contained real words and nonsense words. The participants were asked to read the sentence aloud. Afterwards, the testing phase as described in the procedure was commenced. The participants were required to read the passage as quickly and as accurately as possible. The investigator used a clock timer to measure the duration of the session in addition to identifying and later scoring the number of reading errors made. Based on previous indications of performance-related difficulties (e.g., Snowling, Gallagher, & Frith, 2003; Snowling, Gallagher, & Frith, 2003), it was hypothesized that adults with dyslexia would perform significantly less well than adults without the condition in the DAST nonsense word passage.

2.1.3.3 Spelling assessment: WORD spelling test (Wechsler, 2010)

The spelling component of Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993) task is a well-established and commonly used test to check spelling ability and age (e.g., Nergård-Nilssen & Hulme, 2014; Nielsen et al., 2016). This literacy assessment for reading was administered in accordance with structured procedures (see Nielsen et al., 2016). In this task, the investigator read aloud a word at a time for the participant to spell. The investigator pronounced the word, then contextualized the word in a sentence and then pronounced it again. The task provides a spelling age of the participant. Word spelling difficulty increased as participants progressed. Testing was terminated in the event of a participant having made six successive spelling errors. Participant answers were collected for later scoring. In this task, participants were asked to spell specific words by writing each word on paper. The task required the investigator to read out loud, words that needed to be spelt to the participants. This was followed by reading a sentence containing the word and then the word was repeated. In total, there are 50 items. However, all participants responded to items 21 to 50 only. The words progressively increased in difficulty. A testing session was ended if a participant made six consecutive spelling errors. A spelling age indicative of an adult was indicated by raw scores equal to or in excess of 42/50. Scores lower than the cut-off yielded a spelling age in the child range and thus provided support for a diagnosis of dyslexia. Consistent with the pattern of previous findings (e.g., Nergård-Nilssen & Hulme, 2014; Nielsen et al., 2016), adults with dyslexia were expected to perform significantly less than those without dyslexia.

2.1.3.4 Results

An independent t-samples test was performed to assess differences in performance on a short-form IQ test, spelling and reading tests as outlined previously. The participant groups comprised of 26 adults with dyslexia and 28 adults without dyslexia. There was a non-significant difference between adults with dyslexia $N = 26$ and adults without dyslexia $N = 28$ in their overall performance of the WAIS-IV short-form IQ test, $t\ (52) = -.43$, $p = .67$, $d = 0.11$. The results for the WORD spelling test (Wechsler, 1993) showed a significant Levene's test. Therefore, equal variances were not assumed. The independent-samples *t*-test revealed a significant difference in performance between groups, $t\ (41.19) = -.71$, $p<.001$, d = 1.28. The table of means (see table 2.1 above) shows that the group with dyslexia was less accurate in spelling ability (M = 41.56, $SD = 4.30$) than the group without dyslexia, (M = 46.04, $SD = 2.44$). Furthermore, there was a significant difference between groups in the DAST Nonsense reading passage, $t\ (52) = -6.23$, $p<.001$, d = 1.74. The group with dyslexia was considerably poorer (M = 76.61, SD = 15.95) than the group without dyslexia in performance (M = 96.42, $SD = 2.21$).

2.1.3.5 Conclusion

The findings from the screening measures support the three stated hypotheses and indicate that whilst comparable IQ abilities were observed between adults with dyslexia and those without dyslexia, reading and spelling abilities were found to be poorer in adults with dyslexia. The observed performance-related differences in reading and spelling and not IQ means that group-related variance in performance on the planned empirically-based tasks pertaining to PM, EF and TP may be attributed as a function of reading and/or spelling abilities rather than IQ. The empirical chapters pertaining to domains of PM (see Section 3), EF (see Section 4) and TP (see Section 5) are considered through their respective range of measures. The next section presents a table of structure that displays task allocations for each of the three test sessions carried out (see table 2.2).

2.2 Structure of each test session

Data collection was conducted over the course of three sessions, each consisting of one hour thirty minutes per participant. In the three sessions (see Table 2.2), the same participants were administered the short-form IQ screening tests and reading and spelling tests, the prospective memory tasks, the executive function tasks, and the time perception tasks. The educational psychologists' reports for the participants with dyslexia were checked to confirm their dyslexia status.

Table 2.2 presents the structure of tasks per session

Sessions	Tasks presented to participants in each of the three sessions				
Session 1	**Wechsler Adults Intelligence Scale (WAIS -IV: Wechsler, 2010) IQ tests** - Block Design - Comprehension - Vocabulary - Picture Naming	**Spelling assessment** - WORD spelling test	**Reading assessment** - DAST nonsense word passage	**Inhibition Task** - Go-No-Go Task	**Working memory Updating Task** - Automatic Operation Span Task
	Prospective short duration - Time portion estimation task	**Computerized** EBPM task	**Instruction given for** Naturalistic TBPM task	**Phonemic Fluency task**	**Short duration TP Task** - Temporal generalization task
Session 2	**Short duration TP Task** - Verbal estimation task	**Response expected for Naturalistic TBPM task**		**Computerized TBPM task**	**Planning Task** - Trail Making Task
	Set-Shifting Task - Plus/Minus Task	**Retrospective long duration time estimation Task**		**-**	**Dual-task performance** - Semantic Fluency Task - Pursuit rotor Task
Session 3	**Everyday memory measure** - Rivermead Behavioural Task	**Semantic and Episodic remembering measure** - Remember/Know Task		**Ecologically-valid PM measure** - The Dresden breakfast Task	**Short duration TP Task** - Bisection Task

Chapter 3.0 Prospective Memory

3.1 Overview of chapter

Prospective memory, also known as memory for delayed intentions (Winograd, 1998) refers to the ability to form an intention, remembering to remember that intention whilst engaged in ongoing activities and actually executing the intention after a delayed period - either at a specific point in time or in response to environmental cues (Ellis & Kvavilashvili, 2000). Typically, in laboratory-based PM tasks, the PM task is embedded in an ongoing task and carried out during the delayed period between intention formation and intention execution. The ongoing task acts as a distracter to simulate the everyday life context in which PM tasks have to be performed around other intervening activities. This chapter begins with a discussion of a general definition of prospective memory (PM) followed by PM tasks and a range of PM models. A review of PM performance in the general population is considered followed by dyslexia-related PM deficits. After that, a consideration of potential explanations of PM difficulties in dyslexia is given. Prospective memory has been investigated under a range of conditions, and the approach taken in the current work was to explore PM by isolating a range of assessment types in order to facilitate a broader understanding of the processes involved in PM functioning. The range of assessments employed in the current work comprised investigations conducted under laboratory-based and semi-naturalistic conditions as well as under naturalistic conditions.

3.2 Definition and key concepts

Prospective memory refers to recalling a prolonged intention to mind (Winograd, 1998). Einstein and McDaniel (1990) have highlighted two key components of PM. The two components are described as (i) a PM component which facilitates planning and memorizing of the PM intention and the target cues related to its performance and (ii) a retrospective memory (RM) component which facilitates recall of the intention, the related actions to be performed and the environmental or time cue with which the intention is associated.

An alternative way of considering PM has been proposed by Brandimonte and Passolunghi (1994). They identified four stages to PM. Stage One involves the encoding of the prospective information to be recalled and includes intention formation (the inception of forming an intention), a retrospective element (the contents of the intention) and a prospective element (a specific future point in time when the intention is planned to be executed). Stage two comprises execution of a delay between intention formation and intention execution and involves the recollection of planned execution to facilitate successful prospective remembering. Stage three entails the instigation and implementation of the planned execution. Finally, Stage four involves appraisal of the previously executed task so as to avoid doing it again (involving a confirmation from memory that the intention has already been performed). The differing types of prospective memory types are considered in the next section.

3.2.1 Prospective memory tasks

This chapter is focused on two PM types, namely (i) time-based and (ii) event-based. Prospective memory can also include action-based PM (e.g., Shum, Ungvari, Tang, & Leung, 2004; Montgomery, Hatton, Fisk, Ogden, & Jansari, 2010) - and is related to future recall behaviours (i.e., a delayed motor intention). However, event-based PM and time-based PM are more pertinent to the current investigation and much more commonly studied in the literature. Event-based PM (EBPM) entails forming an intention, remembering to remember the intention whilst engaged in ongoing activities, and carrying out the planned task when cued by particular events in one’s surrounding environment (e.g., “I must remember to buy a pint of milk when I next walk by the supermarket”). Event-based PM intentions rely primarily on external or environmental cues and are dependent on the association of the future action to be performed with the related environmental cue, McDaniel and Einstein (2000). The aforementioned association is formed at the encoding phase of intention formation, (Guynn & McDaniel, 2007). So, taking the example above into consideration, the supermarket should act as the environmental cue to buying of the pint of milk – and upon encountering the supermarket, the intention to buy a pint of milk should pop into mind and facilitates the execution of this intention. Intended actions that are dependent on time can be activated by internal or external cues, McDaniel and Einstein (2000). In EBPM task performance, external cues assist with improved performance owing to the increased automaticity in the triggering of the PM intention. Additional evidence has been presented by McDaniel and Einstein (2007) which suggest that EBPM tasks are overseen mainly by automatic processes.

In contrast, time-based PM (TBPM) tasks involve remembering to execute the intention at a certain timepoint in the future. An example of a TBPM task would be, "In 40 minutes' time I must remember to ring the Doctor's surgery to book an appointment". Time-based PM tasks are acknowledged to be supervised largely by strategic attentional demanding processes (Einstein & McDaniel, 2000). For instance, in the example above, the individual cannot rely on external cues to prompt remembering because the time cue related to the action to be performed is internally generated. In other words, the time awareness required to trigger performance of the TBPM task is primarily contingent on internal monitoring and self-initiated processes to facilitate its successful execution. Sellen, Louie, Harris, and Wilkins (1997) have argued that intended actions that are cued by time, are better activated by external cues rather than internal cues. This is because, whilst PM intentions that are activated by internal time cues demand additional attentional resources; those that are activated by external time cues require a lesser extent of attentional allocation.

With reference to the strength of correlation between the PM cue and to-be-performed action (see Section 3.3 for a broader discussion), the reflexive-associative theory (McDaniel & Einstein, 2007; McDaniel, Guynn, Einstein, & Breneiser, 2004) stipulates that at the planning phase of a PM task, an individual forms an association or a binding between the PM cue and the related intended response. This theory postulates that when the PM target emerges at a future point in time, dependent on the strength of association between the cue and the response, retrieval of the associated action to be performed may occur without requiring strategic attentional resources. The successful retrieval of a delayed intention is considered to be contingent on the degree to which the target cue is coded at the point of encoding and the extent of encoding completeness pertaining to the target cue and the intended action (Einstein et al., 2005). The theory of reflexive-associative processes (McDaniel & Einstein, 2007; McDaniel, Guynn, Einstein, & Breneiser, 2004) postulates that in EBPM tasks, when the relationship between cue and planned action is strongly correlated, merely encountering the PM cue should facilitate a quick automatic retrieval of the related PM action into consciousness. Einstein and McDaniel (1996) have suggested that PM can be measured through different experimental paradigms – characteristically, this involves a dual-task approach. In a dual-task paradigm, a participant may be asked to encode and sustain an intention to perform its related action at a certain time in tandem with performing an ongoing task. In dual-task mode, conscious control is crucial in the management of information because attentional resources are competed for by the tasks at hand. In assessing PM, different assessments and strategies have been employed. These are considered in the next section.

3.2.2 Processes and strategies involved in PM

According to McDaniel and Einstein (2000), an essential characteristic of PM tasks is that they must be remembered to be executed whilst an individual is concurrently engaged in ongoing tasks. Contrary to EBPM tasks in which the occurrence of the target event is to some extent arbitrary, in TBPM tasks, the target times are definitive and may require one to engage in preparatory time monitoring, McDaniel and Einstein (2000). Preparatory time monitoring may be regulated by proactive or reactive strategy control contingent on an individual's attentional resources (Mahy & Moses, 2011). Adopting a proactive strategy in a TBPM task involves monitoring and self-initiated execution of an intention that is instigated by internally generated temporal representations (Mahy & Moses, 2011). Conversely, adopting a reactive strategy comprises of the execution of an intention in response to an environmental cue - such as an external clock without self-initiated expectancy of the target time. Mahy and Moses (2011) have argued that successful TBPM task performance should be enhanced in those who engage in preparatory time monitoring through a proactive control strategy. Preparatory time monitoring through a proactive strategy requires self-prompting for time awareness to assist with the implementation of an intention. Mahy and Moses have suggested that although a proactive strategy demands greater attentional resources relative to a reactive strategy, strategies of a proactive nature are more reliable for the successful execution of an intention. Prospective memory can be understood through different models. These are discussed in the next section.

3.3 Prospective memory theories

Extant theories of PM processes are the preparatory attentional and memory processes theory (the PAM theory; Smith, Hunt, McVay, & McConnell, 2007), the reflexive associative theory (Einstein & McDaniel, 1996; Guynn, McDaniel, & Einstein, 2001) and the multi-process framework (McDaniel & Einstein, 2000). The preparatory attentional and memory processes theory (Smith et al., 2007) postulates that an intention may be retrieved only if one engages in a preparatory process leading up to its planned execution (i.e., monitoring the environment for cues that signal when to execute that intention). The model contends that monitoring and preparatory processes are strategic and voluntary and further suggests that maintaining these processes necessitates attentional resources that would otherwise be dedicated to executing ongoing events (Smith et al., 2007). The PAM theory argues that the delayed execution of a PM intention should consistently and negatively impinge on the performance of ongoing tasks. In demonstrating this, Smith et al. looked at the cost of EBPM performance using salient target events and showed that slower performance of ongoing task occurred when a PM task was embedded compared with when the ongoing task was performed alone. A criticism of the PAM theory relates to whether PM retrieval can occur in the absence of preparatory attentional processes, a point raised by McDaniel and Einstein (2000).

Contrary to PAM, the reflexive-associative theory of PM stipulates that when one is engaged in an ongoing task and a PM cue is processed (Einstein & McDaniel, 1996; Guynn, McDaniel, & Einstein, 2001), the activation of the intention in conscious awareness can be executed by the reflexive-associative memory system. In explaining the retrieval process, at the intention formation stage, the planned intention and the related PM cue(s) are considered to be stored as a PM memory representation. Furthermore, the theory holds that the retrieval procedure is rapid, involuntary and occurs without needing mental resources. The theory postulates that when the cue is processed, an automatic associative process either retrieves or is unable to retrieve intentions and that retrieval of an intention is contingent on the activation received by PM memory representations. The reflexive associative theory – an activation model of memory places great emphasis on the triggering of intentions that are more precisely related to cues. According to the reflexive-associative theory, routine strength (i.e., the potency of the association between a PM cue and a planned intention) is not predictive of PM, in that if retrieval of an intention is involuntary, the load of contending routine activities is unimportant. Rather, the theory stipulates that retrieval is motivated by the PM memory representation of the PM cue and the intended action.

To expand on the reflexive-associative theory, feature binding processes (Guynn & McDaniel, 2007) have been proposed to facilitate successful PM retrieval. Explicitly, Guynn and McDaniel (2007) have argued that PM execution is dependent on the strength of correlation between the PM cue and the action to be performed. In PM terms, the strength of feature binding relates to the association between the PM cue and its related to-be performed action. The encoding stage, in which the contents of an intention are memorized, is processed through the prospective component of PM. The prospective component (see Section 3.2) has formerly been described as allowing the process of remembering a future action and the related contents of the intention. At the encoding stage, during intention formation, a relationship between the PM cue and its future action are created. Guynn and

McDaniel (2007) have indicated that a weakly associated PM cue and the action to be performed can lead to difficulties during retrieval as well as the execution of the related intention. On the other hand, the retrospective memory element of PM is recognized as allowing recall of an action to be performed together with the accompanying target cued events. The ability to successfully retrieve the relevant verbal information from long-term memory along with its associated future-action is argued to be facilitated through the strength of binding between PM cue and the to-be performed action (e.g., Gonneaud et al., 2011).

On the other hand, the multi-process framework (McDaniel & Einstein, 2000) presents a different account maintaining that the cognitive system facilitates PM retrieval through two general trajectories. Trajectory 1 is reliant on top-down strategic attentional control processes and sustains the triggering of an intention and/or the monitoring of the environment for target cues that indicate that an intention should be executed. In contrast, Trajectory 2 is contingent on bottom-up spontaneous retrieval processes that are often triggered in response to PM-related environmental cues. Spontaneous retrieval is not considered to require monitoring of an intention but is primarily directed by automatic cognitive resources. In support of the multi-process theory, McDaniel and Einstein's work demonstrated that (a) spontaneous retrieval can occur and can assist good PM and (b) depending on task demands and individual differences, individuals depend on varied extents of monitoring versus spontaneous retrieval for prospective remembering.

In sum, the reflexive-associative theory (McDaniel & Einstein, 2007) postulates that when an intention is formed to perform a PM-related task, an association is created between the target cue and the intended action. At a future timepoint when the target cue is presented, retrieval of the to-be-performed action into conscious awareness is activated by the automatic associative-memory system. Thus, on condition that the target cue transpires, the previously formed association activates the retrieval of the to-be performed action. This is considered to be the case whether or not the intention is in conscious awareness. Conversely, the PAM theory (Smith et al., 2007) argues for successful PM-intention that necessitates preparatory attentional processes. This model demands continual monitoring of the environment for target cues via attentional processes. However, preparatory attentional processes cannot account for the occurrence of spontaneous retrieval processes which relates to the retrieval of PM-related intentions that occur spontaneously in the absence of preparatory attentional processes. The multi-process theory (McDaniel & Einstein, 2000) transcends the PAM theory and the reflexive-associative theory by proposing a dual-process system – with PM-intention retrieval that can occur spontaneously through one route without the necessity of monitoring and dedicated attentional resources. The second route assists PM retrieval via strategic attention that requires deliberate monitoring and attentional processes. The next section is focused on a discussion of dyslexia-related difficulties in PM.

3.4 Prospective Memory problems and dyslexia

Early anecdotal evidence has indicated dyslexia-related difficulties in heightened extents of forgetfulness and clumsiness in dyslexia (e.g., Augur, 1985; McLoughlin, Fitzgibbon & Young, 1994; Miles, 1982); Organization, time-keeping, and planning have all been shown to be related to PM in terms of the ability to carry out complicated daily PM tasks (e.g., Waldum and McDaniel, 2016). The aforementioned indirect evidence is therefore suggestive of poorer dyslexia-related PM performance (see Smith-Spark, 2018 for a review).

Following up on such anecdotal reports, Smith-Spark, Fawcett, Nicolson and Fisk (2004), investigated everyday cognition in adults with dyslexia using the self-report Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald & Parkes, 1982). The results indicated that the respondents with dyslexia self-reported a greater incidence of everyday cognitive lapses than adults with dyslexia. Dyslexia-related self-reported problems were identified with over-focusing (such that non-essential information is overlooked), problems with word-finding, and distractibility. In addition to the CFQ, close friends of the CFQ respondents were assessed with the CFQ-for-others. It was revealed that the results for CFQ-for-others was comparable to those of the CFQ. The close-associates of the participants with dyslexia deemed that those with dyslexia exhibited greater tendencies towards distractibility, greater disorganization, and greater absent-mindedness. However, the abovementioned difficulties are not explicit PM measures; rather a link is being made to illustrate their likeness to PM-related processes. Smith-Spark et al.'s results indicate that cognitive functioning is negatively impacted in adults with dyslexia. Furthermore, the results indicate that dyslexia-related problems extend beyond those recorded on literacy-based and in experimental laboratory-based tasks and impinge on daily life. More recent studies of PM have focused on children with and without dyslexia (self-reports; e.g., Khan, 2014); and adults with and without dyslexia on subjective measures, and objective laboratory measures (e.g., Smith-Spark, Ziecik & Sterling 2016 a, b) and under naturalistic conditions (e.g., Smith-Spark, Ziecik & Sterling, 2017b). These studies have consistently revealed group differences in PM performance between people with dyslexia and those without dyslexia. They will now be described in more detail.

Firstly, dyslexia-related PM problems have been identified using self-report questionnaires. These are considered next. Two self-report questionnaires have been used to assess PM function in dyslexia; namely, the Prospective and Retrospective Memory Questionnaire (PRMQ, Smith, Della Sala, Logie & Maylor, 2000) and the Prospective Memory Questionnaire (PMQ; Hannon, Adams, Harrington, Fries-Dias & Gibson, 1995). Such questionnaires provide the opportunity to tap into distinctive occurrences of PM in individuals across diverse time points (e.g., over the course of a week, month or over longer intervals). The PRMQ (Smith, Della Sala, Logie & Maylor, 2000) was employed by Smith-Spark, Ziecik et al. (2016b). The results revealed that adults with dyslexia indicated greater occurrences of memory failures in PM. Additionally, adults with dyslexia indicated more frequent problems with their retrospective memory, linked to episodic memory. Moreover, close associates of the adults with and without dyslexia who were assessed on the PRMQ were requested to provide a rating of their associate's PM performance, using the same set of questions as administered to the respondents. The proxy-rating given by close associates of respondents indicated that the adults with dyslexia experienced greater regular memory problems. The proxy-rating eliminates the probability of a respondent's decreased self-esteem deficits or metacognitive awareness being at the root of the self-reports of more frequent memory problems. Using the PMQ (Hannon, Adams, Harrington, Fries-Dias and Gibson, 1995), Smith-Spark, Ziecik et al. (2017a) assessed PM in adults with dyslexia. The results indicated that adults with dyslexia self-reported a greater overall occurrence of PM failure. In particular, it was revealed that adults with dyslexia indicated more difficulties related to instances wherein an intention was infrequent or one-off and when having to remember it across an extended delay period. In addition to this, adults with dyslexia identified greater difficulties in instances wherein internal cues needed to be generated in order to remember to perform a planned task. Conversely, no between-group difference was found in the regularity of self-reported PM problems in instances in which planned tasks were regular and habitual in nature, and over short intervals.

Objective measures of PM have also been employed to explore dyslexia-related difficulties. In order to ascertain whether PM-related problems could also be observed in a standardized laboratory environment, Smith-Spark, Ziecik et al. (2017a) administered the Memory for Intentions Test (MIST; Raskin, Buckheit & Sharrod, 2010) to the same participants who participated in the self-report PMQ (Hannon et al., 1995). In the MIST, participants were required to perform a 30-minute word search puzzle. The task was devised in such a way that participants must break out from the ongoing activity (the word search puzzle) in order to carry out the PM tasks. The eight PM tasks were presented to the participants at particular intervals over the course of the 30-minute task. The PM tasks required responses that should be triggered either by event-based or time-based cues and the type of response required were either action or verbal. The task additionally differed in the delay period between the participant being given a PM instruction and the future point in time when its performance was required. This delay was either two minutes or 15 minutes. As found with the self-reported problems, the MIST indicated that adults with dyslexia showed a reduced accuracy in their successful performance of

PM tasks in general. Furthermore, the group with dyslexia showed a reduced likelihood of executing their PM-related responses when they were presented with time-based cues. However, there was no group difference between adults with dyslexia and those without when presented with event-based cues. Moreover, no group difference was observed in relation to remembering the PM instruction accurately when participants were required to identify what they had been asked to do following completion of the MIST. Smith-Spark, Ziecik et al. interpreted the latter finding as evidence that adults with dyslexia were successful in the encoding of PM instructions and that they had additionally sustained the instructions in memory. The participants also reported remembering the PM instructions from time to time over the intervening week. The authors concluded that the difficulties experienced by adults with dyslexia could be linked to successfully accessing the PM information at the particular point in time when it is required.

Using a computerized TBPM task, Smith-Spark et al. (2016b), presented groupings of faces of famous people, requiring their participants to make a decision as to whether the majority of the faces of famous people belonged to famous people who were living or dead. This formed a-14-minute ongoing task. The TBPM task comprised of participants remembering to press a particular key on a keyboard every three minutes on another computer which was placed behind them. The participants were permitted to check a computer-based clock which could be accessed on the computer placed behind them and could check the time as frequently as they needed to. The frequency of clock checks was logged. The importance of positioning the second computer behind and out of sight from the participants was to remove noticeable cues that could have reminded them to perform the PM responses. This thus ensured that the task remained a TBPM task and not an EBPM task. The participant group with dyslexia demonstrated reduced levels of accuracy in successfully performing the PM task compared to the group of adults without dyslexia. Furthermore, the group with dyslexia additionally demonstrated reduced regularity of clock checks across the 14-minute task. In order to determine whether PM problems in dyslexia can be observed in semi-naturalistic and in naturalistic conditions, Smith-Spark et al. (2016b) employed two TBPM tasks that were embedded in more naturalistic settings. In one of the tasks, which was set in a laboratory environment, the participants were initially given an instruction to remember to remind the experimenter to save an important computer file in 40 minutes time. In Smith-Spark et al. (2017a), the task consisted of a requirement to leave a telephone message for the experimenter after a delayed period of 24 hours. It was found that in both of these TBPM tasks, the group with dyslexia showed a reduced likelihood of remembering to perform the task successfully and a greater likelihood of failing to carry it out.

Smith-Spark et al. (2017b) employed an extended delay duration naturalistic EBPM task to assess adults with dyslexia versus those without dyslexia. The participants were required to respond to a text message relayed to them one week after attending a laboratory-based testing session. The text message sent to the participants was blank and so did not contain any conceivable supplementary information that could assist their PM greater than the event-based cue that was presented upon acknowledging the text message. It was revealed that the adults with dyslexia demonstrated a greater likelihood of not executing the PM response than to implement it. Conversely, the adults without dyslexia showed a greater likelihood to carry out the PM task than not to perform it. After responding to the EBPM task, the participants were asked to rate how important the task was to them. The participants were also asked to indicate how often they had thought of the task in the intervening week. Furthermore, the participants were asked to indicate if they had recalled the task instructions or not. Group performance did not significantly differ between adults with dyslexia and those without dyslexia in terms of how often the participants self-reported having thought about the task during the intervening delay of one week. Moreover, it was revealed that the groups did not significantly differ in their self-reported extents of motivation to successfully carry out the task. Nevertheless, a lesser number of adults with dyslexia self-reported successfully remembering the task instructions.

In sum, Smith-Spark, Ziecik et al. (2016a, 2016b, 2017a, 2017b) have revealed weaker PM performance in adults with dyslexia in self-report questionnaires, in laboratory-based tasks and in naturalistic conditions. Problems in dyslexia-related PM performance appear to occur predominantly when PM performance is time-based, and when PM performance is dependent on self-initiated processes. Self-initiated processes are dependent on internally self-generated prompts to assist with remembering that an action needs to be executed at a particular time in relation to a previously formed PM intention (McDaniel & Einstein, 2000). Self-initiated processes in this regard, imply that there are no salient environmental cues to aid remembering. Additionally, PM problems in adults with dyslexia seem to occur when tasks are one-off compared with when they are habitual in nature. Moreover, when instructions are required to be recalled over an extended delayed interval between intention formation and intention execution, compared with adults without dyslexia, those with dyslexia are more likely to demonstrate PM failure.

3.4.1 Possible explanations of PM difficulties in dyslexia

Possible explanations that account for PM problems in dyslexia are couched from the perspective of the retrospective component and the prospective component. These are discussed in this section.

3.4.1.2 Problems with the retrospective component of PM as an explanation of dyslexia-related PM deficits

The retrospective element of PM assists with remembering of an action to be performed together with its accompanying target event-related cues (see Section 3.2). In dyslexia, difficulties in the retrospective component of PM have been identified as one of a number of possibilities that may be linked to retrieval of verbal information from long-term memory at a future point in time when it is needed (e.g., Smith-Spark, 2018). This conclusion is derived from Smith-Spark, Zięcik et al. (2017a) who deduced that the given PM instructions did not pose problems for adults with dyslexia during the encoding phase - since no group difference was found between adults with dyslexia and those without with regards to their self-reported frequency of periodically thinking about the PM task. In view of that, Smith-Spark, Zięcik, and Sterling (2017b) argued that EBPM difficulties in adults with dyslexia appear be linked to reliable access to verbal instruction in retrospective (or episodic) memory at a certain point in time when it was required.

Support for this line of reasoning is derived from a small body of work that has reported long-term memory difficulties in children (e.g., McNamara & Wong, 2003; Menghini, Carlesimo, Marotta, Finzi, & Vicari, 2010). Likewise, there is evidence to suggest self-reported deficits in the ability of adults with dyslexia to recall facts (e.g., Mortimore & Crozier, 2006) and personally or episodically experienced events (Smith-Spark, Ziecik et al., 2016a). Generally, in dyslexia, weaker long-term memory performance is typically understood to be a result of deficits in phonological coding (e.g., Menghini et al., 2010). Albeit in children, Menghini et al. (2010) have indicated extensive episodic long-term memory deficits in dyslexia. These learning problems were found in both verbal and non-verbal (visual-object and visual-spatial) long-term memory.

Additionally, in adults, dyslexia-related problems have been reported in long-term memory representations. For example, Smith-Spark and Moore (2009) looked at face naming and age of acquisition in participants ability to name faces of famous people who were matched for facial distinctiveness and familiarity. The results indicated that performance did not differ significantly between adult with dyslexia and those without in terms of speed and accuracy in face naming ability. A significant participant group by age of acquisition interaction revealed that performance was superior for early-learned famous faces compared with later-learned famous faces across the board. The group without dyslexia was significantly quicker at naming early-learned compared with later-learned famous faces. In contrast, those with dyslexia demonstrated a considerably lesser effect of age of acquisition and the difference was not statistically significant. Smith-Spark and Moore concluded that the results are indicative of variances in dyslexia-related representations that could be linked to difficulties in attention, executive functions (see Sections 4.5; 4.11) and automaticity (see Section 4.11).

In Smith-Spark, Ziecik et al. (2016a), self-reported increased prospective and retrospective memory difficulties were reported in adults with dyslexia. It was argued that greater recurring problems in prospective and retrospective memory types are seemingly experienced by adults with dyslexia in day-to-day living. Smith-Spark, Ziecik et al. (2016a) suggested the need to investigate both retrospective and prospective memory types in dyslexia with the aim of uncovering the cognitive mechanisms underlying exactly how these problems occur. The current study considered this recommendation by extending the types of PM tasks that have typically been employed in PM studies to include the Rivermead behavioural test, RMBT-III; Wilson et al., 2008) as a measure of everyday memory. Dyslexia-related deficits in the prospective component of PM may be explained by facets of EF functioning. These are discussed next.

3.4.1.3 Prospective component of PM as an explanation of dyslexia-related PM deficits

The prospective component of PM remembering has been described (see Section 3.2) as facilitating the planning of the contents of the what (action), the how and the when (time) related to the planned future intention. Organization of the contents related to the PM-intention involves the coordinating of verbal instructions comprising the relative target cues, and the required response when it is needed at a later point (e.g., Smith-Spark, Ziecik et al., 2017b). The planning of the contents is related to the scheduling of action sequences that are experienced prior to the intention's performance. Dual-task performance refers to the concurrent supervision of the concurrent ongoing task-unrelated event whilst maintaining task relevant PM information in mind. Inhibition is required when a PM-related response is called upon to break out from the ongoing task performance in order to attend to the PM intention. Set-shifting is necessitated in order to flexibly shift from the ongoing task to perform the PM intention. Preservation of the PM-related task-relevant information in memory is necessary for later retrieval together with managed access to verbal information stored in long-term memory. In dyslexia, deficits reported in facets of executive function abilities (see Sections 4.5 and 4.11) indicate problems in inhibition

(Miyake et al., 2000); set-shifting (Miyake et al., 2000); dual-task performance (Nicolson & Fawcett, 1990); and the storage and retrieval of verbal long-term memory (Menghini et al., 2010). These PM-related difficulties have been linked to the prospective component of PM and may be experienced in dyslexia in the following way.

At the encoding stage of intention formation - where one must organize and plan the features of an intention, features such as target cues are planned and organized along with the verbal instructions pertaining to the PM intention (McDaniel & Einstein, 2000). After the encoding of the intention, the verbal instructions related to the intention are required at a future point in time. Difficulty with retrieval of the PM intention-related verbal information may be experienced at the retrieval stage of an intention if efficient and flexible access to verbal information stored in long-term memory is problematic. Adults with dyslexia have been reported to have problems with phonemic fluency ability (e.g., Brosnan et al., 2002; Miller-Shaul, 2005). Some extent of the PM problems that are encountered in dyslexia may be associated with the phonemic fluency facet of executive functioning (see Section 4.8.4) and, to a greater extent, access of information in verbal long-term memory in terms of efficiency and flexibility (Fisk & Sharp, 2004). In terms of PM performance, when the prospective component is required at a future time-point to assist with successful PM performance, the verbal instructions relating to the task must be retrieved from long-term memory. Smith-Spark, Ziecik et al. (2017b) highlighted that problems with efficiency and flexible access to information in long-term memory may be to the detriment of adults with dyslexia.

Additionally, once a PM intention has been formed at the intention formation stage, specific PM-related cues must be monitored from time to time to assist with successful PM performance. The Supervisory Attentional system (SAS; Norman & Shallice, 1986; see Section 4.5.1), a limited attentional resource system is considered to be required at the beginning of a willed action to regulate the required action. The SAS implements the coordination, integration, and regulation of information, and draws from attentional resources in order to optimize behaviour.

The SAS is necessitated when task expertise is inferior or when inadequately acquired action sequences are necessitated. In PM terms, this would be implicated in cue-monitoring subsequent to a successful PM performance. The monitoring process draws attentional resources from core executive functions (see Section 4.3). In dyslexia, problems identified in the SAS in Smith-Spark and Fisk (2007) indicate particular difficulties in the scheduling of cognitive schemata to efficiently manage demands when task novelty is high or when poorly learned sequences related to a task are required at a later point. The behavioural adaptation required in response to PM-related cues would be necessitated in order to assist with the successful performance of a PM intention. The capacity to successfully adjust behaviourally may well be problematic in adults with dyslexia owing to task novelty in response to a PM cue and the required a self-initiated response.

Furthermore, Cockburn (1995) has suggested that activation of the SAS is necessitated for the purpose of assisting one to break out from an independent ongoing task in order to execute the PM task. This implies that inhibitory control of ongoing responses is necessitated in order to efficiently engage with the required PM-related responses. For PM to proceed effectively, the inhibitory control responses required are equivalent to those regulated by contention scheduling processes of Norman and Shallice's model).

3.4.1.4 Time perception as an explanation of dyslexia-related PM problems

Within the general population, evidence has indicated the mixed nature of findings regarding the relationship between time perception and TBPM performance. A summary of the limited explorations of the role of time perception as an explanation of PM performance (e.g., Mioni & Stablum, 2014) are discussed (see Section 5.5). The relationship has been demonstrated directly in terms of PM accuracy, and indirectly through time monitoring tendencies. Time monitoring in relation to PM is concerned with the view that for successful performance of an intention to be executed, the environment must be monitored for PM-related cues. Generally, the variation of interval durations that have been employed to assess time perception typically represents durations that fall within the milliseconds and seconds range. However, interval durations that fit in the extended range that are associated typically with TBPM tasks (i.e., representative of delays generally in the minutes duration) have been overlooked.

McFarland and Glisky (2009) found no relationship between time perception abilities and PM accuracy. Similarly, more accurate time perception abilities have been found to predict monitoring (or clock-checking) behaviour but not PM accuracy directly (e.g., Labelle, Graf, Grondin, & Gagné-Roy, 2009; Mioni & Stablum, 2014; Vanneste, Baudouin, Bouazzaoui, & Taconnat, 2016). In contrast, Mackinlay, Kliegel, and Mäntylä (2009) and Mioni, Santon, Stablum, and Cornoldi (2016) have reported a positive relationship between time perception and the accuracy of PM performance. However extant research has failed to use tasks that tap into extended durations that are more representative of most day-to-day experiences. The time perception tasks used to predict TBPM performance have generally tended to be in the seconds range (e.g., McFarland & Glisky, 2009; Mioni & Stablum, 2014; Mioni et al., 2016; Talbot & Kerns, 2014). The nature of the association has been indicated as a direct prediction, indirect prediction (time monitoring tendencies), or accuracy. Accordingly, the general PM investigations should explore the predictive ability of extended intervals that encompass the minutes span on TBPM performance. These extended durations fall within the cognitive range of time perception and interval judgments. Extended durations are associated with the attentional processes that are dispensed when performance involves cognitive management of time perception (e.g., Block, George, & Reed, 1980; Glicksohn, 2001; Thomas & Weaver, 1975; Zakay & Block, 1996).

Smith-Spark (2018) has argued that the intervals that are consistent with extended durations would be more representative of PM task timings with an increased predictive likelihood of obtaining a strong association with PM accuracy as opposed to time monitoring. General time perception research thus needs to focus on durations in the range of minutes and hours as predictors of PM if it is interested in its relationship with PM. In the current study, the minutes range employed to measure time perception is representative of extended duration span. Such durations fall in the cognitive range of time perception and temporal judgments and are linked to the attentional processes distributed between cognitive task performance and temporal perception (e.g., Block, George, & Reed, 1980; Glicksohn, 2001; Thomas & Weaver, 1975; Zakay & Block, 1996). As mentioned above, Smith-Spark has argued that intervals that are consistent with extended durations would be more representative of PM task timings. He further argued that the predictive nature of time perception and PM may be indicated by a robust association to PM accuracy as opposed to time monitoring. For adults with dyslexia, their problems with TBPM are not well understood, and such extended durations would map on to PM task timings more directly and offer the possibility of revealing more robust predictive relationships to PM accuracy as opposed to time monitoring. It is thus possible that dyslexia-related TBPM deficits may be related to time perception difficulties in dyslexia (see Section 5.5). It is also possible that TBPM deficits in dyslexia may be linked to dyslexia-related impairments in EF (e.g., Smith-Spark et al., 2016b; see Sections 3.4.1.2; 3.4.1.3). However, the empirical research directly linking the two is lacking.

3.5 Rationale for including multiple measures to explain PM failure in dyslexia

In Smith-Spark, Ziecik et al. (2016a), the need to examine retrospective and prospective components in dyslexia-related PM problems was raised in order to ascertain the precise cognitive processes that may explain dyslexia-related problems in PM functioning. Taking the explanations for dyslexia-related PM problems into consideration, distinct processes have been isolated that are specific to the prospective and retrospective components (e.g., McDaniel & Einstein, 2000). Additionally, time perception has also been suggested as a possible explanatory account for dyslexia-related PM problems. In the prospective component of PM, the dyslexia-related problems highlighted (see Section 3.4.1.3) relate to the encoding phase of intention formation and specifically involves planning and organization of verbal instructions and target cues related to the PM intention. In the retrospective component, dyslexia-related problems in PM were emphasized as being problems linked to the retrieval of verbal information from long-term memory at a future time-point when it is necessitated. To date, a number of investigative paradigms (e.g., Khan, 2014, Smith-Spark, Ziecik et al., 2016 a,b; Smith-Spark, Ziecik et al., 2017a,b) have been employed to facilitate the understandings of specific processes that may underlie PM problems in dyslexia (e.g., self-reported questionnaires, laboratory-based measures; semi-naturalistic; and naturalistic measures). However, for a broader understanding of the cognitive processes that can explain PM functioning, research ought to diversify the scope of task types that have hitherto been employed to capture PM intentions performance. Such additions may be useful if the task-types resemble as closely those experienced in daily life as possible. In light of this point, the approach employed by the current study was to employ a repertoire of diversified PM measures. To this end, a novel measure, a laboratory-based ecologically-valid PM task, was incorporated – given that it is representative of everyday PM performance and may potentially tap into processes related to habitual PM functioning. Additionally, time perception has been discussed in Section 3.4.1.4 as a third potential explanatory factor of PM difficulties in dyslexia. Distinct indicators (PM accuracy and time monitoring) have been shown to be pointers of the relationship found between PM and time perception. However, time perception has been investigated using the milliseconds range but does not incorporate extended timing range that tends to encompass day-to-day interval durations that are relevant to an individual. Thus, a more comprehensive timing range was considered to be important to provide an enhanced understanding of the processes that underlie measures of time perception with particular measurements of short (milliseconds) as well as longer (minutes) durations.

3.6 Materials for PM tasks

The computer-tasks were programmed in E-prime. A 17” computer monitor was connected to an IBM-compatible personal computer to display PM stimuli. A qwerty keyboard was connected to the IBM computer and was used to input responses. Two laboratory-based tasks that assessed different PM measures were employed. A naturalistic PM task that assessed PM performance outside the lab-setting was employed.

3.7 Design for PM tasks

A variety of analyses were employed to analyse the battery of PM tasks, consisting of EBPM and TBPM computerized tasks, the Rivermead behavioural memory test (Wilson et al., 2008), the Dresden Breakfast task (Altgassen, Koban, & Kliegel, 2012) and the Naturalistic TBPM task. These measures are described in detail in Sections 3.10.1, 3.11.1, 3.12, 3.13.1, 3.14. The analyses comprised of 3*2 MANOVA analysis, an independent samples T-test and a Chi-square test of association and have been indicated in the individual studies.

3.8 Study 1: Laboratory-based EBPM and TBPM measures

3.9 Task 1: Rationale and hypotheses for computerized EBPM task

As noted in Section 3.4, Smith-Spark, Zięcik and Sterling (2016b) reported dyslexia-related difficulties in adults in a TBPM semi-naturalistic task and a computerized TBPM task. The objective of the current investigation was to investigate whether the dyslexia-related PM difficulties indicated in the TBPM tasks described in Section 3.10.1, 3.11.1, 3.12, 3.13.1, 3.14 occur when the PM cue was triggered by specific events in a computerized laboratory-based task. In line with previous investigations (e.g., Smith-Spark, Ziecik et al., 2016b), firstly, it was hypothesized that compared with adults without dyslexia, those with dyslexia would perform significantly less well in terms of their accuracy in successfully remembering to perform the EBPM task. planned analysis In view of previous studies (e.g., Smith-Spark, Ziecik et al., 2016b), secondly, it was hypothesized that there would be a significant group difference in performing the on-going tasks – with the group with dyslexia expected to perform less well than those without dyslexia. Thirdly, given previous research, (e.g., Smith-Spark, Ziecik et al., 2016b), a group difference in reaction times to responses given on the on-going task was not anticipated.

3.10.1 Task 1: Computerized EBPM task

A computerized TBPM version of the current task was employed in Smith-Spark, Ziecik and Sterling (2016b). The task has previously been used as a valid TBPM measure and has been discussed in Section 3.4. In the current work, when performing the computerized EBPM task, participants were asked to execute an ongoing-task and were additionally required to break out of the ongoing task to make a PM-related response whenever a particular symbol (event) occurred on the bottom side of the computer screen (see Section 3.10.2) for a fuller description of the task.

3.10.2 Design, method and procedure - laboratory-based computerized EBPM task

Participant groups comprised of 25 adults with dyslexia and 26 adults without dyslexia. The EBPM task involved performing an ongoing task whilst responding appropriately to the event-based prospective memory component. In the ongoing semantic decision-making task, famous faces were presented on the monitor screen. The participants were asked to decide as quickly and as accurately as possible whether the majority of the six celebrities presented were alive or dead, using one of two push-buttons. Whilst engaged in the ongoing task, the participants were required to perform an EBPM task. In this task, each array of six famous faces was surrounded by a red frame and presented with specific shapes around the frame in the form of a square, circle, triangle, or rectangle. The shapes were randomly attached on any side of each stimulus array of pictures (e.g., top, bottom, left, or right). The participants were asked to press a specific button (i.e., ‘’Y ‘’) every time an event cue (in the form of a triangle) appeared at the bottom of the computer screen in addition to making ongoing decisions as to whether the majority of the six faces in each array were living or dead. To ensure that sufficient data could be gathered whilst minimizing demand characteristics, the EBPM cue appeared at the bottom of each stimulus array of pictures 30 percent of the time versus 25 percent of the time for all other shapes.

The independent variable was participant group, with the levels being adults with dyslexia and adults without dyslexia. The dependent variable were reaction times and accuracy (expressed as percentage) of remembering to perform an action. The action was carried out by pressing “spacebar” on a keyboard when presented with an event-based cue (the appearance of a diamond) on a computer screen. All the three stated hypotheses (see Section 3.9) were analysed with independent-samples t-tests.

3.10.3 Results

3.10.3.1 Results: between-group comparison on EBPM task performance

The results in table 3.1 show descriptive statistics of the data for the computerized EBPM task performance-related accuracy.

Table 3.1: Descriptive statistics for t-tests carried out on between group accuracy of performance on the computerized EBPM task.

Group:	Mean	*SD*
Adults without dyslexia (N=26)	0.91	0.16
Adults with dyslexia (N=25)	0.93	0.07

An independent–samples t-test was conducted to analyse the EBPM performance of adults with dyslexia and adults without dyslexia. There was a non-significant difference in the successful performance of the EBPM task in adults with dyslexia (M = 0.93, *SD* = 0.07) and those without dyslexia (M = 0.91, *SD* = 0.16), *t* (49) = .67, *p* = .51, d = 0.04.

3.10.3.2 Results: Between-group comparison on ongoing-task performance

The results in table 3.2 show descriptive statistics for the correct ongoing task responses data on the computerized EBPM task.

Table 3.2: Descriptive statistics for t-tests carried out on the ongoing task performance of the computerized EBPM task.

Group:	Mean	*SD*
Adults without dyslexia (N=26)	0.92	0.60
Adults with dyslexia (N=26)	0.87	0.07

An independent–samples t-test was performed and revealed that the group with dyslexia (M = 0.87, *SD* = 0.07) was significantly less accurate in their performance of the on-going decision-making task concerning the celebrity faces compared with the group without dyslexia (M = 0.92, *SD* = 0.60), *t* (49) = -2.70, *p* = .01, d = 0.12.

3.10.3.3 Results: Between-group comparison on RT on ongoing-task performance

The results in table 3.3 show descriptive statistics for RT of the correct ongoing task responses data on the computerized EBPM task.

Table 3.3: Descriptive statistics for t-tests carried out on between group RT on ongoing task performance.

Group:	Mean	*SD*
Adults without dyslexia (N=26)	0.37	825.76
Adults with dyslexia (N=26)	0.39	1133.7

The results from an independent–samples t-test indicated a non-significant between-group difference in reaction times for the ongoing performance between the adults with dyslexia (M = 3925ms, *SD* = 1133.7) and those without dyslexia (M = 3734ms, *SD* = 825.76); *t* (49) = 0.70, *p* = .26; d = 0.19.

3.10.4 Discussion

The findings indicate no evidence of dyslexia-related difficulties on a computerized PM task that is cued by a specific event and were thus consistent with previous findings. The current findings supplement that of Smith-Spark, Ziecik and Sterling (2016b). Although the task employed in Smith-Spark, Ziecik et al. was a TBPM version, they reported comparable performance on the successful ongoing task performance between adults with dyslexia and adults without dyslexia. In the current work, although the reaction times to the ongoing task were comparable between-groups, adults with dyslexia were significantly less accurate on their performance of the ongoing task. A plausible explanation could be that with the EBPM task, the extra cognitive demands resulted in lower performance on the ongoing task, due to reduced attentional capacity. This instruction was necessary in order to ensure that participants were not strategically delaying their responses to the on-going task in order to free up more processing power to respond to the EBPM task. On one hand, it can be deemed that adults with dyslexia might have placed greater weight of consideration on the PM task in comparison the ongoing task - since their PM performance were comparable to adults without dyslexia. Even so, the PM task embedded in the ongoing task relied on cues that are automatically triggered in response to the occurrence of a specific event. From the viewpoint of the multi-process framework (McDaniel & Einstein, 2000; see Section 3.3), PM retrieval is facilitated through via two standard trajectories. Contrary to the second of two trajectories that assist PM retrieval via strategic attention for monitoring and attentional processes; the first trajectory facilitates PM retrieval through spontaneous processes without the need for monitoring and dedicated attentional resources. In line with this multi-process framework, in the current work, the absence of dyslexia-related problems in their performance of the EBPM task type employed may be explained by the task's dependence on primarily automatic cues that are characteristic of event-based task types.

3.11 Task 2: Rationale and hypotheses for a computerized TBPM task laboratory-based task

Smith-Spark, Zięcik and Sterling (2016b) reported dyslexia-related difficulties in adults in a TBPM semi-naturalistic. Additionally, significant time monitoring deficits were indicated in adults with dyslexia in a computerized TBPM task. The objective of task 2 was to assess whether PM difficulties indicated in TBPM tasks previously mentioned in a computerized laboratory-based task could be replicated. Firstly, it was hypothesized that compared to adults without dyslexia, those with dyslexia would significantly less accurate in successfully remembering to perform the TBPM task. Secondly, it was hypothesized that there would be a significant group difference in performance for clock-checking behaviour – with the group with dyslexia expected to perform significantly fewer clock checking tendencies. Thirdly, it was hypothesized that a non-significant group difference would be found for reaction times to responses made on the on-going task.

3.11.1 Design, method and procedure for the computerized TBPM Task

The task involved performing an ongoing semantic processing task whilst also responding appropriately to the TBPM component. The participants were asked to perform an ongoing task (i.e., making decisions as to whether abstract images of everyday items such as an airplane or a bear were ‘’living’’ or ‘’dead’’). The images were presented one at a time on a computer screen. The image stimuli consisted of 268 common everyday items of living and non-living things. Whilst engaged in the ongoing task, the participants were required to perform a TBPM task. Similar to the design employed in Smith-Spark, Ziecik et al. (2016b), in the current task, the participants were required to press the ‘’A’’ key on the keyboard of a laptop computer placed behind them every three minutes (i.e., at three minutes, six minutes, nine minutes and 12 minutes from the start of the 14-minute-long experiment). The participants were able to make unlimited checks on how much time had elapsed by pressing the space bar on a computer keyboard to reveal a clock on the laptop computer screen in front of them. The frequency of clock checks and successful responding to the TBPM task at three minutes, six minutes, nine minutes and 12 minutes, as well as responses to the ongoing task, were logged by the investigator. In the practice session, the participants were shown images of 12 abstract items, comprising of living and non-living items, one at a time. The participants were asked to make a decision as to whether each image represented a living or non-living item by pressing ‘’A’’ or ‘’D’’ respectively. After the practice trials, the experimental session was started in which the ongoing task was performed with the added computerized TBPM task. The planned analyses for all the three stated hypotheses (see section 3.11) were independent-samples t-tests.

3.11.2 Results

3.11.2.1 Results: Between-group comparison on TBPM task performance

The results in table 3.4 show descriptive statistics of the accuracy data on the computerized TBPM task.

Table 3.4: Descriptive statistics for t-tests carried out on the accuracy of performance on the computerized TBPM task.

Group:	Mean	*SD*
Adults without dyslexia (N=27)	3.78	0.42
Adults with dyslexia (N=24)	3.83	0.48

An independent–samples t-test showed that there was a non-significant difference in the computerized TBPM performance between adults with dyslexia (M = 3.83, *SD* = 0.48) and adults without dyslexia (M = 3.78, *SD* = 0.42), *t* (49) = 0.44, *p* = .54, d = 0.11.

3.11.2.2 Results: Between-group comparison on clock checking tendencies

The results in table 3.5 show descriptive statistics of the accuracy data on the computerized TBPM task.

Table 3.5: Descriptive statistics for t-tests carried out for performance on participants clock checking tendencies.

Group:	Mean	*SD*
Adults without dyslexia (N=27)	15.15	7.97
Adults with dyslexia (N=24)	17.38	13.62

An independent–samples t-test revealed a non-significant between-group difference for clock checking tendencies between the participants with dyslexia (M = 17.38, *SD* = 13.62) and those without dyslexia (M = 15.15, *SD* = 7.97), *t* (49) = 0.72, *p* = 0.11*,* d = 0.20. The group with dyslexia carried out slightly more clock checks compared with the group without dyslexia.

3.11.2.3 Results: Between-group comparison on reaction times to ongoing task

The results in table 3.6 show descriptive statistics of the RT data on the ongoing task.

Table 3.6: Descriptive statistics for t-tests carried out on RT of the ongoing task performance.

Group:	Mean	*SD*
Adults without dyslexia (N=27)	876.56	390.73
Adults with dyslexia (N=24)	780.42	381.34

The results from an independent–samples t-test indicated a non-significant difference in the mean ongoing task reaction times between adults without dyslexia (M = 876.56, *SD* = 390.73) and those with dyslexia (M = 780.42, *SD* = 381.34), *t* (49) = -0.89, *p* = .78, d = .25.

3.11.3 Discussion

A TBPM computerized task was employed to assess whether there would be a group difference in the performance between adults with dyslexia and adults without dyslexia. The findings indicated comparable task performance accuracy in the successful remembering to carry out the TBPM task. Comparable performance was indicated in clock-checking tendencies and accuracy of responses made on the on-going task respectively between adults with dyslexia and those without. The first hypothesis stated that the group with dyslexia would demonstrate significantly less well TBPM task performance and was not supported by the findings. This finding is inconsistent with Smith-Spark et al. (2016b) who reported dyslexia-related deficits in their computerized TBPM task performance. The second hypothesis which stated that there would be a significant group difference in clock checking behaviours was not supported by the results. This finding is also inconsistent with Smith-Spark et al. (2016b) who revealed that adults with dyslexia produced significantly fewer clock checking behaviours. The results of the first finding suggest that adults with dyslexia in the current study appeared to be able to cope with remembering to successfully carry out a task that was triggered by time-based cues across the 14-minute span. Additionally, the second finding indicates that adults with dyslexia seemed to be able to manage their clock checking tendencies without difficulty.

Prospective memory deficits in adults with dyslexia have been indicated to occur mainly when PM performance is cued by time and when PM performance is reliant on self-initiated processes (e.g., in self-report questionnaires, in laboratory-based tasks and in naturalistic conditions; Smith-Spark, Ziecik et al., 2016a, 2016b, 2017a, 2017b). Self-initiated processes that assist with remembering a PM-related action that requires implementing at a certain point in time, depend on internally generated prompts. Despite evidence from the abovementioned studies - but more specifically in Smith-Spark, Ziecik et al. (2016b) in which a computerized PM task was experimentally used to assess TBPM - in the current work, adults with dyslexia showed no evidence of TBPM deficits. To fully consider the implication of the discrepancy found in the current work, some important points are explored further.

The nature of the TBPM task employed in the current study involved time monitoring and self-initiated processes in order to assist with executing predetermined PM actions. The precise target times at which PM performance were required were definitive. Specifically, in order to be counted as correct, participants had to provide a response within a 30-second time limit of the target time. In the event that a response was provided before the 30 seconds had elapsed, the following trial was immediately activated. If no response was given prior to the 30-second limit, the next trial immediately presented. Without the use of an external clock to rely upon to assist with the PM performance or clock monitoring; the participants were constrained to engage in preparatory time monitoring to assist with the successful performance of the PM task via self-initiated prompts (a proactive strategy). Mahy and Moses (2011) have argued that though proactive strategies demand greater attentional resources, they are more reliably enhanced in those who engage in preparatory time monitoring in a PM task that is time-based. Additionally, Labelle, Graf, Grondin, and Gagné-Roy (2009); Mioni and Stablum (2014), and Vanneste, Baudouin, Bouazzaoui, and Taconnat (2016); have reported that a greater extent of accuracy in time perception ability is predictive of monitoring or clock-checking tendencies rather than PM accuracy directly. Accordingly, to explain the current work's findings, it could be reasoned that the successful TBPM performance by adults with dyslexia may have resulted indirectly from their observed engagement in time monitoring. Another explanation may be that the successful TBPM performance may have been influenced by a more direct relationship between time perception and accuracy of TBPM performance in adults with dyslexia, (see Mackinlay, Kliegel, & Mäntylä (2009) and Mioni, Santon, Stablum, & Cornoldi (2016) for experimental evidence that demonstrates a direct relationship between time perception and the accuracy of PM performance). The lack of deficits in TBPM performance by adults with dyslexia obtained in the current work contradicts that of Smith-Spark et al. (2016b). A possible explanation for this disparity may be that the repetitive nature of the same PM required response (press "A" on a qwerty keyboard every 3 minutes in a 14-minute test window), meant that the PM task was more habitual and thus somewhat undemanding over the relatively short testing span of the task. The effects of dyslexia from direct studies (e.g., Khan, 2014; Smith-Spark, 2000; Smith-Spark, Zięcik et al., 2016a, 2016b, 2017a, 2017b) have indicated that the effects of dyslexia on PM are less likely to occur when task demands are repetitive or habitual compared with when task demands are one-off or episodic in nature.

3.12 Task 3: The Rivermead Behavioural Memory Test (Wilson, et al. 2008) – An everyday memory laboratory-based task

The Rivermead Behavioural Memory Test (RBMT; Wilson et al., 2008) is a conventional and widely used measure of everyday memory performance (e.g., Requena, Alvarez-Merino & Rebok, 2019; Wester, 2014). The most recent version of the RBMT-III includes 14 subtests assessing verbal and nonverbal episodic memory, spatial memory, aspects of prospective memory, and procedural memory. In several subtests, memory is tested both immediately after stimulus presentation and after a filled delay. The subtests each address an important aspect of everyday memory function. For instance, participants are required to remember a route and deliver messages (which demands spatial memory) as instructed by the investigator, remember a short story (which calls upon verbal memory); remember photographs of people (which demands verbal memory for face recognition); remember to retrieve two personal belongings (which requires memory for everyday objects) at the end of the test session; remember to ask two specific questions after a delayed period (which calls upon verbal episodic memory) and memory for orientation and date (which requires memory for episodic memory) e.g., date of birth. The duration of the task is approximately 30 minutes.

3.12.1 Rationale and hypotheses for the inclusion of the RMBT-III

The rationale for including the RMBT-III assessment in the current work is that the test adds a unique dimension to the range of tasks that have been explored in the study of PM in dyslexia - with a larger focus on RM than PM tasks. Specifically, the task makes allowance for the measurement of multi-modalities in immediate versus delayed memory recall linked to spatial memory, verbal memory, verbal memory for face recognition, memory for everyday objects, verbal episodic memory and memory for episodic memory. It was expected that the wide-range of perceptual modalities measured by this task would assist in expanding current understandings of PM failure in dyslexia. Two groups of hypotheses were generated. The first group of hypotheses was defined to predict main effects and interaction effects between task type, participant group and time of testing. The second group of hypotheses was delineated to predict group performance differences. In the recall of first and second names respectively, and appointments after a delayed period; combined indices of immediate versus delayed recall ability and overall summary performance score. The formulated hypotheses are based on dyslexia-related deficits from previous studies of TBPM (e.g., Smith-Spark, Ziecik et al., 2016b, 2017a) and EBPM performance (e.g., Smith-Spark, Ziecik et al., 2017b). The se PM failures are associated with PM-intentions that were sporadic, habitual, one-off, over lengthier delayed periods and augmented problems in PM performance that require internally generated cues.

In the first group of hypotheses, firstly, it was hypothesized that there would be a significant main effect of task type. Secondly, it was hypothesized that there would be a significant main effect of time of testing. Thirdly, it was hypothesized that there would be a non-significant interaction effect for task type * time of testing. This line of prediction was formulated on the basis that, without considering participant group, the difference between immediate and delayed recall performance would be reduced. Owing to PM problems in PM performance over extended delayed periods (e.g., Smith-Spark, Ziecik et al., 2017b), and in longer delayed periods, the pattern of results that was expected when participant-group was considered was for dyslexia-related performance to be negatively impacted on in delayed recall performance. On this basis, fourthly, it was hypothesized that there would be significant interaction effects between (i) task type * participant group; (ii) time of testing * participant group; task type * time of testing * participant group; (iii) time of testing * participant group; task type * participant group; and (iv) task type * time of testing * participant group.

Based on previous research on dyslexia-related deficits in EBPM over extended delayed PM responses (e.g., Smith-Spark, Ziecik et al., 2017b) and over short interval periods (e.g., Smith-Spark, Ziecik et al., 2016b; 2017a), the following hypotheses were generated. In the second group of two hypotheses, it was hypothesized that compared to adults without dyslexia, those with dyslexia would be significantly less accurate at (i) recalling first names after a delayed period; (ii) recalling second names after a delayed period; (iii) recalling appointments after a delayed period (iv) combined indices of immediate versus delayed recall ability and (v) overall summary score.

3.12.2 Design, method and procedure for the Rivermead Behavioural Memory Test version III

The RMBT-III test contains five different tasks and are discussed next. First and Second Names - Delayed Recall Task: In this task, the participants were shown three photographic portraits one at a time and were asked to remember the first and second names of both people in the photographs at a later point. Route - Immediate Recall Task: In this task, the investigator showed the participant a route to walk around the room and then asked the participant to demonstrate it. Route - Delayed Recall Task: The investigator showed the participants a route around the room. The investigator subsequently asked the participants to demonstrate the route the examiner took around the room earlier immediately after the route had been demonstrated to the participants. Messages - Immediate Recall Task: The participant is required to take a message and book with them when they demonstrate the route and put the two objects in the same places that the investigator did. Messages - Delayed Recall Task: Participants are required to take a message and book with them when they demonstrate the route again and put them in the same place that the investigator carried out the orientation. The participants are assessed on indices related to names, relay of messages, time, and place. The first and second groups of hypotheses (see Section 3.12.1) were analysed with a 3 by 2 MANOVA and an independent-samples t-test respectively.

3.12.3 Results

3.12.3.1 Results: MANOVA analyses: Main effects and interaction effects between task type, participant group and time of testing

The results in table 3.7 show descriptive statistics of performance-related data on indices of the RMBT-III task.

Table 3.7: Descriptive statistics for MANOVA analyses carried out on indices of task-type, and time of testing on the RMBT-III task.

Group	Adults without dyslexia		Adults with dyslexia	
	(N=27)		(N=24)	
Task	Mean	*SD*	Mean	*SD*
Story - Immediate recall	11.11	4.08	8.77	3.65
Story - Delayed recall	10.28	4.88	7.33	3.12
Route - Immediate recall	13.41	2.47	12.79	3.16
Route - Delayed recall	13.26	2.68	12.46	3.13
Messages - Immediate recall	6.00	0.00	5.71	0.81
Messages - Delayed recall	6.00	0.00	5.92	0.28

Prior to conducting a 3x2 MANOVA, the homogeneity of variance assumption was tested for all 5 subscales (first and second names delayed recall; route immediate recall and route delayed recall; messages immediate and messages delayed recall) of the RMBT-III test. The multivariate test revealed statistically significant main effect of task type, F (2, 98) = 99.30, p <.001, η_p^2 = .67. A significant interaction effect was found for task type * participant group, F (2, 98) = 3.32, p = .04. The group with dyslexia recalled less than the group without dyslexia in immediate recall, and this difference was larger in delayed recall for the group with dyslexia. Non-significant interaction effects were found for time of testing * participant group, F (1, 49) = .65, p = .43, η_p^2 = .01, and task type * time of testing * participant group, F (2, 98) = .90, p = .41, η_p^2 = .02.

3.12.3.2 MANOVA analyses: Within-subjects time of testing performance

Time of testing (immediate vs delayed) was also found to be statistically significant, F (1, 49) = 12.40, p = .001, η_p^2 = .21. A significant effect was indicated for participant group, F (1,49) = 5.32, p = .03, η_p^2 = .098. Mauchly's test indicated that the assumption of sphericity had been significantly violated on the interaction effect of task type * time of testing ($\chi^2(2)$ = .54, p <001. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. A significant interaction effect of task type * time of testing was found, F (1.37, 67.18) = 8.92, p = .002, η_p^2 = .015.

3.12.3.4 Results: Independent-samples t-tests for between-group performance analyses related to first and second names recall, appointments after a delayed period recall, combined indices of immediate versus delayed recall and overall summary performance.

The results in table 3.8 show descriptive statistics performance data on a range of indices of delayed-recall and overall summary recall abilities.

Table 3.8: Descriptive statistics for t-tests on performance in relation to first, and second names delayed recall, appointments delayed recall, belongings delayed recall, picture recognition delayed recall, and overall summary score on the RMBT-III task.

Group	Adults without dyslexia		Adults with dyslexia	
	(N=27)		(N=24)	
Task	Mean	*SD*	Mean	*SD*
First names - Delayed recall	11.11	4.08	8.77	3.65
Second names - Delayed recall	10.28	4.88	7.33	3.12
Appointments delayed recall	13.41	2.47	12.79	3.16
Belongings - Delayed recall	13.26	2.68	12.46	3.13
Picture recognition - Delayed recall	6.00	0.00	5.71	0.81
Overall summary of recall	6.00	0.00	5.92	0.28

Six independent t-tests were carried out to analyse group performance differences in these indices - first names delayed recall, second names delayed recall, appointments delayed recall, combined indices of immediate versus delayed recall ability summary score, belongings delayed recall. In order to minimize the chances of obtaining a false positive on the multiple pairwise comparisons on the same data, Bonferroni-adjusted was applied by changing the significance threshold and calculated – the alpha level was 0.008 (0.05/6). The Levene’s test indicated a violation of likeness of variance between “appointment delayed recall” and “belongings delayed recall”. Thus, the traditional adjustments were reported instead.

Adults with dyslexia (M = 107.73, *SD* = 15.26) performed significantly less well over all the combined indices of immediate and delayed recall ability summary score compared with those without dyslexia (M = 119.38, *SD* = 12.55), *t* (49) = -3.11, *p* = .003, d = 0.86. A non-significant between-group difference in means was obtained for recalling of first names after a delayed period in adults with dyslexia

(M = 4.38, *SD* = 1.28) and in those without dyslexia (M = 5.15, *SD* = 1.03), *t* (49) = -2.39, *p* = .021, d = 0.69. A non-significant between-group difference was revealed in adults with dyslexia (M = 3.42, *SD* = 2.19) and adults without dyslexia (M = 4.59, *SD* = 1.60) at recalling second names after a delayed period *t* (49) = -2.21, *p* = .032, d = 1.01. There was a non-significant between-group difference in means in adults with dyslexia (M = 3.25, *SD* = 1.89) and those without dyslexia (M = 3.81, *SD* = 0.56) at recalling appointments after a delayed period *t* (49) = -2.13, *p* = .04, d = 0.42. A non-significant between-group difference in performance was revealed for belongings delayed recall in adults with dyslexia (M = 6.42, *SD* = 2.28) and those without dyslexia (M = 7.26, *SD* = 1.58) *t* (49) = 1.51, *p* = .14, d = 0.43; and for the face recognition delayed recall, in adults with dyslexia (M = 13.33, *SD* = 1.63) and those without dyslexia (M = 13.63, *SD* = 1.55), *t* (49) = -.67, *p* = .51, d = 0.19.

3.12.4 Discussion

The results indicated significant main effects of participant group, task type, and time of testing respectively. A significant main effect was also revealed for the interaction effect for task type*time of testing. This was consistent with the stated hypotheses. The interaction effect shows that irrespective of participant group, when the type of task (route recall and messages recall) and time of testing (immediate vs delayed) were considered; the tasks that required immediate recall response were more accurately remembered and performed in comparison with delayed recall. However, non-significant interaction effects were found between task type*participant group, time of testing*participant group; task type*time of testing*participant group, time of testing*participant group; task type*participant group, and task type*time of testing*participant group. These findings were not consistent with the specified hypotheses concerned. The lack of interaction effects in this case suggests that when participant group was featured to test its' influence on task type and time of testing, performance was comparable between adults with dyslexia and those without dyslexia. Moreover, this indicates that when specific types of tasks are considered (comprising of - route recall, story recall, and messages recall), then irrespective of whether the delay period prior to recall was immediate or delayed, adults with dyslexia appeared to show no evidence of lowered performance.

Dyslexia-related difficulties have been indicated in enactments of PM intentions over 40-minutes delayed intervals in a semi-naturalistic task (e.g., Smith-Spark, Ziecik et al., 2016b) and over extended delayed periods in a more naturalistic task over a one-week period (e.g., Smith-Spark et al., 2017a). In the current work, the delayed period employed in the RMBT task ranged between 20 to 25 minutes. The findings obtained in the current work suggests that the extent of delay periods experienced in the RMBT task that requires memory for motor, verbal and visual-related performances did not pose performance-related problems for adults with dyslexia in the specified delayed period. Apart from combined indices of immediate versus delayed recall ability and (v) overall summary score - which adults with dyslexia performed significantly lower than those without. There was no evidence of dyslexia-related difficulties in their performance related to (i) recalling first names after a delayed period; (ii) recalling second names after a delayed period; (iii) recalling appointments after a delayed period. These findings indicate that adults with dyslexia were successfully able to recall and verbalize first and second names of people after a 25-minute delayed period based a one-time exposure. Adults with dyslexia did not indicate any deficits with regards to remembering to carry out future appointments that were cued by an audible alarm, after a 20-minute delayed period. These findings suggest that after a modest 20-to-25 minutes delayed interval, the retrieval and execution of information related to people’s names and future appointments do not present notable problems in adults with dyslexia. Performance of adults with dyslexia and those without did not significantly differ on the indices of (i) belongings delayed recall; and (ii) face recognition delayed recall. These findings were inconsistent with the specified hypotheses and suggest no evidence of dyslexia-related problems in the recall of faces after a 15-minutes delayed period and remembering to reclaim personal belongings after a delayed period of 30 minutes. The implications of these findings are discussed more broadly in the general discussion (see section 3.15).

3.13 Study 2 Laboratory-Based Meal Preparation Simulation Task

3.13.1 Task 1: The Dresden Breakfast Task

The Dresden Breakfast task (Altgassen, Koban, & Kliegel, 2012) is a simulated laboratory-based meal preparation task with established ecological validity. This task emulates real-world encounters of PM in which participants are required to set the table and prepare food items following specific rules. There are six subtasks which require either event-based or time-based PM. In the Dresden Breakfast this task, participants are asked to perform all six subtasks within seven minutes whilst adhering to particular rules. The rules reflect the typical constraints that arise while preparing meals (e.g., putting the table-cloth down first, followed by the tableware) and then subsequently preparing specific foods (e.g., eggs, bread) and drinks (e.g., tea, orange juice; Altgassen et al., 2012). In adherence with Craik and Bialystok’s (2006) recommendations to examine planning and task coordination in a contextual setting, the participants were required to make breakfast for two people using actual cooking equipment and food items. The six subtasks included four TBPM tasks and two EBPM tasks. In the EBPM tasks, responses were scored as correct if participants completed these tasks within 20 seconds after occurrence of the events. In the TBPM tasks, responses were scored as correct if the participants completed these tasks 30 seconds either side of the target times. A stopwatch timer was positioned on the dining table and activated when the Dresden Breakfast task was begun.

3.13.2 Rationale and hypotheses for inclusion of Dresden Breakfast task

As previously stated, the Dresden Breakfast task (Altgassen, Koban, & Kliegel, 2012) is a well-established laboratory (simulated) based meal preparation task with high ecological validity. One of the means through which the current work sought to extend the existing literature on dyslexia-related PM deficits is to study PM using a wide range of tasks including an ecologically-valid task. The task is representative of real-life exemplars of PM and offers a means of assessing group differences in a realistic task that requires the participants to use real materials in preparation of a breakfast-based task according to strict rules. Furthermore, the task assesses the execution of a variety of indices related to TBPM and EBPM tasks. This addition to existing work on dyslexia-related problems in PM is an original contribution to the literature with respect to adults with dyslexia.

Previous findings have shown EBPM performance to be unaffected in dyslexia (e.g., Khan, 2014; Smith-Spark, Ziecik et al., 2016a; Smith-Spark, Ziecik et al., 2017a). In contrast, Smith-Spark, Ziecik et al., 2017b) found EBPM to be impaired on a naturalistic task following a week's delay period. Based on highlighted findings, in the current study, it was expected that adults with dyslexia would not significantly differ from those without dyslexia in their EBPM performance. The proposed hypotheses were generated based on the pattern of findings that have revealed dyslexia-related TBPM deficits when self-initiated and monitoring processes involved in TBPM are required for PM performance (e.g., Smith-Spark, Ziecik et al., 2016b; 2017a). Furthermore, self-initiated and monitoring processes involved in TBPM task performance have been shown to be closely linked to EF ability (e.g., Schnitzspahn et al., 2013) – and in dyslexia there is evidence to suggest a range of EF deficits including set-shifting.

In the first grouping of hypotheses relating to PM performance, it was hypothesized whilst performance was expected to be comparable between adults with dyslexia and those without on EBPM tasks, adults with dyslexia were expected to perform significantly less well at TBPM tasks in comparison to adults without dyslexia. Lastly, adults with dyslexia were predicted to perform significantly fewer clock monitoring tendencies in comparison to adults without dyslexia.

In the second grouping of hypotheses relating to the ongoing performance of the Dresden Breakfast task, adults with dyslexia were predicted to perform significantly less well than adults without dyslexia in (i) rule adherence (i.e. - how closely the participants followed the set instructions), (ii) frequency of occurrence of inefficiency (i.e. - how often the participants were unsuccessful at executing tasks), (iii) performing detailed elaborated actions in task performance as per plan (i.e., - overall successful performance of each of the itemized individual actions to be executed), (iv) following specific rules that were required to be executed in accordance with the task plan (i.e., - successful shadowing of specified ruled as per task plan), and (v) the total number of room and task switches (i.e., successful switching between kitchen and dining room locations and moving between the designated tasks).

3.13.3 Design, method and procedure for the Dresden Breakfast task

The Dresden Breakfast task (Altgassen, Koban, & Kliegel, 2012) is a laboratory-based meal preparation task that requires participants to follow a set of rules when making breakfast. In the practice phase, the task was explained first and then participants were invited to read the requirements of the task. Following this, the participants were shown a laboratory room in which one half of the room was utilized as a dining room whilst the other half was used as a kitchen. The kitchen area contained all the various items needed to perform the task (e.g., tablecloth, carton of milk, cutlery). The dining area contained a table with two chairs. Next, the participants were guided through the task requirements to ensure they had understood the task. The investigator invited participants to read the instructions regarding the order of how the six subtasks were to be performed. Six subtasks were instructed to be carried out in the following order.

1: Put the table cloth on the table as soon as the investigator begins the task,
2: After one minute, put the tableware on the table for 2 people – 2 plates, 2 knives, 2 spoons and 2 forks
3: Immediately after putting the tableware on the table, put 2 teabags into the 2 teacups
4: Put a carton of orange juice and 2 drinking glasses on the table 2 minutes before guests arrive
5: Remember to put a carton of milk and a loaf of bread on the table 1 minute before guests arrive
6: Put the 2 glasses you placed on the table upside down 30 seconds before guests arrive.

A stopwatch timer was placed on the dining table which was started at the beginning of the breakfast task. The participants were permitted to check the time in order to remember when to perform the TBPM-cued tasks. The participants were then asked to complete a test phase prior to actual task performance and were invited to develop and write down a plan of how and in which order they intended to perform the subtasks. Afterwards, the participants were asked to verbally communicate their plan to the investigator who recorded it through a voice recorder for later scoring. The investigator kept the recorded plans and the participants did not have access to them or any other written notes again prior to or during task performance. The participants were explicitly encouraged to switch between tasks to complete all tasks on time and were informed that some of the tasks were more important than others (e.g., ensuring that the table is ready when guests arrive and making sure that the carton of orange juice is placed on the table just before the guests arrive). After the participants successfully developed their plans, they were asked to complete a filler task, namely the Digit Ordering test (Daneman, & Carpenter, 1980), which provides a measurement of' working memory. This task has been employed as a filler task in the Dresden Breakfast task (e.g., Altgassen et al., 2012) and was used for the same purpose in the current study. In the Digits Ordering test, the experimenter read out accumulative numbers of digits. The participants were asked to verbally repeat the sequence of numbers in ascending order. Initially the investigator verbally presented three single digits to each participant (e.g., 3, 1, 9). After each trial, the previous digit span increased by one. The maximum digit span was eight. The number of correctly identified digits per sequence was counted to ensure that participants were engaged in the task.

Afterward, the participants performed the Dresden Breakfast Task. The investigator measured when and which tasks participants began and completed. The Dresden Breakfast Task was assessed using the (i) rule adherence, (ii) frequency of occurrence of inefficiency, (iii) performing detailed elaborated actions in task performance as per plan, (iv) following specific rules that were required to be executed in accordance with the task plan, and (v) the total number of room and task switches. Additionally, the number of clock checks and the number of tasks completed by task type (EBPM, TBPM) were also assessed. The first group of hypotheses (see Section 3.13.2) was analysed with 2-Way ANOVAS. Separately, as part of the first group of hypotheses, clock monitoring tendencies was assessed using an independent-samples t-test. The second group of hypotheses (see Section 3.13.2) was analysed with 2-Way ANOVA tests.

3.13.4 Results

3.13.4.1 Results: 2-Way ANOVA PM task type within-group performance

The results in table 3.9 show descriptive statistics of the data on TBPM and EBPM task performance on the Dresden breakfast task.

Table 3.9 Descriptive statistics for the within-group TBPM and EBPM task performance on the Dresden breakfast task.

Within group (N=48)

Task	Mean	*SE*
TBPM task performance	1.89	0.038
EBPM Task performance	1.90	0.045

The main effect of participant group on overall PM performance was found to be significant *F* (1, 46) = 7.27, *p* = .01, η_p^2 = .136. The performance of PM task-types (EBPM vs TBPM) differed significantly irrespective of group.

3.13.4.2 Results: 2-Way ANOVA PM task type performance between-groups

The results in table 3.10 show descriptive statistics of the TBPM, EBPM performance data, and clock checking tendencies on the Dresden breakfast task.

Table 3.10: Descriptive statistics of TBPM and EBPM task performance, and clock checking tendencies on the Dresden breakfast task.

Group	Adults without dyslexia		Adults with dyslexia	
	(N=24)		(N=24)	
Task	Mean	*SD*	Mean	*SD*
TBPM task performance	1.98	0.36	1.79	0.36
EBPM Task performance	1.92	0.28	1.88	0.34

	Adults without dyslexia		Adults with dyslexia	
	(N=23)		(N=24)	
Task	Mean	*SD*	Mean	*SD*
Clock checking tendencies	37.91	13.90	28.71	10.65

The adults with dyslexia performed significantly fewer time-based tasks correct (M = 1.79, *SD* = 0.36) than the adults without dyslexia (M = 1.98, *SD* = 0.10*)*. This result was found to be significantly different between-groups, *F* (1, 46) = 6.07, *p* = .02, η_p^2 = .117.

The performance between the two groups did not differ significantly in the number of correct event-based PM tasks successfully carried out, *F* (1, 46) = .215, *p* = .65, η_p^2 = .005. In event-based tasks, PM performance of adults with dyslexia (M = 1.88, *SD* = 0.34) were only just less than adults without dyslexia (M = 1.92, *SD* = 0.28).

Adults with dyslexia performed significantly fewer clock monitoring (M = 28.71, *SD* = 10.65) compared with adults without dyslexia (M = 37.17, *SD* = 14.08), *F* (1, 46) = 5.51, *p* = .02, η_p^2 = .107.

3.13.4.3 Results: 2-Way ANOVA Ongoing Breakfast Task performance between-group

The results in table 3.11 show descriptive statistics for the data of general task performance on the Dresden breakfast task.

Table 3.11: Descriptive statistics of general task performance on the ongoing task in relation to rule adherence, plan quality, flexible room and task switches, and efficiency on the Dresden breakfast task.

Group	Adults without dyslexia		Adults with dyslexia	
	(N=24)		(N=24)	
Task	Mean	*SD*	Mean	*SD*
General PM task performance	5.83	0.48	5.42	0.83
Rule adherence	5.81	0.48	5.31	0.83
Plan quality	5.95	0.20	5.46	0.78
Flexible room & task switches	31.25	2.44	28.04	6.95

To investigate general task performance, rule adherence and plan quality, ANOVAS were performed. In the general task performance, adults with dyslexia performed significantly less well (M = 5.42, *SD* = 0.84) than adults without dyslexia (M = 5.83, *SD* = 0.48), *F* (1, 46) = 6.52, *p* = .014, η_p^2 = .124. The results indicated that adults with dyslexia (M = 5.31, *SD* = 0.83) adhered significantly less to the task rules compared with adults without dyslexia (M = 5.81, *SD* = 0.48), *F*

(1, 46) = 6.48, $p = .01$, $\eta_p^2 = .123$. The results for plan quality showed that the quality of plan for adults with dyslexia were less detailed (M = 5.46, *SD* = 0.78) than adults without dyslexia (M = 5.95, *SD* = 0.20), *F* (1, 46) = 9.25, $p = .004$, $\eta_p^2 = .167$. The result for flexible-room and task switches showed that adults with dyslexia (M = 28.04*, SD* = 6.95) made significantly fewer switches between rooms and tasks compared with those without dyslexia (M = 31.25, *SD* = 2.44), *F* (1, 46) = 4.56, $p = .04$, $\eta_p^2 = .090$. The results for efficiency showed that adults with dyslexia (M = 0.88*, SD* = 0.99) were significantly less efficient compared with those without dyslexia (M = 0.29, *SD* = 0.55), *F* (1, 46) = 6.35, $p = .02$, $\eta_p^2 = .121$.

3.13.5 Discussion

The naturalistic Dresden Breakfast Task was employed to assess group performance between adults with dyslexia and those without dyslexia on their ability to execute a number of indices related to TBPM and EBPM tasks. In the first grouping of findings in which PM performance was assessed, the results indicated a significant effect of participant group on the type of PM task that was performed. Adults with dyslexia were significantly less successful at carrying out PM tasks that were cued by time than adults without dyslexia. This finding suggests adults with dyslexia were weaker at executing PM tasks that were triggered by time cues. This finding is consistent with previous research (Khan, 2014; Smith-Spark, Ziecik et al., 2016a, b; 2017a; who also reported greater PM failures in TBPM rather than EBPM tasks (although see Smith-Spark, Ziecik et al., 2017b) for dyslexia-related EBPM problems over an extended delay period). Adults with dyslexia carried out fewer time monitoring tendencies during performance of the Dresden Breakfast task. This finding is consistent with that of Smith-Spark et al. (2016b) who also reported reduced time monitoring behaviours. This particular finding may be linked to and may well explain dyslexia-related PM performance that is contingent on time-based cues and self-initiated processes that are associated with TBPM. In contrast, adults with dyslexia were comparably successful at executing EBPM tasks as adults without dyslexia. This indicates the absence of dyslexia-related deficits in PM tasks that were cued by particular environmental cue. All three findings were consistent with and supported the hypotheses. The results are also consistent with previous findings that have indicated a greater extent of dyslexia-related deficits in TBPM tasks than in EBPM through subjective measures (Khan, 2014; Smith-Spark, Ziecik et al., 2016a) and in objective laboratory-based measures (e.g., Smith-Spark, Ziecik et al., 2016, b). The current study's findings supported all three hypotheses in their predictions.

In the second group of analyses, the ongoing Breakfast task performance was assessed across five indices. The findings indicated that adults with dyslexia performed significantly less well at (i) general task performance, (ii) adhering to rules (iii) flexible switching between room and tasks, (iv) plan quality, and (v) efficiency in task performance. All five hypotheses were supported by the findings and are consistent with previous research. Firstly, the results indicate that adults with dyslexia showed difficulty in their ability to follow specific rules during task performance in addition to frequent occurrences of inefficiency during task performance. The deficits were specific to tasks that were cued by time in nature as opposed to those cued by specific events and this pattern is consistent with TBPM dyslexia-related problems that have been indicated in Smith-Spark, Ziecik et al. (2016 a,b). Furthermore, dyslexia-related problems were indicated in the general task performance. This measure encompassed detailed executed actions relative to the participants original plan – but excluded PM tasks. Adults with dyslexia indicated problems in their ability to carry out detailed actions during performance of the Dresden Breakfast task. These problems were linked to a greater extent to TBPM tasks than EBPM tasks. This suggests that problems associated with the ability to follow specific detailed actions in order to execute certain operations in the task were specific to TBPM as opposed to EBPM.

With regards to the index of set-shifting (flexible switching), deficits were revealed in adults with dyslexia and is in line with that of Schnitzspahn et al. (2013). However, set-shifting was not directly assessed and thus is indirectly predictive of

TBPM performance. The findings of the current study indicate that flexible switching or set-shifting ability (see Section 4.3.3) appears to be an important aspect of the cognitive process that is indirectly involved in TBPM performance in adults with dyslexia. It has been demonstrated that effective TBPM task performance is associated with self-initiated and monitoring processes (e.g., Martin, Kliegel, & McDaniel, 2003; McDaniel & Einstein, 2000). Self-initiated and monitoring processes are closely linked to EF ability and appear to be needed to trigger TBPM instead of EBPM task performance.

3.14 Study 3 Naturalistic TBPM task

3.14.1 Task 1 Naturalistic TBPM task over longer intervals

This task tested the participants' ability to execute an intention over extended intervals in response to a time-based cue. Smith-Spark, Zięcik and Sterling (2017a) employed an EBPM version of this task. However, in the current work, a naturalistic TBPM task-kind was adopted. To assess whether PM executions over extended intervals that rely on time-based cues would demonstrate dyslexia-related performance deficits. The task entailed the investigator requesting the participants at the end of testing session; to remember to carry out a specific instruction on the way to the laboratory for the next testing session. The participants were explicitly informed not to set any reminders to aid task performance – but to rely solely on their memory instead. Under naturalistic conditions, Smith-Spark, Zięcik and Sterling (2017b) reported group differences in EBPM in their study. The complexity of the task employed exemplified comparable task-demands that are closely associated with those experienced in day-to-day life. The task was administered to groups of adults with and without dyslexia, matched for age and short-form IQ (see Section 2.1 for details). The participants were required to make a response outside the laboratory setting one week following the instruction being verbally given. The adults with dyslexia performed significantly poorer at remembering to carry out the event-based PM task one week later, even though equivalent levels of motivation to perform it successfully was reported by both groups. Furthermore, fewer adults with dyslexia reported recalling the PM instruction at the particular time point when it was needed. Dyslexia-related EBPM deficits were revealed over longer delay time periods. Smith-Spark, Zięcik and Sterling (2017b) argued that dyslexia-related difficulties in event-based PM may be linked to the reliable access to verbal information at a certain time point when it is necessitated.

3.14.2 Rationale and hypotheses for using a Naturalistic TBPM task - longer interval

The rationale for including the naturalistic TBPM task over a longer interval is to extend the work of Smith-Spark, Zięcik and Sterling (2017a). The current investigation sought to ascertain whether naturalistic TBPM deficits can be found over longer intervals in adults with dyslexia. Firstly, it was hypothesized that compared with the group without dyslexia, the group with dyslexia would be significantly less likely to remember to execute the naturalistic TBPM longer interval task. Secondly, it was hypothesized that there would be a between-group difference in the use of mental strategies to aid task performance. Compared with adults without dyslexia, those with dyslexia were expected to use significantly more mental strategies to help them to remember to perform the task. This prediction was based on self-reported use of mental strategies in Smith-Spark, Ziecik et al. (2017b) to aid successful PM performance. The use of mental strategies was assessed via a short questionnaire that asked whether or not a strategy was used. An additional analysis was performed to analyse the gap between the TBPM instruction being given and the execution of the expected response between the two groups.

3.14.3 Design, method and procedure

The task entailed the investigator requesting participants at the end of Session 1 to remember to carry out a specific instruction. The participants were asked to rely on their memory and were specifically asked not to set any reminders to aid their performance of the set task. The instruction was verbally presented as follows: “On your way to the university for your next test session, remember to look at the day’s newspaper headline and remember to tell the investigator at some point in the next session without prompting”. After a longer interval delayed period and without being prompted, the participants’ either gave their responses or failed to give a response. A questionnaire was devised to accompany the longer interval naturalistic task. The participants were asked to complete the questionnaire after completing the naturalistic task. The questionnaire was devised to tap into strategies used by participants to remember. The participants were not previously advised on the usage of such techniques. They were simply informed not to set reminders on their mobile phones or electronic devices to assist with successful remembering and performance of the set PM task. The questionnaire additionally tapped into participant motivation to perform task - which was rated on a scale ranging from 0 = no motivation to 10 = high motivation. The questionnaire also measured participant interest in performing the task and was rated on a scale ranging from 0 = No interest to 10 = high interest. Additionally, the questionnaire was used to obtain how often the participants thought about the task after the instruction had been received in Session 1. Due to the need to fit appointments with participants’ diary, the interval length between the participants being given the TBPM instruction and the point in time when the expected response was required ranged between 24 hours and a few days. Thus, an independent samples *t*-test was performed to ascertain whether the group variance in the length of gap differed between adults with dyslexia and those without. The first and second hypotheses (see Section 3.14.2) were analysed using 2 x 2 Chi-squared tests of association.

3.14.4 Results

3.14.4.1 Results: 2 x 2 Chi Squared Test of Association on the likelihood of the successful performance of naturalistic TBPM task

The results in table 3.12 show frequency counts of participants with and without dyslexia who remembered and did not remember to perform the naturalistic TBPM extended delay task.

Table 3.12: Frequency counts of Chi-squared tests on the performance of the naturalistic TBPM extended delay task.

Group	Adults without dyslexia	Adults with dyslexia
	(N=25)	(N=24)
Task	Frequency counts	Frequency counts
Did not remember	9	12
Remembered	16	12

A 2 x 2 Chi-square test analysed the likelihood of successful performance of the naturalistic TBPM longer interval task between adults with dyslexia and those without. The results of the 2 x 2 Chi Squared Test of Association showed that in terms of accuracy, 48% of adults with dyslexia compared with 64% of adults without dyslexia successfully remembered to carry out the Naturalistic TBPM task after an extended delay period. This variance did not differ significantly between-groups χ2 (2, *N* = 50) = 2.00, *p* = .37, φ = .12.

3.14.4.2 Results: 2 x 2 Chi Squared Test of Association on the use of mental strategies between-groups

The results in table 3.13 show frequency counts of participants with and without dyslexia who used and did not use mental strategies to aid their remembering to perform the naturalistic TBPM extended delay task.

Table 3.13: Frequency counts of Chi-squared tests on the use of mental strategies on the naturalistic TBPM extended delay task.

Group	Adults without dyslexia	Adults with dyslexia
	(N=25)	(N=24)
Task	Frequency counts	Frequency counts
Used mental strategies	5	12
Did not use mental strategies	20	12

A Chi-square test analysis showed a significant difference between adults with dyslexia and those without dyslexia in their self-reported use of strategies to aid remembering (χ2 (1, *N* = 50) = 5.56, *p* = .02, w = *0.31*. Twenty percent of adults without dyslexia reported using a strategy to assist with remembering to perform the Naturalistic TBPM task compared with 52% of adults with dyslexia.

3.14.4.3 Results: Independent-samples t-test on the length of gap between the given instruction and expected response between-groups

An independent samples *t*-test indicated that there was a non-significant group difference between adults with dyslexia (M = 8.64, *SD* = 6.56) and those without dyslexia (M = 9.12, *SD* = 6.55) on the length of gap (min = 1 day, max = 9 days) between the instruction being given out and the expected response, *t* (48) = -2.6, *p* = .80, *d* = 0.07.

3.14.5 Discussion

This study was designed to test naturalistic TBPM performance over a longer interval in adults with and without dyslexia. Inconsistent with the hypothesis, the results indicated comparable between-group performance-related difference in the successful performance of a naturalistic TBPM longer interval task. However, adults with dyslexia were marginally (but not significantly) less likely to remember to execute the TBPM task. The results indicate the absence of dyslexia-related deficits in a naturalistic PM task that was reliant on a time-based cue.

This finding is inconsistent with Smith-Spark, Ziecik and Sterling (2017b) who indicated particular dyslexia-related difficulties in the successful performance of a naturalistic EBPM task that required enaction outside of the laboratory setting after a seven-day delayed period between the instruction being given and the point of enactment. The finding is also inconsistent with that of Smith-Spark, Zięcik and Sterling (2017a) who reported dyslexia-related difficulties in a naturalistic TBPM task that required participants to provide a response outside of the laboratory environment precisely after a 24-hour delayed period. In the current work, a time-based naturalistic task was employed and required remembering to remember to perform a PM intention and then remembering to report its performance back at the laboratory environment over a longer interval. There was typically 24 hours and 9 days gap between the instruction being given and the expected response. In Smith-Spark, Zięcik and Sterling (2017b), as well as in the current study, adults with dyslexia and those without reported equivalent levels of interest in performing the task. Despite this, in the current work, there was no evidence of dyslexia-related difficulties in a naturalistic TBPM task over longer intervals. The lack of obtaining a significant finding must be considered cautiously.

On one hand, adults with dyslexia appear to have performed as well as adults without dyslexia. However, only 48% percent of adults with dyslexia remembered to perform the task and also remembered to inform the investigator of its performance. it is plausible to infer that the 52% of adults with dyslexia who failed to successfully perform the TBPM task may have likely experienced difficulties in two ways. These are (i) at the information retrieval stage when PM enactment was required – an argument put forward by Smith-Spark, Ziecik et al. (2017b); and also (ii) at the stage when the participants were required to remember to inform the investigator of their performance of the task. The latter point is a novel contribution to the literature in that this component of the task is illustrative of participants ability in two-fold remembering – that is remembering to perform the task and then remembering to notify the investigator of the task’s performance. Consistent with the stated hypothesis, the results revealed that adults with dyslexia showed an increased employment of mental strategies to help them to remember to perform the task. This finding is important and is consistent with that of Smith-Spark, Ziecik et al. (2017a) who similarly indicated that participants with dyslexia self-reported greater frequently occurring PM difficulties - even though adults with dyslexia self-reported having used more strategic means to assist their recall to perform the PM-related task. The uniformity in the use of mental strategies to aid remembering in more naturalistic environments (EBPM; Smith-Spark, Ziecik et al. (2017a) and in in the current study (TBPM), suggests that adults with dyslexia frequently rely on specific tactics to assist with memory recall of undertaking that require event-based and time-based cues. It can be seen from the means that the group without dyslexia overall underwent a slightly longer intervening gap between the instruction being given and when the TBPM response was required. This difference was not found to be statistically significant. But in general, the interval gap patterns between task initiation and task response varied. Those who experience a longer interval between task instigation and task response in itself makes it less likely for them to remember. The current researcher endeavoured to keep the intervening gap to a minimum to account for this limitation. However, the objective was constrained by participants' availability.

3.15 General Discussion

A summary table indicating the main findings of the multiplicity of PM measures is presented next.

Table 3.14 shows the key results of the plethora of tasks employed to investigate PM.

Laboratory-based measures	**Group difference**	***p* value**	**d**
Computerized TBPM Task	Between group	.54	.11
Clock monitoring tendencies	Between group	.11	.20
Ongoing Task	Between group	.78	.25
Computerized EBPM task	Between group	.51	.04

Ongoing Task	Between group	.01	.01
Interaction effects		***p* value**	η_p^2
Rivermead Task			
Task type * Participant group		.04	.06
Time of testing * Participant group		.43	.01
Task type * Time of testing * Participant group		.41	.02
	Group difference	***p* value**	**d**
Summary score (immediate/delayed recall)	Between group	.003	.86
First names delayed recall	Between group	.021	.07
Second names delayed recall	Between group	.032	1.0
Appointment delayed recall	Between group	.04	.04
Face recognition delayed recall	Between group	.51	.19
	Group difference	***p* value**	η_p^2
The Dresden Breakfast Task			
Event-Based PM Tasks	Between group	.65	.01.
Time-based PM Tasks	Between group	.02	.12
Flexible switching	Between group	.02	.12
Naturalistic TBPM Measure	**Group difference**	***p* value**	**d**
Naturalistic TBPM task (extended delay interval)			
TBPM task performance	Between group	.37	.12
Use of mental strategies	Between group	.02	.31.

A summary of the discussions presented for the range assessments used to assess PM performance is considered next. This comprises inferences that are drawn from four groupings of PM assessments to give an overall PM performance profile of adults with dyslexia. The three task groupings are: (i) a laboratory-based computerized EBPM task and a laboratory-based computerized TBPM task; (ii) a laboratory-based test of everyday memory for immediate versus delayed recall – RMBT-III; (iii) an ecologically-valid meal preparation simulation task (the Dresden Breakfast Task) and (iv) a Naturalistic TBPM extended delay interval task. In the EBPM task in which PM performance was cued by the occurrence of a specific event, adults with dyslexia performed just as well as adults without dyslexia. From the perspective of the multi-process theory (McDaniel & Einstein, 2000), PM performance on event-based tasks is automatically triggered by PM related target cues. Furthermore, fewer attentional demands are placed on the cognitive system (McDaniel & Einstein, 2000) and, thus PM task performance is thus unlikely to be disrupted. For adults with dyslexia, in a computerized task that is cued by specific event-related target cues, it appears that spontaneous retrieval processes function uninterruptedly. With regards to the TBPM task, successful task performance was triggered by time-based cues and self-initiated processes in prompting task performance and clock monitoring tendences. However, the task performance data presented no evidence of processing difficulties in adults with dyslexia compared with those without dyslexia. What is more, compared with adults without dyslexia, those with dyslexia actually carried out more clock monitoring tendencies – a tendency that is reliant on self-initiated processes.

In view of the multi-process framework (McDaniel & Einstein, 2000), the occurrence of the TBPM and EBPM retrieval occurs through two distinct trajectories – with TBPM performance placing increased attentional demands on the cognitive system. Whilst the successful PM performance of EBPM tasks is considered to be spontaneously triggered by the target event; in TBPM tasks, the target times are characteristically fixed and may well necessitate one’s engagement in a preparatory time monitoring process. This thus places greater attentional demands on the cognitive system. Considering the reflexive or spontaneous nature of the triggering of EBPM task performance, in the current work, it appears that the 10-minutes duration of the task did not disrupt PM performance in adults with dyslexia.

With regards to the TBPM task, PM performance problems have been shown previously in Smith-Spark, Ziecik et al. (2016b) to transpire primarily when PM performance is cued by time and/or when PM performance is reliant on self-initiating processes. Despite this, in the current work, even with the added demand of attentional resources (e.g., Mahy & Moses, 2011) required for the successful execution of the TBPM performance and for activating self-initiating processes, adults with dyslexia appeared to be able to manage to perform a TBPM computerized task without any evidence of deficits. In fact, clock monitoring which had to be self-initiated were actually carried out more frequently by adults with dyslexia. What can be drawn from the findings is that performance over the 14-minute task's duration (in which TBPM responses were executed in tandem with an ongoing task), appears to have been undemanding enough to negatively impact on the performance of the computerized TBPM task. This may have to some extent contributed to some extent, a ceiling effect in the performance of adults with dyslexia. However, this conclusion is untenable considering that in Smith-Spark, Ziecik et al. (2016b), a non-significant participant group x task load interaction was found and indicated that regardless of the cognitive load (low–high), the performance of adults with dyslexia were unaffected by load.

The RMBT-III (Wilson et al., 2008) assessed perceptual processing ability on immediate versus delayed PM recall related to spatial memory, verbal memory, verbal memory for face recognition, memory for everyday objects, verbal episodic memory and episodic memory. Over the duration of task performance, the delayed period between specific requests to perform a PM action in the future and task enactment ranged between 20 to 25 minutes. The general pattern of the findings indicates that adults with dyslexia showed no performance-related deficits in route recall, story recall, and messages recall regardless of whether immediate or delayed recall was required. With regards, to delayed recall only, adults with dyslexia likewise did not demonstrate any performance-related difficulties in the indices of belongings delayed recall, face recognition delayed recall or recall of people's names and future appointments. These tasks demanded PM-related actions that required performance that were reliant on motor memory, verbal memory and visual-memory - and did not pose any evidence of performance-related problems for adults with dyslexia. Smith-Spark, Ziecik et al. have previously asserted that when PM-related instructions need to be remembered after an extended delayed period, PM failure has an increased likelihood of occurring in adults with dyslexia. Thus, in the current work, it is reasonable to infer that perhaps the 20 to 25 minutes delayed period experienced by adults with dyslexia were not substantial enough to show any negative effects on performance. From the multiplicity of task modalities in the RMBT-III test that encompassed spatial memory, verbal memory, verbal memory for face recognition, memory for everyday objects, verbal episodic memory and episodic memory, it can be seen that adults with dyslexia did not demonstrate specific problems that were attributable to particular perceptual modalities. The only statistically significant difference was obtained in the overall score of combined indices of immediate and delayed recall; in which adults with dyslexia were found to perform less well than those without dyslexia. This indicates that, without evidence of deficits in specific sensory systems, adults with dyslexia performed inferior to those without dyslexia only when the overall summary score on immediate and delayed recall were considered.

The Dresden Breakfast Task (Altgassen, Koban & Kliegel, 2012) was employed as an ecologically-valid naturalistic task - owing to its application as a real-life simulation of a meal preparation task that assesses PM performance. The task produced indices of time-based and event-based PM activities. The overall summary of task performance presents clear indications that adults with dyslexia exhibited difficulties in PM task performance that were cued by time (TBPM); but not in PM tasks that were triggered by event-related target cues (EBPM). An additional finding pointed to lesser clock monitoring tendencies by adults with dyslexia across the duration of performance. On the one hand it is possible that TBPM task performance (which relied on self-initiating processes and time-based cues) was inversely impacted on by the reduced clock monitoring tendencies (also reliant on self-initiating processes) in adults with dyslexia. These self-initiating processes rely on self-instigated triggers in order to assist (i) with recalling that a time-based action requires implementation at a future point and (ii) frequent prompts to carry out clock monitoring.

On the other hand, it is also conceivable that TBPM performance difficulties and reduced clock monitoring tendencies were negatively affected by problems related to self-initiating processes (a primarily self-prompting mechanism) during task performance. Previously, performance-related problems have been indicated in adults with dyslexia when a TBPM task implementation is required, and/or when the TBPM performance is contingent on self-initiating processes in Smith-Spark, Ziecik et al. (2016a, 2016b, 2017a, 2017b). Therefore, the latter assertion can be deemed reasonable as a possible explanation of TBPM failure in adults with dyslexia. Overall, the occurrence of TBPM difficulties demonstrated by adults with dyslexia, were characterized by deficits in rule adherence; and inefficiency in TBPM task performance. But of particular importance in this discussion is the lack of fluidity in the abilities of adults with dyslexia to allow flexible switching between the kitchen and dining areas and between tasks in the performance of the Dresden breakfast task. Flexible switching, also known as Set-shifting (see Section 4.3.3 for a broader discussion) has previously been shown to be involved in self-initiated and monitoring processes linked to PM tasks that are time cued (see Martin, Kliegel, & McDaniel, 2003; McDaniel & Einstein, 2000). Thus, for adults with dyslexia, their common deficits in flexible shifting ability (e.g., Poljac et al., 2010) may play a role in their TBPM task performance deficits. The inclusion of a naturalistic TBPM task was to assess time-cued extended delay interval PM performance. With the PM instruction given at the previous test session, both the PM task itself and the remembering to inform the investigator of its performance were to be carried out on the day of the next test session. This set-up allowed for the assessment of PM performance (remembering to perform the PM task) with another element of remembering to report the task's performance to the investigator at the next test session. Though the findings showed that performance was comparable between adults with dyslexia and those without in a naturalistic TBPM task, it is noteworthy to consider the following points. Under half of the participants with dyslexia were successful at both components of the set TBPM task; whilst just over half of adults with dyslexia failed to remember to perform the TBPM task. Adults with dyslexia reported an increased reliance of employing mental strategies, yet 52% of adults with dyslexia were unsuccessful at remembering to perform the TBPM task, even though they reported frequently remembering the PM task from time to time. It is possible that the problem may be localized at the retrieval stage of PM intention recall. On the one hand, failing to remember to execute the PM task after reporting frequent recall of the PM task from time to time may suggest that at the retrieval point when the PM instruction was required, adults with dyslexia experienced difficulty retrieving the verbal instructions from long-term memory. This is a point that has been raised in Smith-Spark, Ziecik et al. (2017a) who attributed extended delay EBPM problems in adults with dyslexia to deficits in access to verbal information in long-term memory.

Another line of argument that could explain TBPM failure in adults with dyslexia concerns the strength of binding between the PM cue and the PM action to be performed. To elaborate on this, the successful retrieval of PM-related verbal information from long-term memory and its associated PM-related target cues is dependent on the strength of binding (the degree of robustness of association) between the PM cue and the action to be performed (Gonneaud et al., 2011). In relation to the current work, since adults with dyslexia reported that they frequently remembered the TBPM task from time to time over the intervening period between forming the intention and acting upon it, it may be reasonable to argue that perhaps the strength of binding between the PM cue and the action to be performed may have weakened over the extended delayed period between the intention being given and the point of execution were longer than the average interval period.

The overall profile that can be assembled based on the findings suggest that adults with dyslexia appeared to be able to cope with task performance demands in computerized PM tasks that are dependent on time-based cues and event-based cues respectively. The significant participant and task-type interaction effect on the RMBT-III task (Wilson, et al., 2008) indicate that adults with dyslexia recalled less on delayed recall in comparison to immediate recall. The tasks encompassed a range of sensory processing tasks (i.e., story recall, route recall and messages recall). It is thus reasonable to assert that adults with dyslexia show vulnerability to decay of information in a variety of sensory processing modalities related to both verbal and non-verbal information over time. Additionally, adults with dyslexia appeared to perform as well as adults without dyslexia in a naturalistic TBPM task with an extended delay interval – although see the discussion points raised in Section 3.14.5 on this task. Finally, PM problems on the ecologically-valid Dresden Breakfast task (Altgassen, Koban, & Kliegel, 2012) indicated dyslexia-related problems on PM performance that were reliant on time-based cues and self-initiating processes as well as flexible shifting ability. These problems were not evident in adults with dyslexia in PM tasks that were reliant on event-based cues. The outlook of the overall PM profile in adults with dyslexia implies that TBPM problems are evident in a simulated meal preparation task. Furthermore, TBPM performance that required episodic and one-off PM responses were more likely to be problematic for adults with dyslexia compared with PM responses that were repetitive and habitual in nature.

Chapter 4.0 Executive functioning

4.0.1 Executive summary

Executive functions constitute a collection of complex mental processes that distribute attentional resources for the purpose of enabling efficiency in the management of planned behaviours. Executive functions can be divided into core EFs (e.g., Miyake., 2000; Miyake & Friedman, 2012) and broader EFs (e.g., Collins & Koechlin, 2012). The four core EFs encompass - inhibitory control, updating working memory, set shifting, and according to Fisk and Sharp (2004), verbal fluency. Broader EFs include dual-task performance and planning. Dyslexia-related EF problems are indicated within the literature – albeit mostly in children. Only a few studies have explored EFs in adults with dyslexia. The study reported in this chapter assessed a series of traditional laboratory-based EF measures and compared performance between adults with and without dyslexia. All four core EFs were assessed. The broader EFs assessed were dual-task performance and planning. The core EFs results showed dyslexia-related problems on set shifting, and phonemic fluency, but not on inhibitory control. The results for the broader EFs demonstrated dyslexia-related difficulties in dual-task performance and planning. The core EF of updating working-memory was also assessed – but the data could not be analysed due to technical issues. The EF deficits indicated, point to extensive cognitive problems in adults with dyslexia that occurs in addition to phonological processing deficits.

4.1 General definition and chapter overview

Executive functions (EFs) are higher-order mental abilities that regulate different cognitive processes. They are involved in the management of goal-directed or non-habitual behaviours (e.g., Banich, 2009). Executive function skills are necessary for one's cognitive and social maturity, physical and mental health as well as in education and work settings (e.g., Diamond, 2013) and include inhibition, set shifting, and updating processes (e.g., Miyake et al., 2000). These are considered as core EFs (e.g., Miyake & Friedman, 2012). Other broader EFs that are generated as a function of core EFs are planning, behaviour organization, self-monitoring dual task performance, and sequencing (Collins & Koechlin, 2012; Lunt et al., 2012). In this chapter, a broad definition of EFs is given, followed by a consideration of the EF framework from which two classifications of EFs are explained. The approach taken in the current work was to separate the empirical investigation into the two classifications of EF such that core EFs were considered first followed by examination of broader EFs. In both core EFs and broader EFs, a summary of the general research findings was given, followed by a discussion of dyslexia-related difficulties in core and broader EFs. The identified problems as highlighted in the existing literature points to the continuity of dyslexia-related EF problems into adulthood. This formed the basis of the rationale for the need to assess a comprehensive range of EFs in dyslexia. The general EF framework is discussed in the next section.

4.2 Executive functioning framework

Diamond (2013) has defined a framework for EF to explain how the core EFs are differently involved in assisting higher order cognitive processes (e.g., reasoning, planning and fluid intelligence; Diamond, 2013; Friedman & Miyake, 2017; Snyder, Miyake, & Hankin, 2015). Generally, there are considered to be three core EFs (e.g., Lehto et al., 2003, Miyake et al., 2000) comprising inhibition and interference control, working-memory, and set shifting (also referred to as cognitive flexibility or, mental flexibility; see Section 4.3 for a broader discussion of core EFs). It is from these core EFs that broader EFs are constructed (e.g., planning, reasoning and problem solving Collins & Koechlin, 2012, Lunt et al., 2012). Diamond’s framework additionally highlights how core EFs are connected and how they collectively organize and execute higher order cognitive processes such as self-regulation, planning, reasoning and fluid intelligence. There is evidence (e.g., Miyake et al., 2000) to suggest that facets of EFs contribute distinctly in explaining complex human behaviours. In accordance with Diamond’s (2013) EF framework, a grouping of shared EF such as inhibitory control and other core EFs (e.g., switching and updating working-memory) can assist higher order cognitive processes such as reading, whereas shared EFs may well facilitate efficient self-regulatory skills (e.g., socio-emotional welfare and effortful control).

4.3 Core EFs

As noted in Section 4.2, the general consensus is that there are three core EFs (e.g., Davidson et al. 2006; Diamond, 2013; Lehto et al., 2003; Miyake et al., 2000). These are: inhibition (inhibitory control, including self-control - behavioural inhibition - and interference control - selective attention and cognitive inhibition), updating working-memory, and cognitive flexibility which includes set shifting and mental flexibility. These core EFs are discussed in turn in the following subsections.

4.3.1 Inhibitory Control

Inhibition refers to one’s ability to prevent the production of habitual behaviours in favour of more task-appropriate response (e.g., Nigg, 2017). Inhibitory control has been explored through a variety of means under laboratory, typically under conditions of conflict, delay, or other challenges (e.g., Carlson & Moses, 2001). The general focus of laboratory-based tasks is to assess the ability to actively inhibit or delay a dominant response in order to attain an end goal, with the end goal being in contention with a dominant response. Inhibitory control therefore facilitates the ability to regulate and select a preferred response to a specific event as opposed to a habitual activated response (e.g., Diamond, 2013). There is evidence to suggest that the inhibition facet of EFs contributes separately in explaining complex human behaviours (e.g., Friedman & Miyake, 2004). For example, inhibitory control is associated with emotional regulation, attentional problems, cognitive failures, arithmetic skill and early literacy (Carlson & Wang, 2007; van der Sluis et al., 2007).

4.3.2 Updating working-memory

Updating working-memory refers to regulation of mental processes to inform the contents of working memory in light of new information (Chein, Moore, & Conway, 2011). Working memory is an aspect of EF that regulates cognitive functioning (Bayliss, Jarrold, Baddeley & Gunn., 2005; Conway et al., 2005). Working memory is a memory system in which features of previous events that require temporary storage can be held temporarily. It requires the simultaneous storage and manipulation of information in order to achieve an outcome (e.g., Baddeley & Hitch 1994). Working memory capacity allows information to be perceived, attended to, and retrieved (Baddeley, Logie, Bressi, Sala & Spinnler, 1986; Unsworth & Engle, 2007a). One's updating resources may refresh working memory by assessing and incorporating novel information central to the upcoming event. There are at least two kinds of working memory, namely verbal working memory and visual-spatial working memory (e.g., Baddeley, 2012; Baddeley & Hitch, 1974). Verbal working memory refers to one's capacity to hold and remember verbal information and to be able to utilize this memory for the purpose of completing an activity. The ability to successfully access and use the information held is an indication of verbal working memory ability. Visuospatial working memory refers to the ability to encode store and retrieve information relating to images shapes and sounds. Unlike verbal working memory, visuospatial working memory facilitates retention and recalling specific information pictorially as opposed to information recall of spoken nature or written word (e.g., Alloway, Gathercole, & Pickering, 2006). In sum, working memory is important in daily life and has been linked to verbal reasoning, fluid intelligence, crystallized intelligence, and attentional problems (Friedman et al., 2007; van der Sluis et al., 2007).

4.3.3 Set shifting

Set shifting signifies the ability to flexibly shift between different cognitive operations or task shifting between different cognitive representations (e.g., Miyake et al., 2000; Monsell, 2003). A classic task, the plus–minus task (Jersild, 1927) is a three-part assessment comprising of three lists of 30 two-digit numbers. Each list contains two-digit numbers that are randomly ordered and are completed in turn following differing rules per list. The first two lists require participants to either add three to or take away three from each two-digit number as quickly and as accurately as possible. Thus, participants perform only one cognitive operation per list. In the third list, participants must alternate between adding three and taking away three from each two-digit number. The cognitive flexibility in shifting is needed to reduce the cost of switching between the two cognitive operations. The plus minus task has been used to assess set shifting (e.g., Miyake et al., 2000; Ober, Brooks, Plass, & Homer, 2019). The set shifting facet of EF plays an important role in daily functioning and is linked to reading aptitude, non-verbal reasoning and effortful control (Blair & Razza, 2007; van der Sluis et al., 2007).

4.3.4 Verbal fluency (Phonemic Fluency)

Fisk and Sharp (2004) have proposed a fourth core EF, verbal fluency. This additional factor indicates the efficiency of access to information in long-term memory. Verbal fluency refers to a cognitive ability that assists with retrieval of information from memory. The verbal fluency test assesses verbal ability performance (e.g., Lezak, Howieson, Bigler, & Tranel, 2012). There are two types of verbal fluency tests. These are semantic fluency (Benton, 1968) and phonemic fluency (Newcombe, 1969). The traditional method of the tests requires participants to generate as many words as they can within one minute in either a given category (semantic fluency task) or beginning with a certain letter (phonemic fluency). The correct number of words generated is tallied to represent a participant score. The verbal fluency tasks have been employed to assess executive control ability (e.g., Fitzpatrick, Gilbert, & Serpell, 2013; Henry & Crawford, 2004; Mahone, Koth, Cutting, Singer, & Denckla, 2001; Takács, Kóbor, Tárnok, & Csépe, 2013, 2014). In non-clinical populations (e.g., Federmeier, Kutas & Schul, 2010) verbal ability has been assessed in the form of lexical knowledge and lexical retrieval ability. The successful retrieval of verbal information from long-term memory is considered to be regulated by an executive regulator that has control over these cognitive processes – set-shifting, selective inhibitory control, selective attention and self-monitoring. Other studies (e.g., Baldo & Shimamura, 1998; Schwartz & Baldo, 2001) have revealed that impairment to the frontal regions of the brain is linked to weaker performance in fluency tasks. Although it has been argued that it is unclear as to which precise aspect of executive control regulates performance on fluency tasks (Shao, Janse, Visser, & Meyer, 2014). In the present work, an aspect of verbal fluency is assessed in the empirical work. In the next section, a range of dyslexia-related difficulties in EF abilities are presented. These are considered from the perspectives of dyslexia-related difficulties in the supervisory attentional system (Norman & Shallice, 1986), the dyslexia automatization deficit hypothesis (Nicolson & Fawcett, 1990) and the cerebellar deficit hypothesis (Nicolson, Fawcett & Dean, 2001) and their relatedness to core EF functioning.

4.5 Core EF problems in dyslexia

In dyslexia, core EF difficulties have been reported in set shifting (Poljac et al., 2010), inhibition (e.g., McLean, Stuart, Coltheart & Castles, 2011; Wang, Tasi & Yang, 2012), updating working-memory (e.g., Bacon et al., 2013; Smith-Spark & Fisk, 2007). Dyslexia-related problems have also been identified in a fourth core EF - phonemic fluency (e.g., Smith-Spark, Henry et al., 2017). The extent of the abovementioned difficulties in dyslexia are discussed from a theoretical perspective in the next section.

4.5.1 Supervisory attentional system dysfunction hypothesis

Executive functions have previously been described as a group of higher order cognitive abilities that are employed to manage goal-directed behaviours (e.g., Banich, 2009). Norman and Shallice (1980) put forward a model of attentional control in EF that indicates the way in which thought, and action schemata are triggered or inhibited for habitual and non-habitual behaviours. Based on Norman and Shallice's model, a schema is a representation of a sequence of thoughts or actions that are guided by external stimuli. Baddeley (1986) equates the SAS with the central executive of the multicomponent working memory model owing to the SAS's role in the control, coordination, and integration of information from different sources. Norman and Shallice have argued that the SAS is called upon when new or poorly learned action sequences are needed at a future point. According to Norman and Shallice, each behaviour activates a response schema. In the case of habitual or well-rehearsed behaviours, instigation of the relevant schema is supervised by competing scheduling (SAS). Contention scheduling oversees the management of cognitive resources of competing schemas and proceeds relatively automatically. In non-habitual behaviours, activation of a response schema is considered to be triggered by the SAS (e.g., Norman & Shallice, 1986). The SAS is a supervisory monitoring system that manages competing scheduling through manipulation of schema activation likelihoods and permitting for generic strategies to be utilized in novel conditions or in circumstances necessitating automatic attentional processes. In dyslexia, Smith-Spark and Fisk (2007) have argued for deficits in the SAS (see also Varvara, Varuzza, Sorrentino, Vicari & Menghini, 2014).

In their investigation which looked at working memory functioning, the participants comprised of 22 adults with dyslexia and 22 adults without dyslexia who were age and IQ matched. They were administered with visuospatial and working memory tasks. Group comparisons were made in their performance of simple span, complex span that needed storage and processing of information; and dynamic memory updating in both domains. Smith-Spark and Fisk revealed a significant group difference in performance with the group with dyslexia found to be weaker on both simple span and complex span, as well as the spatial complex span task. Even after controlling for the simple span performance, the problems demonstrated by the group with dyslexia were still evident. Smith-Spark and Fisk argued that dyslexia-related difficulties related to working memory are not constrained merely to the sustenance of information in short-term memory. Rather, it was argued that the results suggest a dyslexia-related deficit in the central executive that appeared to be unrestricted by neither slave systems – that is the phonological loop or the visuospatial sketchpad.

Compared with the group without dyslexia, those with dyslexia showed greater levels of difficulty in the initial trials of the spatial updating task at the point when task demands were at their novelty stage. Smith-Spark and Fisk (2007) argued for the likelihood of dyslexia-related problems in SAS. The basis of this argument was founded on Norman & Shallice's (1986) proposal that the SAS is initiated when poorly learned or novel action arrangements are needed. A significant three-way interaction found by Smith-Spark and Fisk, on the spatial updating task between test-portion, condition, and group. The test portion consisted of first-half recall and second-half recall. The results indicated significantly greater levels of difficulties in the group with dyslexia in comparison to the group without dyslexia at the initial stage the task was encountered. Accordingly, the results were indicated as being consistent with dyslexia-related difficulties in SAS.

Moreover, it was pointed out by Smith-Spark and Fisk (2007) that the presence of working memory problems continues into adult life and that these problems may impact on modalities related to phonological and visuospatial, including the involvement of central executive dysfunction, and storage difficulties. It has been argued that executive control processes are more strongly implicated in a task when it is encountered for the first time and its related task demands are at a novel stage (Morris, Miotto, Feigenbaum, Bullock, & Polkey, 1997; Shallice & Burgess, 1993).

4.6 Study rationale for Core EF's and hypotheses

Dyslexia theories have highlighted areas of weaknesses that are linked to EF processes. The SAS hypothesis (Norman & Shallice, 1986) proposes a higher-level cognitive mechanism that is activated for diagnosis and resolution of difficulties when habitual and automatic processes are inefficient. In Smith-Spark and Fisk (2007), dyslexia-related deficits were elevated in the SAS when task novelty was high and when poorly learned action sequences were required at a later point in time. On the other hand, the dyslexia automatization deficit hypothesis (Nicolson & Fawcett, 1990) puts forward that the way in which an individual's skill learning develops from a voluntary phase to an involuntary stage in order to facilitate ease of performance is known as automatization. The Dyslexia Automatization Deficit hypothesis (DAD) points to problems in the attainment of fluency in cognitive and motor skills under single-task and dual-task. In Nicolson and Fawcett (1990), dyslexia-related problems were reported on a dual-task performance in their difficulty to attain automatization in a simple motor balance task when the concurrent processing of a secondary task was required. Specifically related to adults, dyslexia-related EF deficits have been reported (e.g., Brosnan et al., 2002) with aspects of EF deficits indicated in inhibition (e.g., McLean, Stuart, Coltheart & Castles, 2011; Wang, Tasi & Yang, 2012) and set shifting (Poljac et al., 2010).

Smith-Spark, Henry, Messer, Edvardsdottir and Ziecik (2016) explored EF deficits in adults with developmental dyslexia by assessing the subjective experience of adults with dyslexia relating to their own EF. Smith-Spark et al. employed a self-report measure of EF (BRIEF-A: Behaviour Rating Inventory of EF – Adult Version; Roth, Isquith, & Gioia, 2005) and experimental tasks to assess two IQ-matched groups of adults with and without dyslexia. Three aspects of EF (inhibition, set-shifting, and updating working memory) were tested using laboratory-based tasks. The results showed that the shifting, updating working memory, and inhibition facets of EF contribute differently to the enactment of commonly employed executive tasks; despite that there was a modest correlation between each other. A potential explanation of this was that the ability to concurrently manage two tasks may well differ from those associated with shifting, updating working memory and inhibition. The results of the BRIEF-A also revealed that individuals with dyslexia self-reported more frequent EF difficulties in their everyday life. The EF problems were focused on metacognitive processes involving updating-working-memory, planning, task monitoring, and organization as opposed to regulation of emotion and behaviour. Individuals with dyslexia demonstrated significant weaknesses in aspects of EF. The findings demonstrate that adults with dyslexia feel that they are affected by problems linked to common daily activities. Additionally, the results indicate that problems in EF can be found in the same group of adult participants under laboratory conditions.

Taking into consideration the kind of experimental tasks employed, it is evident that dyslexia-related problems in EF go beyond deficits associated exclusively with phonological processing.

The research reported in the current chapter expanded upon the small number of laboratory-based studies looking at a range of EFs. The objective was to examine the comparative levels of performance in adults with and without dyslexia to ascertain certain areas of weakness in individuals with dyslexia. Data were obtained from paper-based and computer-based executive function tasks which measured different EF facets namely inhibition, set shifting, updating working memory, phonemic fluency, planning, and dual-task performance.

The following hypotheses were generated from theory and previous findings. In line with the findings of previous studies (e.g., Takács, Kóbor, Tárnok, & Csépe, 2014; Smith-Spark, Henry, Messer, & Zięcik, 2017), it was hypothesized that compared with the group without dyslexia, the group with dyslexia would perform significantly less well in their ability to generate words on the basis of their initial phoneme.

Previously reported dyslexia-related inhibition problems (e.g., McLean, Stuart, Coltheart & Castles, 2011; Smith-Spark, Henry et al., 2016) indicated significantly weaker dyslexia-related performance in the No Go condition, but not in the Go condition in the “Go No Go Task”. In the Go condition, the participants had previously been trained to response by pressing a specific key on a keyboard when a particular image of an item appeared on the computer screen. In the No Go condition participants were required to refrain executing the same habitual response when a specific and different image appeared on the computer screen. Whilst the responses to the Go condition stimulus should be spontaneous, in the No Go condition, the inhibitory response demands extra processing control. In the current work, it was hypothesized that the group with dyslexia would perform significantly weaker in their ability to inhibit responses in the No Go condition. A non-significant group difference was expected in the Go condition. Accuracy of responses and RT to responses were recorded.

In accordance with set-shifting problems as indicated in dyslexia on the set shifting task, (e.g., Poljac et al., 2010), firstly, it was hypothesized that the respective performance on “plus” and “minus” conditions would not significantly differ between groups. Secondly, in the “plus-minus” condition, it was hypothesized the cost of shifting between “plus” and “minus” operations would be significantly greater in the group with dyslexia.

Dyslexia-related difficulties have previously been highlighted in the updating working-memory task used in the current chapter (e.g., Smith-Spark, Henry et. al., 2016). It was hypothesized that there would be a significant group difference in performance in total span score. Specifically, the group with dyslexia was expected to perform significantly less well than those without dyslexia. Secondly, it was hypothesized that group performance would not differ on the operation span accuracy error, operation span speed error, and operation span math error measures.

4.7 Method

4.7.1 Participants

Fifty-seven adults aged between 18 to 40 years old were assigned to one of two groups. The group with dyslexia consisted of 30 adults who were diagnosed with dyslexia (M = 23.30 years, *SD* = 3.01; 23 females, 7 males). The group without dyslexia comprised of 27 adults who did not have dyslexia (M = 25.37 years, *SD* = 4.98; 23 females, 4 males). There were variations of group sample numbers across differing tasks due to participant drop-outs across the three testing sessions (see Section 2.1). Where necessary, the sample size in specific analysis that differed from the initial general sample information as shown above have been detailed. Participants were recruited through university-based systems, and third-party dyslexia-support organization poster advertisements. The participants with dyslexia showed an educational psychologist’s report confirming their diagnosis. The participants were assessed on background screening measures to ascertain their IQ, reading ability and spelling ability (See section 2.1.3.4 for the results).

4.7.2 Materials

Computerized tasks consisted of the Go/NoGo task (e.g., Matthews & Martin, 2015) and the AOspan task (e.g., Unsworth et al. 2005). The Go/NoGo task was used in assessing inhibitory control. The AOspan task was used to assess working memory and updating processes. These were programmed in E-Prime 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA). A 17" computer monitor was connected to an IBM-compatible personal computer. A paper-based task – the Plus Minus task (e.g., Jersild, 1927) was measured flexible shifting ability between two alternating operations.

4.7.3 Design and procedures for core EF measures

4.7.4 Inhibition (Go/No Go Task)

The type of tasks that have been employed as measures of inhibitory control aspect of EF include (the Stroop Task; Stroop, 1935). Another task that is a measure of inhibitory control is the Go/No-Go Task. The task is a widely used computerized task which explores one's ability to control designated inhibitory responses – this ability draws from executive function resources related to inhibition (e.g., Miyake et al., 2000) and performance on this task has been found to be poor in dyslexia (e.g., Matthews & Martin, 2015; Smith-Spark, Henry et al., 2016). The procedure employed in the Go/No Go task in the current work is entailed the following. The participants were initially trained to press a certain letter (i.e., the 'a' key) on a qwerty keyboard in response to the presentation of a displayed stimulus (a picture of a mobile phone) on a computer screen. This constituted the habituation phase. After the training phase (specify number of trials), the test (or inhibition) phase commenced. The participants were required to press the 'a' key on a qwerty keyboard whenever a picture of a mobile phone was presented on a computer screen (the 'Go' condition). In the inhibition phase, participants were required to refrain from pressing the same key ('a) on a qwerty keyboard when a newly presented and less frequently occurring stimulus appears on the computer screen (the ‘No-Go’ condition - a picture of a brick). The ratio of presentations of the habitual stimulus (a mobile phone) versus the non-habituated stimulus (the picture of a brick) was presented at a ratio of 75% for go-trials versus 25% for no-go trials. The design employed for this task was a between-subjects design. Participant group was a factor with levels of group with dyslexia and group without dyslexia. The dependent variables were correct responses and incorrect responses in “Go” and “No-Go” conditions. The proposed analyses for the accuracy of responses and RT to responses to the “go” and “no-go” trials were analysed using independent-samples t-tests.

4.7.5 Updating working-memory (AOSPAN Task; e.g., Unsworth, Heitz, Schrock, & Engle, 2005)

The Automated Operation Span (Aospan; Unsworth, Heitz, Schrock & Engle, 2005) is a conventional computer-based task that is frequently employed to assess executive function resources in relation to updating. The planned analyses were 2 by 3 repeated measures ANOVAS. Specific details on how the task was created and administered have been omitted, given that the data was irretrievable for analysis.

4.7.6 Set Shifting (Plus/Minus Task; e.g., Jersild, 1927)

In this three-part task, the following procedure was used. The participants were given a sheet of A4-sized paper containing two-digit number. The task entailed presenting participants with three lists of 30 two-digit numbers. In the first list, the participants were asked to add three to every two-digit number as accurately and as quickly as they could. In the second list, the participants were asked to subtract three from every two-digit number. In the third list, the participants were asked to alternate or switch between adding 3 to and subtracting 3 from every two-digit number presented. The participant’s ability to switch between the two mathematical operations is measured in terms of incurred costs. The design employed for this task was a between-subjects design. Participant group was the between-subjects factor with its levels being adults with dyslexia versus adults without dyslexia. The dependent variable was speed of processing. Two planned tests were used to analyse data for the stated hypothesis (see Section 4.6). Firstly, the “plus” and “minus” conditions were analysed using a 2 by 3 repeated measures ANOVA. Secondly, the cost of switching was analysed using an independent-samples t-test.

4.7.7 Phonemic fluency

The phonemic fluency task (Newcombe, 1969) is a test of verbal access functioning ability and is frequently employed in research involving neuropsychological assessments and executive control proficiency (e.g., Fisk & Sharp, 2004; Henry & Crawford, 2004; Fitzpatrick, Gilbert & Serpell, 2013). The validity of this verbal fluency task is well established and has been used in a considerable number of studies including those linked to dyslexia (e.g., Brosnan et al., 2002; Fisk & Sharp, 2004; Moura et al., 2015). In the current work, the following procedure was employed. The participants were required to say as many words as possible beginning with a certain letter (for example words beginning with the letters F, A, and S separately), excluding plurals of words already named, names of people, cities or countries) in 60 seconds. The total number of correct words vocalized provided an indication of a participant’s verbal fluency capability. A between-subject design was employed. The first factor was letter-type with three levels consisting of F, A and S. Participant group was the second factor with levels of group with dyslexia versus group without dyslexia. The number of words correctly generated was the dependent variable. The mean number of items generated on each trial was calculated. The stated hypothesis was analysed using an independent-samples t-test.

4.8 Results for Core EFs

4.8.1 Inhibition

4.8.1.1 Independent-samples t-test - Habituation phase

An independent samples *t*-test was carried out to assess between-group performance in response to Go stimuli during the habituation phase. The sample of two groups consisted of adults with dyslexia *N* = 24 and adults without dyslexia *N* = 26). Inspection of the means revealed that the group with dyslexia was slightly more accurate in their responses to the Go stimuli (M = .988ms, *SD* = .027) than the group without dyslexia (M = .962ms, *SD* = .196). A *t*-test revealed a non-significant group difference in accuracy of responses provided in the ‘’Go’’ condition, *t* (48) = .65, *p* = .52, d = 0.19. Moreover, an independent samples *t*-test carried out on the RT data in response to stimuli in the ‘’Go’’ condition showed that the group with dyslexia was marginally slower (M = 441.ms, *SD* = 168.79.) than the group without dyslexia, (M = 425.92, *SD* = 142.36). However, this between-group difference was not statistically significant, *t* (48) = .36, *p* = .72, d = .10.

4.8.1.2 Independent-samples t-test - Inhibition phase

An additional independent samples *t*-test was performed on the No-Go condition. The sample of two groups consisted of adults with dyslexia N = 24 and adults without dyslexia N = 26). Examination of the means showed that the group with dyslexia was slightly more accurate (M = .960ms, *SD* = .049) than the group without dyslexia (M = .950, *SD* = .146), but the slight difference was not statistically significant, *t (*48) = .33, *p* = .74, d = .009. Additionally, the means showed slower mean RT in the group with dyslexia (M = 344ms, *SD* = 87.06) compared with the group without dyslexia, (M = 315*, SD* = 89.11) in response to stimuli in the ‘’No-Go’’ condition. A *t*-test revealed a non-significant difference between groups in their RTs for the ‘’No Go’’ condition, *t* (48) = 1.16, *p* = 0.25, d = 0.33.

4.8.2 Updating working-memory

Data collected for the AO Task could not be analysed as planned due to a computer error in the logging of data, making the data irretrievable.

4.8.3 Set Shifting (Plus / Minus Task)

4.8.3.1 2x3 Repeated measures ANOVA main and interaction effects operation mode

A two by three repeated measures ANOVA was performed. The sample consisted of adults with dyslexia *N* = 24 and adults without dyslexia *N* = 25). The results revealed a significant main effect of operation mode, *F* (1.65, 77.54) = 53.89, *p* <.001, η_p^2 = .534. The main effect of participant group was found to be significant, *F* (1, 47) = 7.67, *p* = .008, η_p^2 = .140. A significant interaction effect was found between participant group and operation mode, *F* (1.65, 77.54) = 5.97, *p* = .006, η_p^2 = 0.11. The group with dyslexia showed a slower processing speed than those without dyslexia in single operation, and this difference was larger in the combined Minus/Plus mode (M = 125.17s, *SD* = 53.61) than the group without dyslexia (M = 87.08s, *SD* = 28.10).

4.8.3.2 Independent-samples t-test – Between-group cost of switching

In order to calculate the switching cost, the difference in cost of processing was derived by calculating the mean reaction time between the plus and minus operation modes and then subtracting that from the combined plus/minus operation RT mean. The group with dyslexia showed a greater cost of switching (M = 36.96, *SD* = 28.25) than the group without dyslexia (M = 18.28, *SD* = 13.91). Levene's test for equality of variances was found to be violated for switching cost, *t* (1, 47) = 4.90, *p* = .032. Therefore, equal variances were not assumed. This difference in switching cost was found to be very significant *t* (33.23) = 2.92, *p* = .006, d = 0.84.

4.8.4 Phonemic Fluency

4.8.4.1 Independent-samples t-test – Between-group word production

An independent-samples *t*-test was performed. The sample consisted of adults with dyslexia *N* = 24 and adults without dyslexia *N* = 24). Overall, the group with dyslexia generated fewer words (M = 35.46, *SD* = 8.05) than the group without dyslexia (M = 41.29, *SD* = 11.66). An independent-samples *t*-test revealed that this group difference in overall word production across letter-types was statistically significant, *t* (46) = 2.02, *p* = .05, d = 0.58.

4.9 Discussion of core EFs

Generally, the findings in relation to core EFs indicate that dyslexia-related deficits were found in set shifting, phonemic fluency, but not inhibitory control. Detailed discussion of the results relating to each core EF is presented next.

Inhibition was explored to assess group performance differences between adults with dyslexia versus adults without dyslexia using the Go/No-Go task (Matthews & Martin, 2015). Consistent with the hypothesis relating to the habituation phase, a non-significant difference was revealed in the accuracy of responses to the Go condition between adults with dyslexia versus those without dyslexia. Similar RTs were also recorded between the two groups. Inconsistent with the inhibition hypothesis, a non-significant difference was found between groups in accuracy and reaction times of inhibitory responses carried out for the ‘’No Go’’ condition. This finding is inconsistent with previous research (e.g., Altemeier, Abbott, & Berninger, 2008; Brosnan et al., 2002; Kapoula et al., 2010; Smith-Spark, Henry et al., 2016) who reported inhibitory control deficits in participants with dyslexia. The current study’s findings suggest the absence of dyslexia-related inhibitory control deficits. Furthermore, the results indicate that the performance of adults with dyslexia were slightly superior to those without dyslexia. Whilst on the one hand, it seems that the task did not present a threshold level of complexity that may have showed inhibitory control problems in the group with dyslexia, in Smith-Spark, Henry et al. (2016)

dyslexia-related deficits were reported on the same task. It is noteworthy to point out that in the current work's finding, adults with dyslexia demonstrated slower reaction times compared with those without dyslexia. Even though this difference was not found to be significant, slower processing of responses may have been deployed as a compensatory strategy to enhance the inhibitory control performance in adults with dyslexia.

As an improvement to the task, and to further examine the possible deployment of a compensatory strategy, different levels of difficulty could be manipulated to assess different levels of complexity. This would make it possible to measure disparities in RTs between differing tax complexities. The ratio of presentations in the Go/No-go task employed in the current work comprised of the habitual stimulus being presented at 75% for the go-trials and the non-habituated stimulus being presented 25% for no-go trials. This ratio of presentations could be modified such that the habitual stimulus (a mobile phone) is presented 80% for the habituated stimulus 20% for the no-go trials. The 20% would represent one fifth of all trials. In Criaud and Boulinguez (2013), their meta-analysis considered this ratio of presentations as being complex. This method of ratio of Go/No-go stimuli variation with differing levels of processing may present performance-related differences in adults with dyslexia. Alternatively, Maguire et al. (2009) manipulated levels of complexity in the Go/No-go task by means of increasing extent of semantic processing with an object classification task. In the single condition, an image of a car was associated with Go trials and an image of a dog was associated with the No-go trials. In the multiple condition, distinct images of cars and dogs were associated with the Go and No-go trails. The semantic condition presented an extensive of objects from a variety of categories for the Go trials and a broad range of animals for No-go trials.

Set shifting ability was investigated using the Plus/Minus Task (e.g., Jersild, 1927) to assess differences in switching cost performance between adults with dyslexia and adults without dyslexia. Consistent with the experimental hypothesis, a significant between-group difference was revealed in in terms of the cost of shifting flexibly when participants performed the third phase of the task (plus + minus) combined mode. Specifically, the cost of flexible shifting was significantly greater in adults with dyslexia in comparison to adults without dyslexia. This finding is consistent with previous research (e.g., Altemeier, Abbott, & Berninger, 2008; Moura, Simões, & Pereira, 2015; Poljac et al., 2010; Smith-Spark, Henry et al., 2016). This indicates problems in the ability to flexibly shift between different cognitive operations in adults with dyslexia. This is discussed in light of previous research in the general discussion.

The phonemic fluency task looked at group differences on performance between adults with dyslexia and those without dyslexia. The results showed that when words generated from all categories – ''F'', ''A'' and ''S'' were combined, adults with dyslexia produced significantly fewer words compared with adults without dyslexia. This finding is consistent with the hypothesis in stating that the group with dyslexia would generate fewer valid words across the three given categories. This is also consistent with previous research. Overall, the results are partially supported by previous research in that, the observed significant group difference found with combined (F, A, S) letters is uniform with previous studies (e.g., Hatcher, Snowling & Griffiths, 2002; Marzocchi et al., 2008; Smith-Spark, Henry et al., 2017).

4.10 Broader EFs

4.10.1 Definition

Higher order EFs such as problem solving, planning, and dual-task performance (e.g., Lunt et al., 2012) are generated from inhibition updating working-memory and set shifting – which have been previously indicated as core EFs (e.g., Miyake et al., 2000; see Section 4.3).

4.10.2 Dual Task Performance

Dual-task performance denotes the ability to perform two or more tasks concurrently (e.g., holding a conversation with a passenger while driving) and involve the allocation of conscious attention (e.g., Friston, 2010). Considering that attention is a limited resource, the capacity to distribute attention to two or more on-going tasks can be costly in terms of performance (e.g., Plummer & Eskes, 2015). This may result in declining performance in one or both tasks compared with when one of the other tasks is performed on its own. Anderson (1987) has proposed two primary phases that are involved in the development of a cognitive skill. These have been described as a declarative phase - wherein features concerning the skill domain are decoded; in the procedural phase - the subject information is directly experienced through explicit actions for implementation of the skill. Anderson (1987) advocated that accumulation of knowledge is a process through which there is a transfer of the skill from the declarative phase to the procedural phase. The transfer process comprises of (i) secondary processes of organization – integration of arrangements of information into unitary parts; and (ii) establishment of a procedure – the embedding of factual knowledge into automated skill. After the procedure process has been constructed, enhanced learning processes related to the skill make the productions more automatic in terms of response selectivity. The dual-task paradigm has been used to assess automaticity experimentally. In this task, two tasks are executed concurrently. The principal notion of the paradigm (e.g., Brustio, Magistro, Zecca, Rabaglietti, & Liubicich, 2017) is that, providing that the skill related to the primary task is automatized, its execution should not interfere with the simultaneous performance of the secondary task. The basis of this assertion is grounded in the notion that attentional resources are not engaged in automatic processing (Nicolson & Fawcett, 1990).

Conversely, if skill automaticity is not attained for the primary task, its processing is expected to interrupt the concurrent processing of a secondary task. The reason for this is that limited attentional resources would be competed for by the two tasks. Furthermore, the skills needed for the performance of the secondary task are typically not automatized since competition for limited attentional resources should not be necessary. The performance of two tasks simultaneously (dual-task) may result in a reduced ability in the performance of the primary task compared with when the primary task was executed in single-task condition. The reduction of performance-related ability concurs with the cost of executing a secondary task. This is referred to as the “dual-task cost”. In the neurotypical population, dual-task performance does not routinely result in cost in performance or a decay in performance compared with when one or both tasks are executed in single-task condition. Dual-task performance can result in enhanced performance ability. For example, in (Nicolson & Fawcett, 1990), it was reported that through practice, control participants were able to improve skilled performance and that the enhanced skills required less effort across time.

4.10.3 Planning

Planning refers to the ability to intentionally organize information in a goal-directed manner. This involves the capacity to mentally determine an appropriate means to perform an undertaking in order to achieve a particular objective (e.g., Huizinga, Dolan, & van der Molen, 2006; Miyake et al., 2000). In this way, planning proficiency facilitates the ability to select the essential actions to achieve a goal, determine the order of occurrence, allocate tasks to the appropriate mental processes and determine an action plan. An example of this may be planning how to complete a task which requires multiple elements. People who have planning deficits may have problems in tasks which require other aspects of planning (such as where or how to begin a task; Shallice, 1982).

The Trail Making Test (Reitan & Wolfson, 1985) is an example of a planning task. The Trail Making Test is a neuropsychological test which requires visual scanning and working memory that is time-dependent. There are three parts of the test. The time expended to finish each part is a function of executive functioning. The first part requires participants to draw a line to connect in ascending order numbers from 1 to 25 as quickly as possible. In the second part, participants are asked to connect in ascending order letters consecutively from A to Y as quickly as possible. Part three requires participants to draw a line serially between numbers and letters in an alternating progressive sequence, 1 to A, A to 2, 2 to B etc until the end of the sequence 25 to Y has been reached. Executive functioning ability is derived from the difference from average time taken to complete part A and part B respectively and part C. Alternating between numbers and letters in part C places demands on central executive processes related to inhibition, cognitive flexibility, and the ability to maintain a response set and the completion time. This test may be perceived as being very simple. Yet it relies on extensive cognitive processes comprising attention, visual search and scanning, sequencing and shifting, psychomotor speed, abstraction, flexibility, ability to implement and adjust a plan of action, and the capacity to sustain two concurrent trains of thought. In the next section, EF difficulties in dyslexia are considered from the perspectives of the automatization deficit hypothesis (Nicolson & Fawcett, 1990) and their association with broader EF ability.

4.11 Dyslexia and broader EFs

The means through which skill improvement advances to an enhanced stage - which in turn enable ease of task execution is referred to as automatization. The DAD hypothesis (Nicolson & Fawcett, 1990) posits that through practice, individuals without dyslexia, are able to improve skilled performance and over time, performance demand less effort. In contrast, those with dyslexia tend to have difficulty in improving a skill that they have previously been exposed to, and thus perform at a lower level on tasks that necessitate skill automatization. This difficulty has been found in dyslexia in both cognitive and motor performance. Unlike children without dyslexia, those with dyslexia show deficits in their ability to attain automaticity in the sequential processing of phonemes when performed in tandem with a secondary task during dual-task performance. In laboratory settings, automaticity has been frequently tested using the dual-task paradigm. Nicolson et al. (1999) revealed an association of abnormal cerebellar activation with motor learning difficulties in adults with dyslexia. They assessed brain activation in adults with dyslexia and adults without dyslexia using positron emission tomography as participants either performed a pre-trained sequence or acquired a new finger sequence of finger movements. Nicolson et al. found that brain activation was significantly lower in adults with dyslexia in the right cerebellar cortex and the left cingulate gyrus whilst carrying out the pre-learned sequence. Also, adults with dyslexia were reported to have a significantly lower right cerebellar cortex activation when learning a novel sequence. These findings indications present direct evidence for dyslexia-related problems in fronto-cerebellar activation pathways related to EF performance.

In Nicolson and Fawcett (1990), the dual-task paradigm was employed to assess children with and without dyslexia. The first hypothesis was to test the DAD hypothesis (see Section 1.2.1) that children with dyslexia would demonstrate atypical problems in skill related to either cognitive or motor. The second hypothesis was to test the 'Conscious Compensation' hypothesis – with the prediction that children with dyslexia are typically able to reduce their skill automatization difficulty through the use of intentional compensating strategies such as exerting a higher level of effort by employing strategies to reduce the level of difficulty or to disguise the difficulty being experienced. The simple motor balancing skills task employed is considered by Nicolson and Fawcett to be an appropriate measure of automatization since its performance in skill attainment is not controlled by phonemic awareness or reading ability. Impairment on the motor balancing skills task was measured in a dual-task paradigm to ascertain whether there would be evidence of functioning interference. The results indicated that in the single-task condition which required participants to count backwards, performance of the group with dyslexia was comparable to those without dyslexia. Conversely, in the dual-task condition, the group with dyslexia performed significantly poorer. Poorer performance related to motor balance showed that a simple skill such as motor balance underlines problems in automatization once further complexity is added to its processing by means of executing the simultaneous processing of a second skill in a secondary task. Moreover, problems in dual-task performance in the group with dyslexia was only evident when they were not permitted to apply a conscious strategy either by engaging in a simultaneous dual-task (e.g., Nicolson & Fawcett, 1990) or by means of blindfolding (e.g., Fawcett & Nicolson, 1992).

Wang and Gathercole (2013) investigated working memory difficulties in children with (single word) reading problems and typically functioning children. The participants were matched for age and nonverbal ability. The tasks employed encompassed verbal and visuospatial simple and complex span tasks, and digit span and reaction time tasks. These tasks were executed individually or were performed in combination under dual-task conditions. The results indicated that children with reading problems who demonstrated difficulties in simple and complex span tasks also showed weaker performance when they were required to coordinate two cognitive demanding tasks (dual-task performance). Wang and Gathercole concluded that the results point to working-memory problems in children with reading problems that indicates a core deficit in the central executive (see Section 4.5.1).

Dyslexia-related problems have been demonstrated in tasks necessitating organization (e.g., Levin, 1990), planning (Torgeson, 1977), and temporal sequencing (Miles, 1982) and these difficulties are connected to EF resources. In Smith-Spark, et al. (2004), adults with dyslexia were compared against those without dyslexia on their everyday cognitive lapses using the Cognitive Failure Questionnaire. Proxy ratings of individuals who had everyday interaction with the participants revealed that daily problems experienced by the participants with dyslexia were emphasized in attention, absentmindedness, and organization. Smith-Spark et al. indicated that the deficits in organizational skills provide further substantiation in support of Torgesen (1977) and Levin (1990). Smith-Spark, et al. also indicated that greater levels of susceptibility to distraction and ineffectiveness in planning, revealed in both the CFQ and CFQ-for-others, suggests specific problems linked to attentional or central executive mechanisms (e.g., Baddeley, 1986; Norman & Shallice, 1986). Miles (1996) reported that students with dyslexia experience essay writing difficulties as a consequence of deficits related to planning and structuring. Taken as a whole, the pooled findings present evidence to indicate that problems shown in EF performance extend to broader EFs (i.e., dual-task performance and planning). The rationale and hypotheses for exploring broader EFs in this thesis is considered in the next section.

4.12 Study Rationale for Broader EFs and related hypotheses

Dyslexia theories have also highlighted areas of weaknesses that are linked to EF processes. The DAD hypothesis (Nicolson & Fawcett, 1990; see Section 1.3) puts forward the way in which an individual's skill learning develops from a voluntary phase to an involuntary stage in order to facilitate ease of performance known as automatization. Consistent with the DAD theory, dyslexia-related problems have been indicated in their difficulty to carry out skills that require automatization. In Nicolson and Fawcett, 1990), dyslexia-related difficulties were indicated in a dual-task performance by their failure to attain automatization in a simple motor balance task when the concurrent processing of a second skill in a secondary task was required. Dual-task performance draws on executive functioning ability and assesses the cost of concurrent performance of two tasks (e.g., Yogev-Seligmann, Hausdorff & Giladi, 2008; Titz & Karbach, 2014). The semantic fluency task is widely used to assess semantic knowledge, the controlled retrieval function of executive functioning and distinguish it from memory deficits (e.g., Oriá, Costa, Lima, Patrick & Guerrant, 2009). Difficulties highlighted by dyslexia theories are closely linked to EFs. Based on the EF difficulties identified in dyslexia, the research reported in the current chapter used traditional laboratory-based assessments to explore two measures of broader EFs. The objective was to examine the comparative levels of performance of adults with and without dyslexia to ascertain certain areas of weakness in individuals with dyslexia.

Data were obtained from a paper-based task, a pursuit-rotor motorized task, and a semantic fluency EF task. These tasks measured planning and dual-task performance respectively. Based on theory (e.g., Miyake et al., 2000; Fisk & Sharp, 2004), and previous research dyslexia-related EF difficulties in daily life related to higher order processes such as laboratory-based dual-task performance (e.g., Nicolson & Fawcett, 1990), and planning; BRIEF-A results (e.g., Smith-Spark, Henry et al., 2016), the following hypotheses were derived. In dual-task performance, it was hypothesized that adults with dyslexia would perform comparable to adults without dyslexia when the two tasks employed (Semantic fluency task) and (Pursuit-rotor task) were performed independently. However, when the two tasks are performed concurrently in dual-task mode, adults with dyslexia would perform comparable to those without dyslexia on the semantic fluency task, but significantly less well on the motor-based task. With regards to planning, it was hypothesized that performance of the group with dyslexia would be significantly weaker than those without dyslexia.

4.13 Method

4.13.1 Participants

Fifty-seven participants aged between 18 and 40 years old were recruited through university-based systems, and third-party dyslexia-support organization poster advertisements. They consisted of 30 adults with dyslexia (mean age = 23.30 years, *SD* = 3.01; 23 females, seven males) and 27 adults without dyslexia (mean age = 25.37 years, *SD* = 4.98; 23 females, four males). The composition of the samples differed across the tasks owing to participant drop-outs across the three test sessions (see Section 2.2). Thus, changes to the sample size in specific analysis relative to that specified in the initial presentation of information about the samples shown above have been detailed. All participants were administered to screening measures in order to assess their IQ, reading ability and spelling ability (See section 2.1.3.4) for the results.

Materials

The Trail Making Test was used to assess planning ability. The test consisted of two parts. Part one consisted of two components. The first of the two components contained targets numbers (i.e., 1, 2, 3 up to 25) and the participants were asked to connect the numbers in ascending order. The second component contained only letters as targets (A, B, C up to Y) and the participants were required to connect them in ascending order. The second part of the test required the participants to alternate between numbers and letters (1, A, 2, B, up to Y,25). A pursuit-rotor task and a semantic fluency task were used to assess dual-task performance. The pursuit-rotor task consisted of a motorized rotating disc with a counter and a wand that could be connected to the motorized rotating disc with a metal spot on it. The Semantic fluency test was used in part to assess dual-task performance. The category of stimuli given to the participants in single task mode was animals. In dual-task mode, the given category of stimuli was fruits.

4.13.2 Design and Procedures for broader EF measures

4.13.3 Dual-task performance

The dual-task performance consisted of two modes. These were the independent mode and dual-task mode. In the independent mode, participants were asked to perform the semantic fluency task only. They were required to say aloud as many names of items belonging to a specific category (animals) in a one-minute trial. The investigator then recorded the task duration via audio recordings which is later used to score participant answers. The pursuit rotor task is a well-established task that is suitable to be used in a dual-task performance paradigm (e.g., Krishnan, Watkins & Bishop, 2016). In the independent mode, participants were required to hold a wand with a metal tip. The objective of the task was for the participants to try to keep the tip of the stylus on the metal spot (activating the timer) as the platter turns. In the independent mode, the order of task performance was counter-balanced to account for order effects. Counter balancing meant that half of the participants first performed the semantic fluency task first and then followed by the pursuit rotor task. The other half of participants was given the reverse order. In the independent-mode, participants were given time to familiarize themselves with each component separately. After the participants performed the Pursuit rotor task and semantic fluency tasks independently, they were required to perform the two tasks concurrently in a dual-task performance mode.

While performing the pursuit rotor task in the independent mode, participants were required to hold a wand with a metal tip. The objective of the task is that participants must try to keep the tip of the wand on the metal spot (activating the timer) as the platter turns. To do this, participants must track the circular movement of the turntable. Whilst holding a stylus in one hand, participants were advised to try to follow a disc moving quickly on a turntable. The proportion of time during the trial that participants were 'on' target was a measure of their motor skill. Additionally, the investigator kept count of the number of times a warning buzzer was set off as a measure time spent on target.

In the dual-task mode, the semantic category given to participants was to name as many fruits as they could within one minute. It was predicted that during the independent mode, in both the semantic fluency task and pursuit rotor task, the effect of dyslexia would not disrupt performance. On the other hand, during the dual-task mode, the effect of dyslexia would interrupt performance in one perceptual modality, but not both. The prediction that dyslexia-related deficits would not be found in the semantic fluency task when performed in the independent mode or in the dual-task mode was stated on the basis that word production belonging to a certain semantic category (semantic fluency) is generally not impaired in dyslexia (e.g., Frith et al., 1995; Reid, Szczerbinski, Iskierka-Kasperek & Hansen, 2007). Additionally, the prediction that dyslexia-related deficits would be found when performed in the dual-task mode rather than in the independent mode in the pursuit-rotor task performance was founded on the following basis. Individuals with dyslexia are able to deploy conscious compensatory resources to improve skill acquisition task performance - when working memory resources that would typically be deployed as a conscious compensatory strategy to improve task performance is in contention with a secondary task (Nicolson, Fawcett & Dean, 2001). Thus, in dual-task mode, deficits would show in the pursuit-rotor task owing to difficulty in attaining automaticity in motor-related tasks in dyslexia.

During dual-task performance, the participants were required to perform the pursuit-rotor task and the semantic fluency task simultaneously - as accurately and as quickly as possible. The stimuli for the semantic fluency task in the dual-task mode was a different category (fruits) in order to eliminate familiarity effect of stimuli. In the dual-task mode, a greater number of errors in the pursuit rotor task and/or a significant decline in speed of performing semantic fluency task gave an indication of a deficit in the concurrent management of multiple tasks. The performance of the independent tasks was compared against the performance of the dual-task mode to identify between-group differences. The investigator debriefed the participants after they performed the battery of EF tasks. The design employed for this task was a mixed-measures design. A two-way repeated-measures ANOVA and an independent-samples t-test were used to analyse the data from the stated hypothesis (see Section 4.12). The between-subjects factor was participant group with two levels (adults with dyslexia and adults without dyslexia). The within-subject factors were task-type presentation in independent mode and tasks presentation in dual-task mode. The dependent variables were (i) accuracy of pursuit rotor mode performance in independent mode and dual-task mode respectively; (ii) total number of words generated in independent mode and dual-task mode respectively.

4.13.4 Planning (Trail Making Test)

In the current work, the Trail Making Test (Lezak, 1995) was employed. The Trail Making Test is a neuropsychological test of visual attention and task switching. The test provides information about visual search speed, scanning, speed of processing, mental flexibility, and executive functioning and has been employed to assess adults with and without dyslexia (e.g., Nahri et al., 1997; Shehata & Hassan, 2014). In this task, the participants were required to connect a sequence of 25 consecutive numerical as well as alphabetical targets on a sheet of paper as quickly as possible while maintaining accuracy. There were two parts to the test: in the first component of Part 1, (a measure of cognitive processing speed) the targets are only numbers (1, 2, 3, etc. up to 25); the participants were required to connect them in ascending order. In the second component of Part 1, (a measure of cognitive processing speed) the targets are only letters (A, B, C etc. up to Y); the participants were asked to connect in ascending order. In the Part 2, (the measure of executive functioning) the participants were required to alternate between numbers and letters (1,A, 2,B, up to Y,25). If the participant made an error, the investigator corrected them before they moved on to the next alphabetic or numeric target. The objective of the test was for the participants to finish both parts as quickly as possible. The difference in performance between Part A and Part B gave an indication of task switching difficulty which is a measure of planning ability in EF. Time taken to complete the test was used as the primary performance metric. The design employed for this task was an independent-measures or between-subjects design. The stated hypothesis was analysed using a 2-way repeated measures ANOVA and an independent-samples t-test.

4.13.5 Results for broader EFs

4.13.5.1 Dual-task Performance

4.13.5.2 Two-way repeated measures ANOVA Between-group task performance

A two-way repeated-measures ANOVA was performed. The sample consisted of adults with dyslexia $N = 24$ and adults without dyslexia $N = 25$). The ANOVA revealed that, overall, there was a non-significant effect of participant group, $F\ (1, 47) = 2.52$, $p = .12$. The main effect of task-performance mode was significant, $F\ (3, 45) = 8.24$, $p <.001$, $\eta_p^2 = .36$. This effect of task-performance mode can be observed to show a small difference in accuracy of performance when tasks were executed individually and in the semantic fluency task when performed in dual-task mode. However, this difference appeared to increase in dual-task mode for the pursuit rotor task performance. The multivariate test showed that there was a significant interaction between task-mode and participant group, $F\ (3, 45) = 2.82$, $p = .05$, $\eta_p^2 = .158$.

4.13.5.3 Independent-samples t-test between-group performance on independent task-mode

The participants with dyslexia performed comparable (M = 19.13, *SD* = 5.30) to the participants without dyslexia (M = 20.16, *SD* = 5.51) when they performed the semantic fluency task in independent mode (see Figure 4.1). An independent samples *t*-test indicated that group performance difference on the semantic fluency task when performed in the independent condition did not significantly differ, *t* (47) = -.67, *p* = .51, d = 0.19. Similarly, the performance of adults with dyslexia (M = 12.98, *SD* = 12.27) was comparable to those without dyslexia (M = 14.31, *SD* = 12.67; see Figure 4.1). When the pursuit-rotor task was carried out in the independent mode, between-group difference in performance did not significantly differ *t* (47) = -.37, *p* = .71, d = 0.11.

4.13.5.4 Independent-samples t-test between-group performance on dual-task mode

In the dual-task condition, similar levels of performance were demonstrated by adults with dyslexia (M = 17.54, *SD* = 5.82) and adults without dyslexia (M = 18.12, *SD* = 5.82) in the semantic fluency task (see Figure 4.2). The between-group difference in performance was found to be non-significant *t* (47) = -.40, *p* = .69, d = 0.10. In the dual-task condition, the participants with dyslexia performed weaker (M = 14.23, *SD* = 12.44) than those without dyslexia (M = 22.60, *SD* = 14.89) in the pursuit-rotor task (see Figure 4.2). The between-group difference in performance was found to be significant *t* (47) = -2.13, *p* = .04, d = 0.61.

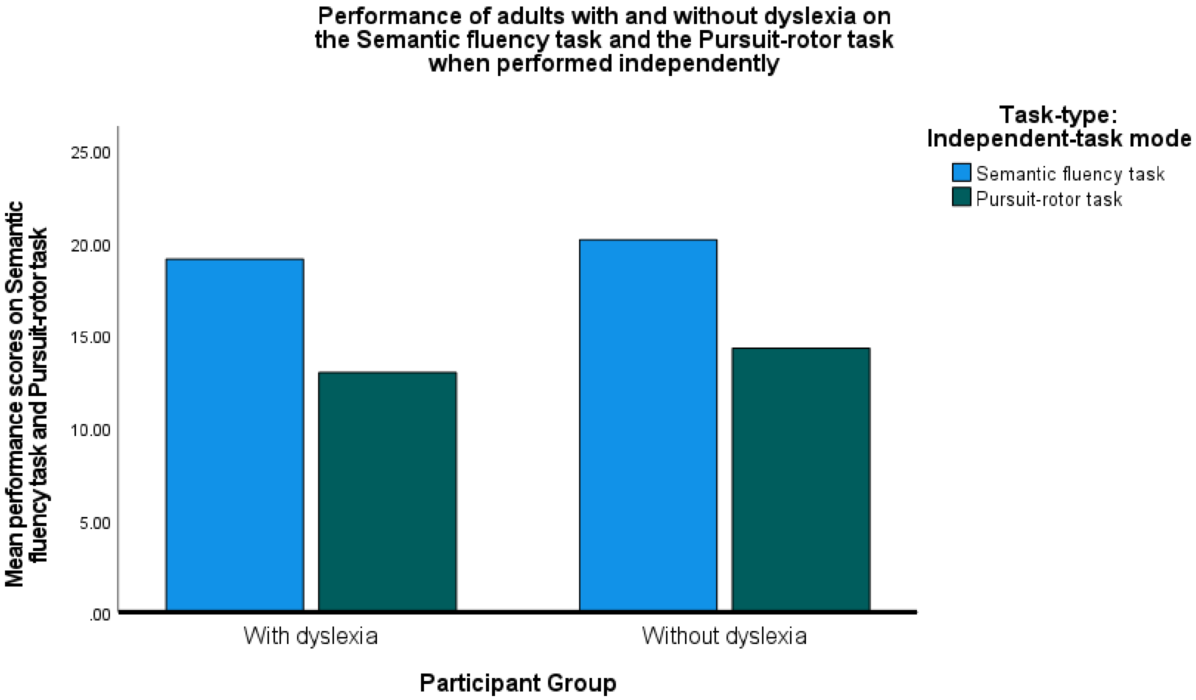

Figure 4.1 Group performance difference when Semantic fluency task and Pursuit-rotor task were performed independently

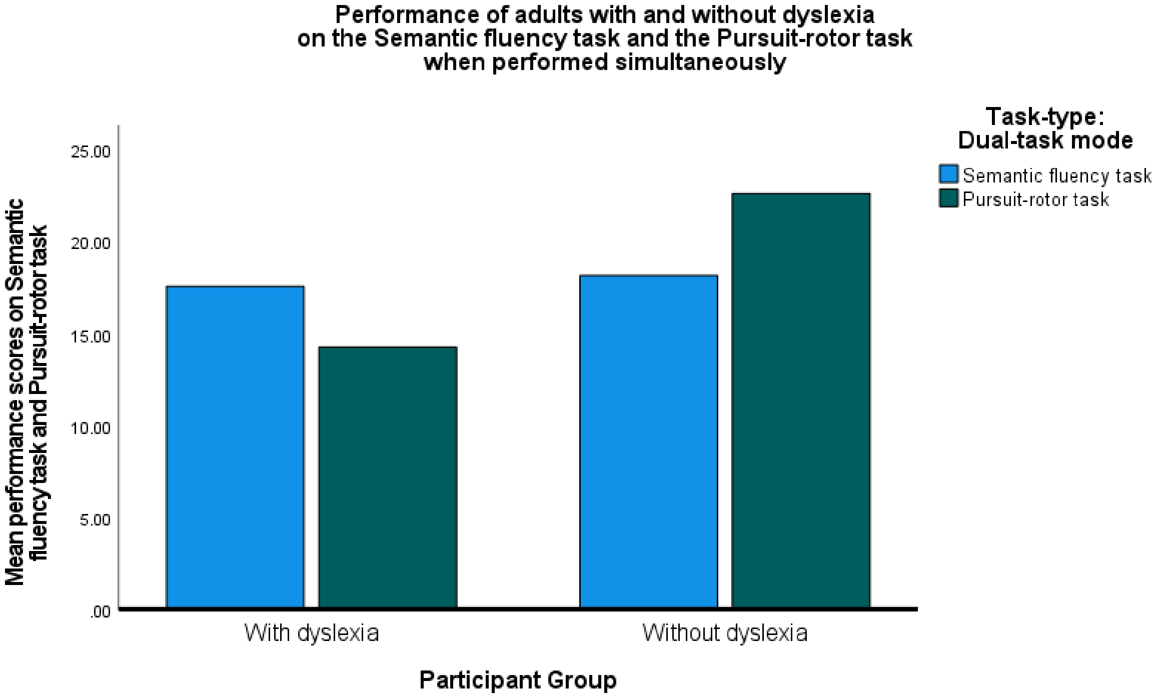

Figure 4.2 Group performance difference when Semantic fluency task and Pursuit-rotor task were performed simultaneously

4.14 Planning

4.14.1 Two-way repeated measures ANOVA performance

A two-way repeated-measures ANOVA was carried out. The sample consisted of adults with dyslexia $N = 25$ and adults without dyslexia $N = 25$. The ANOVA revealed that there was a significant main effect of participant group, $F(1, 48) = 3.96$, $p = .05$, $\eta_p^2 = .08$. Performance differed significantly when participant group was taken into consideration.

The multivariate test revealed that task-type also produced a significant main effect, $F(2, 47) = 31.31$, $p < .001$, $\eta_p^2 = .57$. This effect of task-performance mode (see Table 4.1) shows that the speed of task completion based on letters was marginally slower than when performance was based on numbers. The multivariate test showed that there was a non-significant interaction between task-type and participant group, $F(2, 47) = 1.47$, $p = .241$, $\eta_p^2 = .06$.

4.14.2 Independent-samples t-test: Between-group performance: Cost of switching

A further independent samples *t*-test to compare switching cost when the two groups performed the letters + numbers part of the task. The group with dyslexia was slower (M = 32s.20ms, *SD* = 38.07) than the group without dyslexia (M = 24s.00ms, *SD* = 13.73). There was a significant difference between the group with dyslexia and the group without dyslexia related to their speed of their switching between the letters and the numbers, $t(46) = -2.02$, $p = .05$, $d = 0.29$.

Table 4.1 shows the means and SDs for performance on the trail making test.

Table 4.1. Group mean performance on the Trail Making Test

Task Type	Participant Group	Mean	Std Dev
Letters	With dyslexia	39.96	32.42
	Without dyslexia	27.96	9.37

Numbers	With dyslexia	30.80	23.56
	Without dyslexia	22.56	5.42
Numbers + Letters	With dyslexia	71.80	56.05
	Without dyslexia	49.44	12.67

4.15 Discussion of broader EFs

Two broader EFs (planning and dual-task performance) were investigated in adults with and without dyslexia. Performance over two types of task administration were assessed, firstly in independent mode, and secondly in dual-task performance mode. Group performance did not significantly differ on either the semantic fluency or pursuit-rotor task when these were carried out independently and this was consistent with what was predicted. As also predicted, adults with dyslexia performed at a significantly lower level when performing the semantic fluency and the pursuit-rotor task concurrently. The results are thus in line with previous studies in which dual-task performance problems have been reported in dyslexia (e.g., Menghini, Hagberg, Caltagirone, Petrosini & Vicari, 2006; Gabay, Schiff, & Vakil, 2012; Nicolson, & Fawcett, 1994; Sigmundsson, 2005).

Dyslexia was not found to affect semantic fluency performance. When performed in independent mode and in dual-task mode with the pursuit-rotor task, performance between the two-groups did not significantly differ. However, in the case of the pursuit-rotor task, in the initial phase when the task was performed independently, the performance of the group with dyslexia was similar to the group without dyslexia. In dual-task mode, the group with dyslexia showed a significantly weaker performance on the pursuit-rotor task. The current study’s findings are now discussed in the light of the cerebellar deficit hypothesis (Nicolson et al., 2001; see Section 1.2.1). In dual-task mode, dyslexia-related deficits were indicated in the pursuit-rotor task. This ties in with the cerebellar deficit hypothesis on the basis that the cerebellar deficit hypothesis argues for extensive dyslexia-related problems in improving acquired skills in motor-related procedural learning tasks. However, this finding should be interpreted with caution owing that a clear demonstration of automaticity cannot be asserted since the participants performed the task only for a short while.

As an explanation of this occurrence, the cerebellar error mechanism is considered to impede on the ability to enhance motor-related skills. The problems demonstrated in adults with dyslexia when the pursuit-rotor task was performed in dual-task mode can also be explained by the automaticity deficit hypothesis (Nicolson & Fawcett, 1990). The pursuit-rotor task is a motor-related procedural-learning task that individuals without dyslexia appear to improve from their previously exposed performance. However, for those with dyslexia, particular difficulties in improving have been indicated. The pursuit-rotor task is likely to be more novel to all participants than working with semantic categories. According to the dyslexia automatization deficit hypothesis (Nicolson & Fawcett, 1990), individuals with dyslexia demonstrate problems enhancing a skill which they have previously been exposed to. Accordingly, the hypothesis argues that difficulty in skill automatization explains weaker performance in tasks that require the automating of skill in individuals with dyslexia.

The planning aspect of EF was explored using the Trail Making Task (Reitan & Wolfson, 1985). The results supported the hypotheses and revealed significant main effects of participant group and task-type respectively. The results indicated a non-significant interaction effect between-group and this was not consistent with the interaction hypothesis. Consistent with the hypothesis, the group with dyslexia performed significantly weaker in terms of switching cost when the task was performed in combined letters + numbers mode and participants were required to alternate between letters and numbers. The overall pattern of findings in planning ability demonstrates switching deficits which was indicated with slower processing speed in adults with dyslexia compared with those without dyslexia. This observation was made when participants performed the combined (letters +

numbers) part of the task and is in line with previous work (e.g., Torgeson, 1977). There is a logical reasoning component in the Trail Making Test that does not decline in performance in participants with dyslexia (e.g., Reiter, Tucha, & Lange, 2005). However, it is typical for individuals with dyslexia to perform significantly weaker than those without dyslexia in terms of switching cost. Other studies (e.g., Marzocchi et al., 2008) have reported non-significant group differences in planning time and execution time between participants with and without dyslexia. Consistent with previous studies (e.g., de Lima, Azoni, & Ciasca, 2013), the overall correct responses did not significantly differ between the two groups. The current findings point to problems in slower processing in planning and execution as a result of switching costs in adults with dyslexia.

4.16 General discussion

A summary indicating the main findings of the core EFs and broader EFs is presented in table 4.2.

Table 4.2 shows the key results of the range of tasks used to investigate EFs

Core EFs	**Group differences**	***p* value**	**d**
Habituation Phase	Go condition	p=.52	0.19
Inhibition Phase	No-Go Condition	p=.74	0.10
Updating working-memory	Data unretrievable	-	-
Set Shifting	Processing Speed (Combined Plus + Minus Operation Mode)	p=.004	0.89
	Cost of Switching	p=.006	0.84
Phonemic Fluency	Processing Speed	p=.05	0.58

Broader EFs	Group differences		
Pursuit-Rotor Task	Independent Task Mode	*p*=.71	0.11
Semantic Fluency Task	Independent Task Mode	p=.51	0.19
Pursuit-Rotor Task	Dual-Task Mode	*p*=.04	0.61
Semantic Fluency Task	Dual-Task Mode	p=.69	0.10
Planning	Cost of Switching (Combined letters + numbers Operation mode)	p=.05	0.29

The results revealed dyslexia-related problems across core EF's as well as broader EF's. In relation to core EF's, the findings revealed problems in set-shifting, and phonemic fluency, but not in inhibition. Updating working-memory was not analysed (see Section 4.8.2 for details). Adults with dyslexia demonstrated problems in set-shifting (Plus/Minus Task). Slower processing times were shown in adults with dyslexia when flexible shifting was not necessary in each individual mode of the task. Additionally, significantly slower processing times were indicated in adults with dyslexia when flexible switching between two cognitive operations in the third phase of the task was needed (cost of switching).

In the Phonemic fluency task, the main finding indicated that adults with dyslexia produced fewer words in total across three categories. This difficulty can be attributed to dyslexia-related phonological processing difficulties or a problem with executive fluency (Smith-Spark, Henry et al., 2017). The phonemic fluency task depends on reliable retrieval processes that accesses information stored in long-term memory (e.g., Fisk & Sharp, 2004). It is recognized that in verbal fluency tasks, considerable loads are placed on higher-order cognitive abilities that include set-shifting, and tactical planning (e.g., Parker & Levin, 1997). In Smith-Spark, Henry et al. (2017), adult dyslexia-related difficulties on phonemic fluency tasks pointed to phonological processing problems as the primary problem in attaining fluency. Although, executive control deficits could not be entirely ruled out as another explanation - on the basis that fewer switches made between subcategories on phonemic fluency was predicted by dyslexia status. In the current work, the extent of the role of executive control was not assessed. However, when all letters were combined, although statistical significance was obtained, it was not possible to assess switches made between subcategories. As a result, the indicated dyslexia-related deficit is considered from the stance of phonological processing difficulty in adults with dyslexia in terms of retrieval of verbal information from long-term memory. Inhibitory control (Go/No-go Task) did not indicate performance-related deficits in adults with dyslexia. The findings do not suggest the presence of dyslexia.

For broader EF's, the dual-task performance in the independent mode for the pursuit-rotor task and the semantic fluency task showed similar levels of ability between adults with dyslexia and those without. A main finding in the dual-task performance indicated dyslexia-related problems when the pursuit-rotor task and the semantic fluency task were performed simultaneously. Specifically, dyslexia-related problems were found on the pursuit-rotor task, but not of the semantic fluency task. This indicates that when two modality-distinct tasks were executed concurrently; performance of a previously trained skill for the pursuit-rotor task - a motor-coordinated task, appears to be disrupted relative to the semantic fluency in adults with dyslexia. This ties in with cerebellar deficit hypothesis (Nicolson & Fawcett, 1990; see Section 1.2.1). But a more comprehensive point is that dual-task performance is considered to be dependent on the limited resources of the central executive (Badderley, 1996); and so, there is an argument concerning the executive allocation of attention. According to Nicolson and Fawcett (1990), individuals with dyslexia can mask problems in a series of skills through a conscious compensation strategy. Through this process, additional attentional resources are allocated to the task at hand to compensate for deficits in automatic skill. Nicolson and Fawcett propose that in instances wherein task demands surpass the available volume such as in a stress-induced condition, deficits in dyslexia begin to appear.

Accordingly, when a condition is either novel or involves dual-task performance, there is an increased likelihood of a decline in performance. Smith-Spark and Fisk (2007) have previously underplayed the function of dyslexia-related automaticity problems and have suggested problems with conscious compensation as one component of a larger difficulty with the executive allocation of attention.

In the planning task, a main finding relates to the dyslexia-related greater cost of switching between two cognitive operations. The cost of switching between letters and numbers sequentially indicated slower processing times in the third phase of the task. Adults with dyslexia demonstrated cost of switching between cognitive operations on the Plus-Minus task (Jersild, 1927) that was 1.5 times greater than those without dyslexia. Moreover, other studies have actually reported 2.5 times greater switching cost in adults (e.g., Smith-Spark et al., 2016) and in children (e.g., Poljac et al., 2010) with dyslexia. It was suggested by Meltzer (1991) that weakness in cognitive flexibility could hinder people with dyslexia from accessing metacognitive information efficiently during problem solving. The lack of dyslexia-related difficulties has been shown in alternative set-shifting tasks (e.g., Kapoula et al., 2010; Närhi et al., 1997; Smith-Spark, 2000; Stoet et al., 2007).

Although, Smith-Spark et al. (2016) reported even greater switching costs in adults with dyslexia. Smith-Spark et al. suggested that evidence of deficits may be contingent on the type of task and the design employed. Poljac et al. (2010) had previously highlighted methodological issues with regards to stimulus inconsistency as a possible explanation of the lack of switching cost in studies such as Stoet et al. However, in the case of the Plus-Minus task, the processes required to perform the differing parts of the task are discernible. Whilst in Part A, in the letters only mode and numbers only mode, minimal demands are placed on task performance, in Part B, the requirement to alternate between numbers and letters places demands on central executive resources that are associated with inhibition, cognitive flexibility, and the capacity to sustain a response set and the completion time.

In conclusion, the findings of the current chapter provided evidence for difficulties one core EF ability (set shifting) in adults with dyslexia. No evidence of problems in inhibition ability was shown. The updating working memory core EF facet was measured, but the data proved to be unretrievable and so could not be analysed. Two broader EFs indicated dyslexia-related problems in both Dual-task performance and Planning. With the exception of inhibition and (updating working-memory), indications from the current work findings point to dyslexia-related problems in set shifting, phonemic fluency, dual-task performance and planning facets of EF. These EF deficits in dyslexia would seem to endure into adulthood and are evident under laboratory-based tasks. In adult age, individuals are more self-reliant in the execution of their daily activities and problems are likely to play out there too (see Smith-Spark, Henry et al., 2016). These daily activities draw on a range of EFs (e.g., Diamond, 2013) and so the implications of the indicated deficits are fundamental to consider in line with the design of interventions.

Chapter 5.0 Time perception

5.0.1 Executive summary

Time perception refers to the subjective evaluation of the passage time. Accurate judgement of psychological time is relied upon in order to organize behavioural adjustments in relation to planned action. Dyslexia-related time perception problems in the milliseconds range have been reported through a variety of auditory discrimination tasks. Time perception investigations in the long duration range (minutes, hours) are lacking, despite such durations representing the typical duration of activities that we experience in daily life. The current work employed traditional laboratory-based measures of time perception to explore the performance of adults with and without dyslexia over shorter and longer durations. In the milliseconds range, the results showed no evidence of dyslexia-related time perception deficits in all the three tasks employed. In the minutes range, the results for the long duration time perception tasks showed no evidence of time perception problems in dyslexia in both retrospective and prospective time estimations. The implications of the findings are discussed in line with theory and from the perspective of sample size and statistical power.

5.1 Overview of chapter

This chapter begins with a general definition of time perception. Subsequently, theoretical models of time perception are presented. This is followed by a discussion of the types of experimental tasks that are typically employed in measuring time perception. Next, a consideration of dyslexia-related difficulties in time perception is given. The rationale and hypotheses for the need to investigate dyslexia-related time perception performance under the range of experimental conditions given is justified on the basis of the problems identified in previous research. Following this, the empirical work is presented and then discussed.

5.2 Definition of time perception

Psychological time is different to physical time in that physical time proceeds at a constant pace whereas psychological time is changeable and might be slower or faster than or identical to physical time (Grondin, 2010). Psychological time involves the subjective evaluation of the passage of time (Wittmann, 2013). Psychological timing is a crucial dimension of our perceived world since the ability to accurately judge the passage of time is relied upon in order for appropriate behavioural adjustments to be implemented (e.g., Shi, Church, & Meck, 2013). In day-to-day living, the precision of psychological time estimation can be vital in responding to past or future events. The perception of the passage of time is necessary for actions requiring a sequential procedure (e.g., inserting the key in the ignition before starting the car), executing physical movements (e.g., coordinating the next hand movement when one is juggling or judging when to cross a busy road) or verbal responses (e.g., remembering to ring back a colleague after 30 minutes have passed (e.g., Shi, Church, & Meck, 2013). On the one hand, retrospective time awareness involves circumstances in which one may be required to recall the passage of time between two past timing points without forming a prior intention to do so (e.g., Buhusi & Meck, 2005). Conversely, prospective time awareness is concerned with one's ability to estimate the passage of time between a particular point in time and a future time-point subsequent to previously forming the intention to do so. Kastenbaum (1994) has argued that one's subjective perception of psychological time cannot be considered as a single function, but instead, it should be perceived as a multifaceted response process. Kastenbaum (1994) contends that the awareness of time can be influenced through feedback from both internal and external events to assist with the coordination and interpretation of the related experiences. The means through which one coordinates and interprets events to construct one's view of psychological time is subject to individual differences. Subjective assessment of time may differ from person to person and is related to memory and attentional processes (e.g., Grondin, 2010). Typically, prospective timing in a laboratory paradigm requires an individual to estimate the passage of time subjectively – after he or she has previously been informed of a requirement to do so (e.g., after being informed of the need to make a subjective judgement of time, participants are engaged in a filler task in the meantime). Laboratory-based retrospective timing tasks, on the other hand, require participants to estimate the passage of time between the start and end points of a particular task without any prior warning of a requirement to make a future time estimation (e.g., Block, Grondin, & Zakay, 2018). Theoretical models of time perception explain the phenomenon through different mechanisms. These are presented in the next section.

5.3 Theoretical models of time perception

Theoretical models of time perception have proposed factors that either distort or facilitate accuracy in one's ability to differentiate in subjective timing tasks. Whilst earlier models of time perception proposed the principle of cognitive processes that function devoid an internal clock system (e.g., cognitive-attentional model, Thomas & Weaver, 1975), contemporary models rely on the existence of an internal clock (e.g., Scalar Expectancy Theory; Gibbon, Church, & Meck, 1984).

Thomas and Weaver (1975) explained time estimation through an attentional model. An assumption of this model argues that the number of items to be managed within a specified segment of time is inversely associated with subjective time. This is grounded on the basis that an increase in attention to the given stimuli considerably reduces the extent of attentional resources available for temporal processing. In contrast, Jones and Boltz's (1989) model advocated a dynamic attending system on the basis that attentiveness to future events occurrences may be contingent on prior events. More specifically, the dynamic attending model postulates that the information in the memory system that is replicated from previous temporal experiences is compared with the present state of the clock (e.g., Taatgen & van Rijn, 2011). Thus, the dynamic attending mode is based on the premise that clock and memory components are closely intertwined in generating precise estimates of time, (Taatgen & van Rijn (2011). This form of memory system is known as the temporal reference memory. According to this model, when the reference item corresponds to a previously experienced representation, the recently experienced elapsed time is considered to be identical to the formerly experienced duration. A limitation of the reference memory system relates to the argument of its proposal of a seamlessly flawless system with a reference memory for previously stored items that is insusceptible to deterioration, (Taatgen & van Rijn, 2011).

Whilst some research has looked at disentangling the disparities and associations between discrete components of psychological time models through imaging (e.g., Lewis & Miall, 2006), clinical studies and pharmacological manipulations have showed that the clock and memory components derive from distinct physiological systems (e.g., Buhusi & Meck, 2005). Others have also showed the association between the temporal reference memory system and working memory. For instance, Brown (1997) demonstrated that the presentation of a secondary task during temporal reproduction tasks was adversely influenced if working memory was needed in the task. This implicates the involvement of attentional processes in working memory to manage the demands of the secondary task. Baudouin et al. (2006) showed in a study with older adults that tasks involving reproducing time intervals requires working memory.

A common way of accounting for psychological time-related activities is grounded in the notion of a dedicated internal clock system (Graf & Grondin, 2006). Models of psychological time established in the internal clock system include the Scalar Expectancy Theory (SET; Gibbon, Church, & Meck, 1984). Scalar Expectancy Theory has been applied to study human timing (e.g., Wearden, 2003; Wearden, & Bray, 2001; Wearden, & McShane, 1988). It explains psychological time through the idea that at the start of a psychological timing event, temporal information pulses are emitted by a pacemaker device and stored in an accumulator (see Figure 5.1). The accrued count is considered to inform our perceived interval of elapsed time (Grondin, 2001).

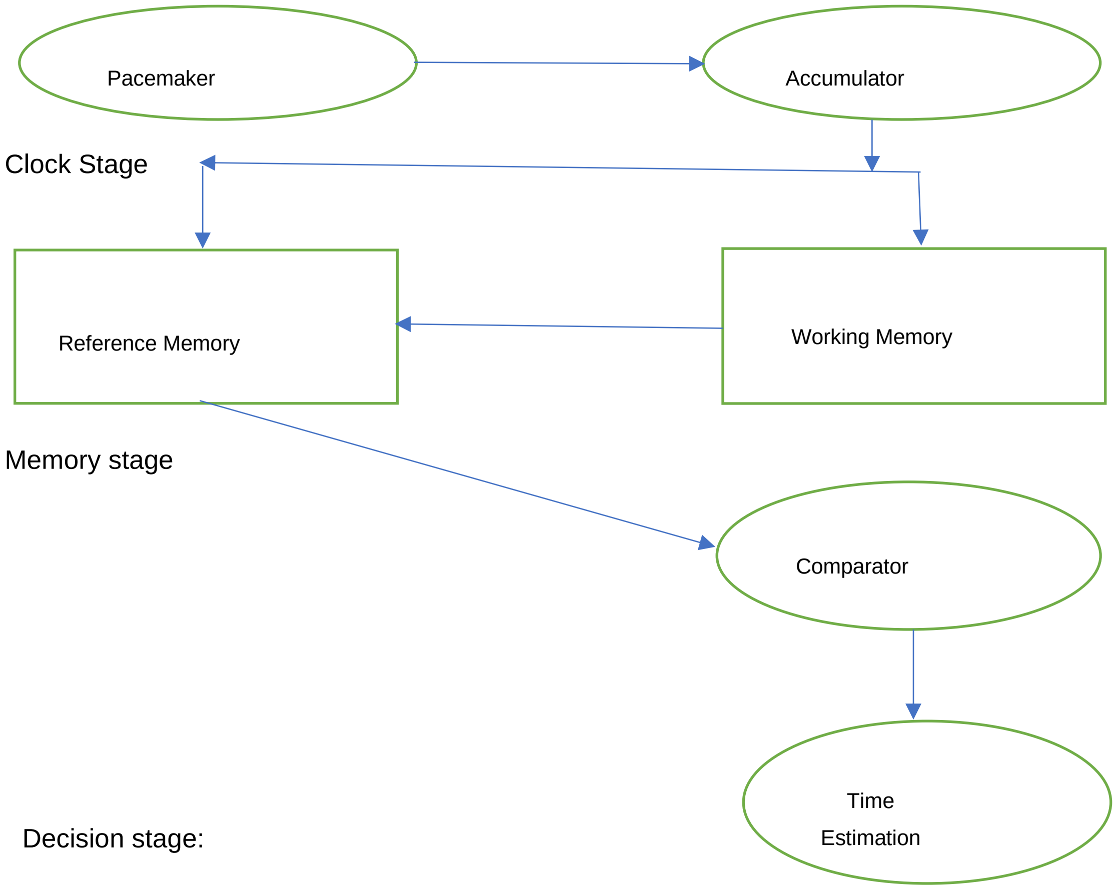

Figure 5.1 The processes involved in the Scalar expectancy model in the estimation of time

As can be seen from Figure 5.1, the SET model proposes three processing levels in clock comparison. These are: clock processes, memory processes and decision-making processes. This model suggests that, at the clock stage, one's perception of the beginning of a-to-be-timed interval signals a switch to be closed. The closing of the switch enables temporal pulses to flow from a pacemaker device into an accumulator. Subsequently, a count of pulses in the accumulator informs a memory representation and is sustained in working memory. If the memory representation is deemed as behaviourally important, it is then relayed to the long-term memory and stored as a reference memory. Next, decision-making processes make a comparison of a time representation in working memory to a time representation that is retrieved from the reference memory stored in long-term memory. The assessment of likeness between the interval representation that was recently presented, and the interval representation retrieved from long-term memory informs the given response. The SET framework has been employed in human timing research (e.g., Wearden, 1991a, 1991b) and has been evaluated in reviews (e.g., Allan, 1998; Wearden, 2003). The abovementioned reviews and studies indicate that the SET model is reliable in the management of specific features of human timing tasks in which sequential counting is not enacted (Wearden, 1991a; Wearden, et al., 1997). Such timing tasks entail short temporal intervals that are in the milliseconds range. A limitation of the SET model concerns the omission of the role of attention in explaining psychological time awareness (Block, 1990; Block & Zakay, 1996; Wearden, 2003).

An alternative model also based on the internal clock system is the attentional gate model (Zakay & Block, 1995). The attentional gate model explains psychological time awareness by means of a pacemaker device that emits temporal information pulses into an accumulator. In the attentional gate model, unlike the SET model, pulses emitted from the pacemaker and entering the accumulator are regulated by an attentional switch. According to Zakay and Block (1997) and Zakay (2000), one's attention to the flow of time, functions to open or close the gate which in turn provides access to the accumulator (see Figure 5.2). When tasks that require temporal processing are performed in tandem with time-unrelated activities, one's subjective awareness of the passage of time is judged as briefer when events require greater foci of attention (Grondin, 2010). This is consistent with the attentional gate model view in postulating that when attention is employed in a time-based event and an ongoing task simultaneously, one generally falls short in the processing of the pulses emitted by the pacemaker because the attentional gate is open. As a result, this may lead to the subjective distortion of elapsed time.

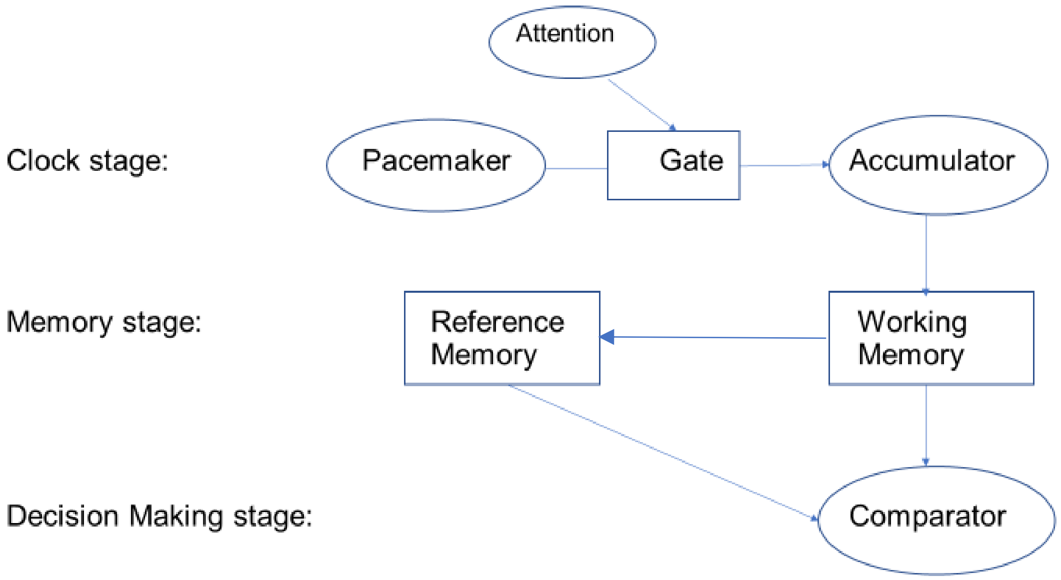

Figure 5.2 The processes involved in the Attentional Gate Model in the estimation of time

There are other accounts in addition to that presented by the SET such as the sensory automatic timing hypothesis (Rammsayer & Lima, 1991) which holds that temporal judgements of brief intervals in the milliseconds range is contingent mainly on modality-specific (visual, auditory) sensory-automatic temporal processing. However, an account of the model has not been included in this section as it is not relevant to the current work. Taken together, and despite alternative models and criticisms, the SET is a model that employs a non-counting system (the use of tone durations that are less than one second long, meaning that counting is not possible). For the durations that are marginally longer than one second (see Section 5.7.4.1 for examples of stimuli longer than one second), the participants are explicitly instructed not to count to determine an interval stimulus duration in temporal duration tasks in the milliseconds range. Also, the SET model has been extensively used, owing to its domination in animals and humans timing research. (e.g., Bizo & White, 1997; Rakitin et al., 1998). It is thus justified as the most appropriate model to be modelled for the short duration temporal judgement tasks used in the current work. There are different laboratory-based experimental tasks that are dependent on the internal clock system. These tasks are used to assess time perception over short durations (typically in the milliseconds range). These tasks are discussed in the next section.

5.4 Types of tasks used in assessing short duration time perception

Generally, three types of tasks have been used to investigate the mechanisms implicated in time perception, namely time comparison, time production, and verbal estimation. A fourth type of task (time reproduction) exists – but is not relevant to the current study because it involves aspects of motor timing. An in-depth consideration of the range of task-types used in this chapter are discussed in the following subsection.

5.4.1 Temporal generalization task

The temporal generalization task is a measure of short duration time perception and uses timings in the range of milliseconds and is employed in interval judgement research (e.g., Grondin, 2012; Shi & Meck, 2013). Temporal generalization requires participants to make a judgement about a currently presented tone with reference to a previously learned standard duration tone (e.g., identifying which was the longer or shorter duration, or whether the second duration was shorter or longer than the first; Grondin, 2010). A range of comparison tone durations are presented which are shorter, longer or equal in duration to the standard. In a typical temporal generalization performance, on practically every occasion, interval duration stimuli that were longer (e.g., 600 ms) than the standard duration stimulus (e.g., 500 ms) had a greater likelihood of being confused with it in comparison to interval duration stimuli that were shorter by an identical duration (400 ms; Wearden, 1992). In analysing the data, the proportion of YES responses (i.e., identifying of a presented stimulus as being the same as the standard duration) as a function of stimulus duration is plotted against stimulus length.

According to the SET model (see Section 5.3), performance of the temporal generalization task can be explained in the following way. Upon commencing the task, a specific reference tone duration is presented to participants. The participants are required to store the tone duration in their memory for future retrieval. The duration representation of the reference tone is formed in long-term memory. After this, at the initial clock stage of each trial, a participant's awareness of a-to-be-timed duration closes a gated switch to allow time-related information pulses to flow from a pacemaker device into an accumulator. Next, during the memory stage, since the memory representation of the duration is deemed important and required for a later action, it is transferred to long-term memory for pending judgments. Subsequently, the memory stage is initiated in which, a sample of the reference tone duration is retrieved from long-term memory and compared against the recently presented tone duration. At the decision-making stage, a judgment is made to evaluate the similarity of the recently presented tone duration against the reference tone. If the two durations are judged to be relatively similar, the recently presented tone duration would be rated as being the same as the reference tone. The purpose of the comparison is to indicate the likeness of the former to the latter in terms of their time frames (e.g., was the comparison tone duration similar to the standard tone duration?).

5.4.2 Bisection task

The bisection task is well established in the literature and can be considered as an example of a time comparison task. The bisection task has been used in assessing the temporal discrimination of stimuli (e.g., Kopec & Brody, 2010). The bisection task requires participants to learn two standard tone durations and to store them in long-term memory, e.g., 300ms (presented as being a short duration) and 700ms (presented as being a long duration). Subsequently a range of comparison tone durations are presented, and participants are asked to indicate whether each was more similar to one or other of the two standard tone durations. This involves trial-by-trial retrieval of the two standards from long-term memory in tandem with monitoring and maintaining the duration of the comparisons in working memory. Although participants contrast the comparison tone to the two standard tone durations, the task places lesser demands on memory resources when likened to the temporal generalization task (e.g., Droit-Volet, Wearden & Zélanti, 2015). Performance on the bisection task can be described by the SET model (see Section 5.3 for a wider discussion of the SET) in the following way. At the beginning of the task, two reference tone durations are presented to participants which are required to be stored in memory for later retrieval. During the experimental trials, at the initial clock stage, the perception of a-to-be-timed duration closes a gated switch which in turn allows time-related pulses to pass from a pacemaker device into an accumulator. Next, the temporal information in the accumulator forms an interval memory representation in terms of its length and is stored in working memory. At the memory stage, given that the memory representation of the recently experienced duration is deemed important, it is held and transmitted into long-term memory for future comparisons. At the decision-making stage, the decision-making processes in working memory compares a recently presented tone duration to two duration representations that are retrieved from long- term memory. The appraisal of likeness between the temporal tone duration representation that was recently presented, and the likeness or otherwise of the two-tone duration representations retrieved from long-term memory updates the response produced.

In sum, the datapoints from the bisection task are represented on psychometric curve plots of the stimuli of the interval durations comprising the comparison and standard interval stimuli are plotted against participants prospect of responding “long”. The functions demonstrate a gradient increase with duration. This implies that participants virtually always do not respond “short” to the longest standard duration, and almost always respond “short” to the shortest duration interval standard duration. But, at roughly the point where an intermediate duration is located, participant judgements overlap 0.5 on the y-axis (bisection point; see Figure 5.3). At the bisection point, there is an equal prospect of a participant to indicate “long” or “short” as a response. The task offers a differing way in which decision-making processes are spent when judgement between a comparison tone duration stimulus (located at the bisection point) and two respective standard temporal tone durations stored in long-term memory have equal chances of being selected.

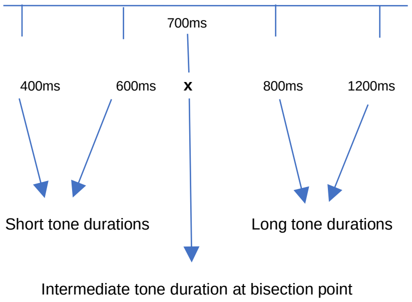

Figure 5.3 The point where an intermediate tone duration is located at (x), this is the bisection. At the bisection point, the propensity of a participant's judgement of a tone duration as "short" or "long" overlap 0.5 on the y-axis

5.4.3 The verbal estimation task

The verbal estimation task offers yet, another way to assess temporal interval duration processes. The task entails participants learning two respective standard tone durations which are stored in long-term memory. Afterwards, seven target tone durations are presented in sequence. The participants are required to convert respective subjectively experienced target duration to an objective duration and to give a verbal indication of each in chronological units. The verbal estimation task is a distinctive tool that can be employed to assess individual differences in the speed rate of the internal clock. Grondin (2008, 2010) and Zakay (1990) argued that verbal estimation tasks produce less accurate temporal processing performance. This is because the task generates an increased likelihood of variability owing to participants tending to round the time duration (e.g., a tone whose duration is 325 milliseconds may be rounded to 300). The verbal estimation task is a conventional task that has been previously used in time perception studies (e.g., Bisson, Tobin & Grondin, 2012; Wearden et al., 2009). In the initial phase prior to the experimental trials, participants are presented with two tone durations representing a short tone duration and a long tone duration respectively and are asked to store the two durations for future retrievals. Subsequently, on each trial, the participants are presented with one of the seven randomly allocated tone duration stimuli. The participants are then asked to give a verbal estimation of the length of the tone duration stimulus they heard. The verbal estimation task can be described by the SET model (see Section 5.3 for a broader discussion of the SET) in this way. At the clock stage, on each experimental trial, one's attentiveness to a-to-be-timed duration closes a gated switch to permit pulses to flow from a pacemaker into an accumulator. At this point, participants are presented with a target duration. The flow of pulses in the accumulator forms a memory representation which is stored in working memory. After that, at the memory stage, participants store the recently presented memory representation of the duration because of its significance in the required forthcoming verbal estimation of its duration. The duration is then transferred to long-term memory for storage. At the decision-making stage, decision making processes in working memory perform an appraisal of the recently experienced duration by retrieving the short reference tone and the long reference tone previously stored in long-term memory. The participants are asked to convert the subjectively experienced duration into temporal units as a measure of subjective time reproduction that is verbally generated. The assessment of the length of the recently presented duration is judged and updates the given verbal response. It has been argued that the verbal estimation task employs executive function abilities related to updating resources to monitor a to-be-timed stimulus (e.g., Ogden, Wearden & Montgomery, 2014). Nevertheless, Wearden, Todd and Jones (2006) have previously argued that participants may consult their long-term memory representations of durations when executing verbal estimation - i.e., their prior representation of the duration of one second. Thus, Wearden et al. imply that greater demand of attention and memory are employed in the task than in the bisection and temporal generalization tasks.

5.5 Time perception in dyslexia

Dyslexia-related problems in time perception have been reported in the perception and allocation of time (e.g., Bruno & Maguire, 1993), time estimation (e.g., Gooch, Snowling, & Hulme, 2011; Khan, Abdal-hay, Qazi, Calle & Castillo, 2014; Nicolson, Fawcett, & Dean, 1995), auditory temporal perception (e.g., Tallal, 1980), and timing precision and rhythm (e.g., Wolff, 2002). In Lovegrove (1993) and Tallal, Miller and Fitch (1993), it has been demonstrated that whether pairs of auditory stimuli or pairs of visual stimuli are presented in rapid sequence, participants with reading problems showed a higher degree of performance related difficulties compared with a neurotypical control group. This difference was evident when distinguishing gaps between a pair of stimuli or when deciphering which of two different stimuli comes first. The work of Lovegrove strengthened the argument that the core discrepancy in developmental dyslexia is associated with primary biological dysfunction of temporal information processing. Lovegrove et al.'s work placed a lesser emphasis on reading problems than the phonological deficit hypothesis (Snowling, 1987) by postulating that phonemic processing problems (see Section 1.3) in dyslexia may be a secondary manifestation stemming from a primary temporal processing deficit.

In Liberman (1993), children with dyslexia could not differentiate between phonologically different consonant and vowel syllables that were phonetically similar (e.g., "ba" and "da"). There were no indicated deficits in their ability to differentiate between paired consonant and vowel syllables that differed phonologically and phonetically (e.g., "ba" and "sa") – even though they place similar stresses on temporal order judgments and gap detection processes (e.g., Mody, Studdert-Kennedy & Brady, 1997). Subsequently, Wolff (2002) suggested that problems in gap detection and temporal order judgement related to non-linguistic sounds may not independently explain dyslexia-related problems in phonological processing at the segmental level. At the segmental level, vowels and consonants (for example) are of short durations often in the range of milliseconds. Sounds are constructed of linear sequences of segments. Wolff suggested that other domain-general problems related to temporal processing may be causally related to language processing deficits in dyslexia.

Wolff (2002) carried out a series of studies to review timing precision and rhythm in developmental dyslexia, comparing children with dyslexia and typical readers. Both groups were assessed on a series of tasks including the timing and serial ordering of rhythmic motor patterns, and the timing and serial ordering of repetitive motor speech. The results indicated that the group with dyslexia was significantly weaker in the anticipation of time and variability of anticipations for isochronic arrangements. The group with dyslexia showed significantly greater problems in their efforts to accurately reproduce the absolute and the comparative timing of manual motor rhythms. The group with dyslexia showed increased problems in reproducing the prescribed speech rhythm and sequential order of syllables. The results point to dyslexia-related temporal processing problems on one hand and also to phonological processing deficits in children. This thus indicate a relationship between phonological processing deficit and temporal processing problems.

In Khan et al. (2014), time estimation in dyslexia was investigated using verbal estimation and time reproduction tasks. The performance of paired short temporal interval tone durations processing was compared in children with and without dyslexia. The results indicate increased generated errors in time estimation in dyslexia. The group with dyslexia showed greater proneness to errors. Temporal duration judgments were more accurate in the temporal verbal estimation task compared with the temporal reproduction task. This indicates that the processes involved in managing the presented stimuli may be modality specific. In both groups, the prospective paradigm duration estimations were superior than the retrospective paradigm. Khan et al. argued that processes involved in measures such as time duration judgements, and speech, implicate the role of the cerebellum (see Section 1.3 for a discussion of the cerebellar deficit theory; Nicolson, Fawcett & Dean, 2001).

Gooch, Snowling, and Hulme (2011) explored measures including time perception and phonological skills in children with dyslexia and/or ADHD symptoms. The participants consisted of a comorbid dyslexia and ADHD group, an ADHD symptoms group, and a dyslexia-only group. All groups were assessed on their non-verbal skills, phonological skills, executive function abilities, and time perception (duration judgement and time reproduction). Details of the time reproduction task have not been reported here due to the lack of relevance to the current work. Dyslexia-related deficits were reported on interval duration discrimination in addition to others. The group with dyslexia and ADHD showed problems on time perception and executive function measures. The groups with dyslexia and ADHD showed a combination of the problems linked to the group with dyslexia only and the group with ADHD only. Gooch, et al. concluded that dyslexia and ADHD are linked with different patterns of cognitive problems (including temporal processing performance) that exist in combination in children with dyslexia and ADHD.

Chiappe et al. (2002) explored why the timing deficit hypothesis (Tallal, 1980; see Section 1.4) does not account for reading disability in adults. According to this hypothesis, motor control processes for speech, non-speech verbal, and limb movement share primary neural substrates (e.g., Binkofski & Buccino, 2004). The participants were comprised of adults with and without reading problems and children with normal reading levels. The participants performed a battery of assessments including timing tasks. Only details of the tasks that are relevant to the current study are considered here. In the temporal order judgment task, participants indicated the syllables they heard by pressing one of two keys. The result indicated that adults with reading problems showed overall inferior performance on almost all timing tasks. Adults with reading deficits outperformed children (who were matched for reading levels) on the timing tasks. The timing task performance shared little variance with phonological awareness. The findings contradict the timing deficit hypothesis and point to the contribution of naming problems in reading deficits.

In Nicolson, Fawcett and Dean (1995), time estimation deficits in developmental dyslexia were explored to test cerebellar dysfunction in dyslexia (Tallal, 1980; see Section 1.2.1). The participants were comprised of age-matched groups of children with and without dyslexia. In the time estimation task, the participants indicated whether the comparison stimulus was shorter or longer than the standard stimulus. The results indicated time estimation deficits in dyslexia.

Nicolson et al. argued that dyslexia-related problems in time estimation are a strong indication of a separate dyslexia-related deficiency from reading.

5.6 Study 1 Rationale

As identified in Section 5.5, there is a small body of dyslexia-related research on time perception. The existing time perception literature has been focused on the milliseconds range and has been studied mainly in children (e.g., Khan et al., 2014; Gooch, Snowling, & Hulme, 2011; Nicolson, Fawcett & Dean, 1995; Wolff, 2002) and very little has been focused on adults (e.g., Chiappe et al., 2002). These studies have employed differing temporal judgment tasks to investigate time perception. For example, Wolff (2002) employed a time reproduction task. Khan et al. (2014), used - verbal estimation and time reproduction tasks to assess tone duration judgements, while Nicolson, Fawcett and Dean (1995) employed a time comparison task to compare the duration of the presented stimulus to a standard stimulus. Chiappe et al. (2002) used a temporal order judgment task. The tasks employed in these studies are diverse and so it is difficult to establish consistency in the interpretation of the general findings taken as a whole. Whilst each of the tasks point to time perception problems in dyslexia; Droit-Volet, Wearden, and Zélanti (2015) have pointed out that differing cognitive processes are involved in the processing of temporal judgments contingent on task-type. Thus, this suggests the importance of studying time perception by assessing participants with a wide range of tasks – an approach employed in the current work.

Furthermore, time perception problems have consistently been indicated in dyslexia - although in chiefly, children and a few on adults. Given that the effects of dyslexia are commonly recognized as persisting into adulthood (e.g., Bacon, Parmentier, & Barr, 2013; Eloranta, Närhi, Eklund, Ahonen, & Aro, 2019; Hachmann, Bogaerts, Szmalec, Woumans, Duyck, & Job, 2014; Smith-Spark, Zięcik & Sterling, 2016 a,b), and the importance of time perception in relation to everyday life (e.g., Buhusi & Meck, 2005; Shi, Church & Meck, 2013), the extent of investigations in adults with dyslexia is warranted in its own right. Furthermore, in the 15 small body of time perception studies in dyslexia, the methodologies for participant inclusion have tended to be unsystematically designed with no indication of an employed method for their inclusion criteria. The objective of this study was to extend the existing literature by employing a broader range of timing tasks than typically used previously (which have often focused on just one task). To reach this objective, three different kinds of time perception tasks were employed to assess the time perception abilities of adults with and without dyslexia. Accordingly, data were obtained from temporal generalization, bisection and verbal estimation tasks. The performance of adults with dyslexia was predicted to be significantly weaker than those without dyslexia across all the three tasks.

5.7 Method

5.7.1 Participants

Overall, 54 participants aged between 18 to 40 years old were tested. They consisted of 28 adults with dyslexia (mean age = 23.30 years, *SD* = 3.01; 23 females, seven males) and 30 adults without dyslexia (mean age = 25.37 years, *SD* = 4.98; 23 females, four males). The number of adults with dyslexia across all tasks were equivalent. However, the number of adults without dyslexia varied slightly between tasks, resulting in these between-task discrepancies (Temporal generalization task *N* = 26; Bisection Task *N* = 30; Verbal Estimation task *N* = 25). The participants were recruited through university-based systems, and third-party dyslexia-support organization poster advertisements. The participants with dyslexia showed an educational psychologist's report confirming their diagnosis. The participant screening measures were undertaken (see Section 2.1.3.4).

5.7.2 Materials

The computer-tasks were programmed in Superlab 4.5. A 17" computer monitor was connected to an IBM-compatible personal computer to present the tone stimuli. In-built computer speakers were used deliver all tone duration stimuli. A qwerty keyboard was connected to the IBM computer and was utilized to input responses.

5.7.3 Study 1 – General temporal Generation Task

5.7.3.1 Design

A 2x7 mixed measures ANOVA design was used to analyse the data from the Temporal Generalization, Verbal Estimation, and Bisection tasks. In each case, the between-subjects factor was participant group (levels: group with dyslexia and group without dyslexia). The within-subjects factor was tone duration with seven levels (see the individual task procedure sections for IV's and DV's with levels of treatment for each specific task). Two-way repeated measures tests were used to analyse the data in the Temporal Generalization, Verbal Estimation, and Bisection tasks.

5.7.4 Study 1: Task design and procedures

5.7.4.1 The temporal generalization task

The between-subject factor was participant group. The within-subjects factor was tone duration with seven levels of treatment comprising (800ms, 933ms, 1067ms, 1200ms, 1333ms, 1467ms, and 1600ms). The dependent variable was the accuracy of the tone duration judgement expressed as a mean proportion of YES responses made by participants to each tone duration. A two-way repeated measures test was used to analyse the data in the Temporal Generalization task. In the temporal generalization task, the participants were initially presented five times with reference tone duration of 1200ms. The participants commenced a training phase in which they had to judge whether two tone durations (presented one at a time) were the same as the standard reference tone duration (by pressing 'y' for yes) or not the same (by pressing 'n' for no). The same temporal duration stimuli employed in Droit-Volet, Wearden and Zelanti (2015) were employed in this task. The tone duration stimuli comprised seven stimulus durations and were 800ms, 933ms, 1067ms, 1200ms, 1330ms, 1467ms, and 1600ms. Similar to Droit-Volet et al's (2015), there were six training trials: two trials for the standard reference tone duration and two trials for the other comparison tone durations which were included in the practice trials only (300ms and 1900ms). These two-tone durations were chosen for the practice trial owing to their dissimilarity to the seven experimental stimulus durations to eliminate familiarity bias. The inter-trial interval was fixed at 2000ms. In the practice phase, a "correct" or "incorrect" feedback display was given when the response was correct and incorrect, respectively. Immediately after the practice phase, the participants were given the testing phase. The experimental conditions were the same as those used in training, except that no feedback was given on responses. In the testing phase, the participants were given nine blocks (giving a total of 81 trials). For each block, there were three presentations of the comparison tone duration identical to the reference duration (1200ms) and one trial for each of the 6 other comparison durations for each block. The trial presentation order was pseudo-randomized across each trial block. The standard reference tone duration was presented again five times at the end of each block.

5.7.4.2 Results

5.7.4.2.1 Two-way repeated measures ANOVA between-group performance

A two-way repeated measures ANOVA was performed on the proportion of "Yes" responses made by the participants. Table.5.1 shows the means and SDs of mean proportion of ''YES'' responses made in each of the seven standard durations used in the task. A two-way repeated measures ANOVA revealed that there was no significant main effect of participant group $F(1, 52) = <1$, $p = .80$, $\eta_p^2 = .001$. Mauchly's test of sphericity showed a violation of group mean variance. Therefore, Greenhouse-Geisser corrected degrees of freedom values were reported.

There was a significant main effect of tone duration, $F(2.57, 133.45) = 35.20$, $p < .001$, $\eta_p^2 = .40$, indicating that different tone durations yielded significantly different proportions of YES responses (see Figure 5.4). Bonferroni-corrected post hoc tests showed significant differences (*p* < .05) in tone duration estimates for all pairwise comparisons, except for the 2*5, 2*6, 2*7, and 3*6 tone duration comparisons which were non-significant.

The interaction between tone duration and participant group was found to be non-significant, *F* (2.57, 133.45) = .53, *p* = .63, η_p^2 = .01.

Figure.5.4 shows the main effect of tone durations.

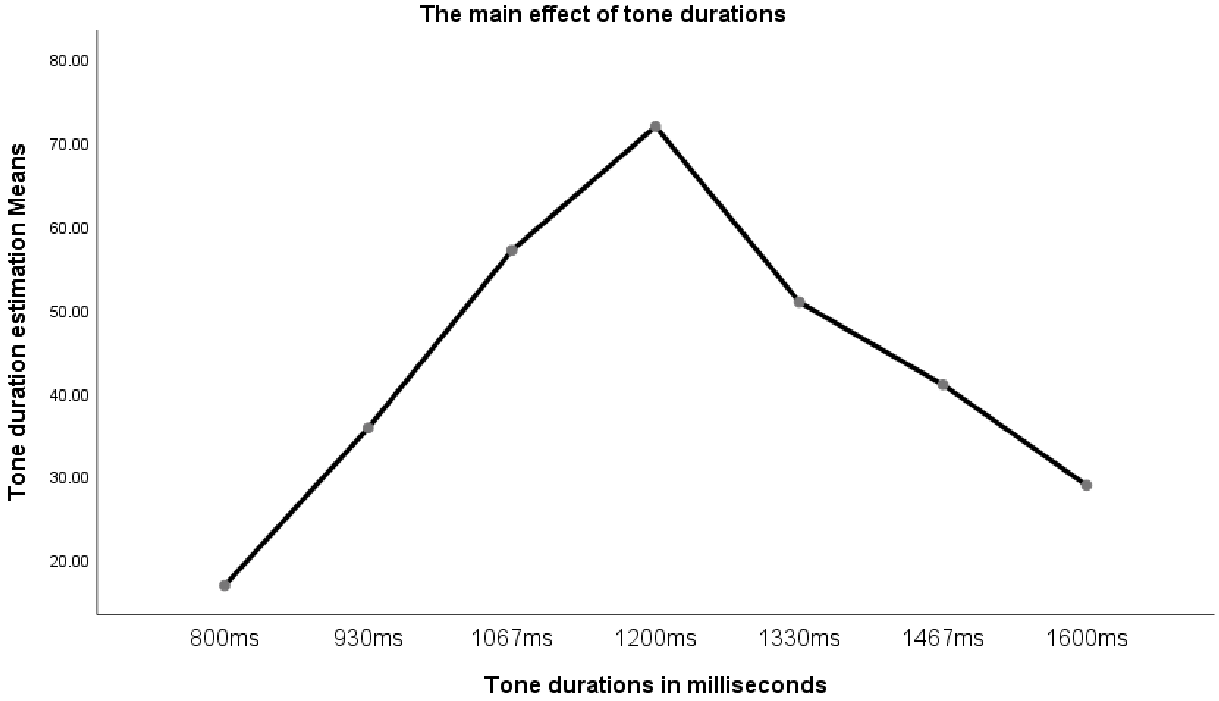

Figure 5.4 The main effect of the YES responses for each of the stimulus tone durations ranging from short to long intervals in milliseconds.

Table 5.1 shows the means and SDs proportion of "YES" responses made.

Table 5.1. Descriptive statistics of mean and SDs proportion of ''YES'' responses made by participants for each of the 7 standard durations

	Group with dyslexia		Group without dyslexia	
	(N=28)		(N=26)	
Duration Range	Means	SD	Means	SD

800-ms	16.67	18.27	17.09	22.27
933-ms	36.51	29.14	35.04	30.58
1067-ms	60.71	22.73	53.42	30.31
1200-ms	69.18	25.24	53.85	24.65
1330-ms	50.00	19.71	74.64	25.71
1467-ms	40.87	28.86	41.03	29.61
1600-ms	34.14	27.94	25.64	25.68

5.7.4.3 Discussion

The results of the temporal generalization task indicated a lack of group effect - this suggests that adults with dyslexia performed comparably to those without dyslexia on the temporal generalization task. The task paradigm itself worked successfully, as indicated by the significant main effect of tone duration. It is commonly acknowledged that in tone discrimination tasks, when a specific tone duration differs by a greater frequency of its occurrence within a sequence of other tones; temporal discrimination is comparatively weaker for the tones with the lesser frequency of occurrence, Hirsh, Monahan, Grant, and Singh (1990). In this task (see Section 5.7.4.2.1; Figure 5.4), the abovementioned pattern was observed such that with a greater incidence of the standard tone duration(1200ms) occurred at ratio of 3:1. On this basis, it is deemed that the functionality of the task itself is reliable in the face of the lack of effect of participant group on tone duration.

Additionally, a lack of interaction was found between tone duration and participant group. The result from the temporal generalization task is inconsistent with the hypothesis which stated that between-group performance of the temporal generalization task would be a significant predictor of time perception ability in the milliseconds range. The current work findings are inconsistent with other previous studies (e.g., Lovegrove,1993; Tallal, Miller & Fitch,1993). In these studies, dyslexia-related deficits were revealed in the discrimination of short duration tone judgements in temporal generalization tasks – albeit in children. Based on the consensus of the abovementioned findings, the general expectation in the current study was to observe dyslexia-related temporal processing difficulties in adults.

In context with the Chiappe et al. (2002) study, it was reported that even though adults with dyslexia performed inferior to neurotypical adults in all timing tasks; in comparison with children with dyslexia, adults with dyslexia were superior on their performance on the timing tasks. Chiappe et al. argued that, unlike children with dyslexia, adults with dyslexia may employ compensatory abilities to cope with duration discrimination tasks in the milliseconds range. In the current work, it may be that the performance of adults with dyslexia were indicative of their ability to effectively manage processes involved in the temporal generalization task timing threshold. This assertion may be such that the attentional resources required by the task may simply not have been demanding enough to affect temporal processing in adults with dyslexia or that there are no differences in time perception between the two groups. Alternatively, like Chiappe et al., it may be that adults with dyslexia may have utilized counteracting abilities to negate any susceptibility to their temporal processing when they performed the temporal generalization task. A broader consideration of this is presented in Section 5.15.

5.8 The Bisection Task

The between-subjects factor was participant group. For the Bisection task, the within-subjects factor was tone duration with seven levels of treatment comprising (800ms, 933ms, 1067ms, 1200ms, 1333ms, 1467ms, and 1600ms). These time durations stimuli from Droit-Volet, et al, (2015) were employed. The dependent variable was mean proportion of “Long” responses expressed as a percentage. A two-way repeated measures test was used to analyse the data in the Bisection task. The temporal task order was pseudo-randomized per trial such that the order of presentations was the same for all participants. The investigator instructed the participants not to count and explained that counting time may bias the data (for a review of methods used to prevent chronometric counting, see Rattat

& Droit-Volet, 2012). The participants were required to store both tone durations in their memory and served as two anchor points. The participants were then trained to respond via a QWERTY keyboard by pressing either “s” (=short) or “l” (=long) on a series of 10 training trials presented in random order (five presentations for “s” and five for “l”), with an inter-trial interval set at 2000ms. Each response was followed either by the “correct” or “incorrect” feedback as a text on a computer screen. The practice phase was immediately followed by a testing phase using the same experimental conditions, except that the participants were presented with the seven comparison durations described above. In addition to the testing phase, no feedback was given. Each participant completed 99 trials. That is, each block contained 33 trials each for the reference duration tones and one trial each for the five intermediate duration tones. The trial presentation order within each block was pseudo-randomized. After three blocks, the participants were again presented five times with each standard reference duration tone. The ability of participants to categorize each tone duration in terms of similarity to the short or long standards was analysed as a psychophysical function with the proportion of long responses (judgments that a presented duration was more similar to the long than short standard) plotted against stimulus duration.

5.8.1 Results

5.8.1.1 Two-way repeated measures ANOVA on task performance

The data from the psychological functions in the bisection gradients (see Figure. 5.5) suggests that in both groups, the proportion of ‘’long’’ responses increased with the stimulus duration. Table 5.2 shows the means and SDs of mean proportion of ‘’long’’ responses given in each of the seven standard durations employed in the task. The ANOVA yielded a non-significant main effect of group, *F* (1, 54) = .08, *p* = .77, η_p^2 = .002. The test of sphericity showed a violation of group mean variance. Therefore, Greenhouse-Geisser corrected degrees of freedom values are reported.

Tone duration as the within-subject factor produced a significant main effect, of tones durations, $F\ (2.73, 147.61) = 206.88$, $p < .001$, $\eta_p^2 = .79$. Bonferroni-corrected post hoc tests indicated significant ($p < .05$) variances in tone duration estimates for all pairwise comparisons, except for these tone duration comparisons (1*7, 2*5, 2*6, 2*7, 3*6) which did not reach statistical significance ($p > .05$). This indicated that the proportion correct across the seven tone durations stimuli significantly differed. This effect is evident as shown in Figure 5.6.

The repeated measures ANOVA indicated that the interaction effect between participant group as a between-subjects factor and tone duration as a within-subjects factor was non-significant, $F\ (2.73, 147.61) = .2.52$, $p = .84$, $\eta_p^2 = .005$. The test of sphericity showed a violation of group mean variance. Thus, Greenhouse-Geisser corrected degrees of freedom values are reported

Figure 5.5 shows the proportion of “long” responses plotted against seven stimulus durations.

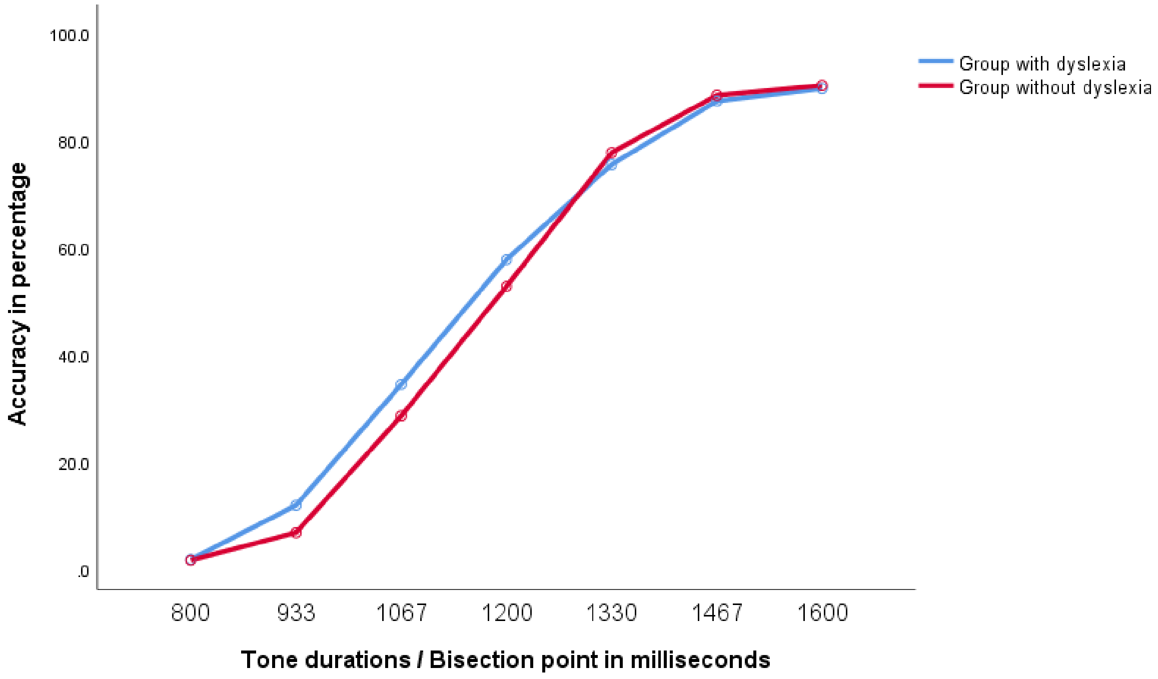

Figure 5.5 The proportion of ‘’long’’ responses plotted against stimulus durations presented separately for the 800/1600 duration range (ms). Altogether there were 7 tones ranging from short (800-ms) to long (1600-ms) intervals.

Figure 5.6 shows the main effect of tone duration of the seven duration tones used.

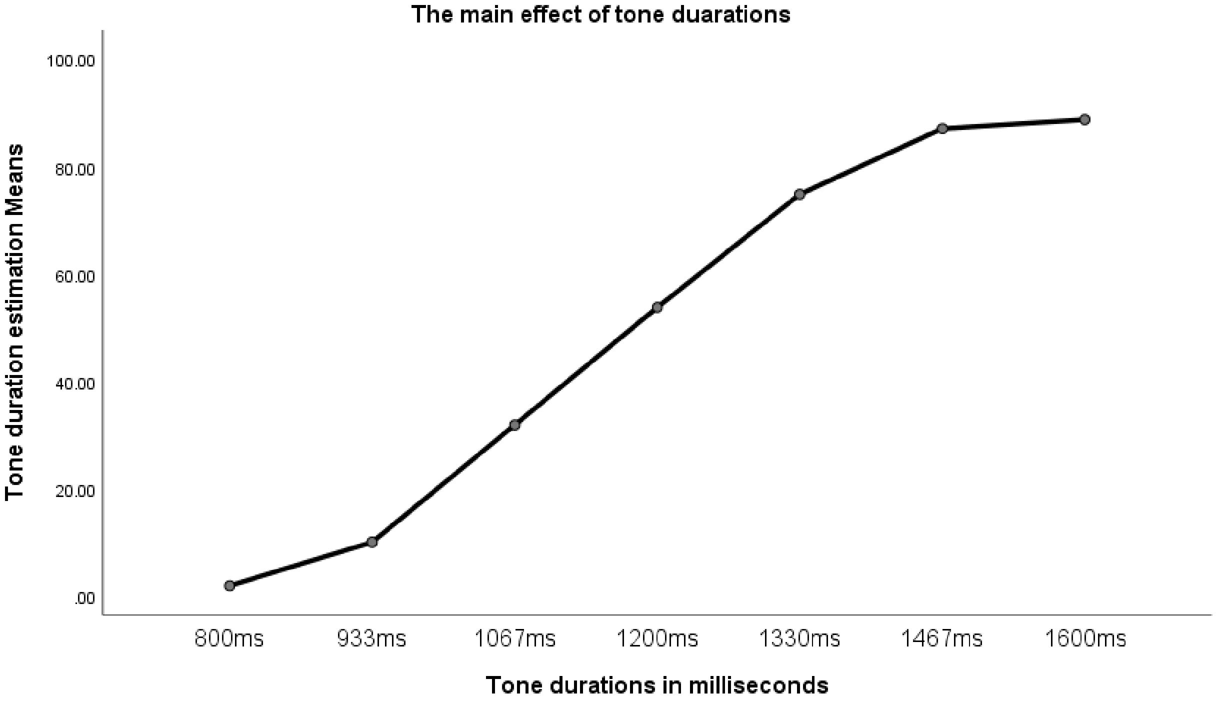

Figure 5.6 The main effect of tone duration expressed as tendency of "long responses" given when an estimation was made between a comparison stimulus tone duration and the standard stimulus tone duration 1200ms (the bisection point).

Table 5.2 shows the means and SDs of the mean proportion of "long" responses indicated for the seven tone durations respectively.

Table 5.2. Descriptive statistics of mean proportion of ''long'' responses given in each of the 7 standard durations

	Group with dyslexia (N=28)		Group without dyslexia (N=26)	
Duration Range	Means	SD	Means	SD
800-ms	1.73	3.03	1.71	3.01
933-ms	11.85	13.67	7.27	11.31
1067-ms	34.44	29.81	30.34	22.35
1200-ms	57.78	32.54	53.85	31.06

1330-ms	75.56	34.57	76.92	27.74
1467-ms	87.70	36.06	88.03	25.13
1600-ms	89.75	36.08	89.61	25.81

Table 5.3 shows a Bonferroni pairwise comparison for the tone duration stimuli in the bisection task.

Table 5.3 Bonferroni pairwise comparisons for bisection task tone duration stimuli in milliseconds

	800	933	1067	1200	1333	1467	1600
800ms	1	<.001	<.001	<.001	<.001	<.001	.439
933ms		1	<.001	<.001	.094	1.00	1.00
1067ms			1	<.001	1.00	0.71	<.001
1200ms				1	<.001	<.001	<.001
1333ms					1	.03	<.001
1467ms						1	<.001
1600ms							1

5.8.1.2 Discussion

The results from the bisection task showed a significant main effect of tone duration. In light of this, it can be seen that in the psychometric curve plotting of the duration of the stimuli (comparison and standard tone duration stimuli) against the tendency of responding “long” (see Figure 5.6), there is a monotonic increase with duration. Specifically, the participants practically almost never responded “long” to the shortest duration (“800ms); and almost always responded “long” to the longest duration (“1600ms”). Moreover, at the intermediate duration (the bisection point -

1200ms), the curve plotting indicates that the participants performance crosses 0.5 on the y-axis. This bisection duration is commonly acknowledged as the point of indifference – The participants demonstrated an equal propensity of responding “long” or “short”. This characteristic behavioural pattern is consistent with previous studies (e.g., Siegel & Church, 1984; Wearden, 1991). Accordingly, in the face of the lack of effect obtained for participant group, the functionality of the task is dependable. Additionally, a non-significant interaction effect was found in participants ability to generate accurate mean proportion of ‘’long’’ responses for the seven standard tone durations. In the Nicolson et al. (1995) study, the observed temporal processing deficits were found in adults with dyslexia with a mean age of 18 years. In comparison, in the current study, the mean age of adults with dyslexia was 23.30 years. The non-significant difference obtained in the current work may well be explained by a slightly older group of adults with dyslexia who may have had more efficient coping ability to deal with the demands of the bisection task. Another explanation could be that, giving that the bisection task is considered as the least taxing temporal judgement task employed in this study, perhaps the demands of the task may not have been taxing enough to interrupt the attentional and memory processes in adults with dyslexia. This assertion is supported by the line of reasoning that there is a continuous development of executive functions into the early 20s in life (e.g., Taylor, Barker, Heavey, & McHale, 2015).

5.9 The verbal estimation task design and procedure

For the verbal estimation task, the within-subjects factor was tone durations (levels: 325ms, 475ms, 625ms, 775ms, 925ms, 1075ms, and 1225ms). These timings were the same as those used in Wearden et al. (2009). The dependent variable was verbal estimation judgement of tone duration. A two-way repeated measures test was used to analyse the data in the Verbal estimation task. A short practice session preceded the procedure in the test session in order to provide participants with some experience of the experimental stimuli. In the practice session, the participants were presented five times each with two tone duration samples. The first tone duration which was represented as “short” was 50ms in duration. The second tone duration which was represented as long was 1500ms in duration. The participants were informed that 50ms and 1500ms represented the shortest and longest responses that would be presented. After this brief pre-exposure, the testing session described above commenced. Following this, durations were randomly presented for seven blocks of 14 trials each. The participants were instructed that they would be presented with a tone and that their task was to estimate how long the tone lasted in milliseconds (ms) being explicitly told that 1000ms = 1 second. At the start of each trial a 500 Hz (Hz) tone was presented. Participants were informed that all stimuli durations ranged from 50ms and 1500ms. After the presentation of the tone whose duration ranged between 1000ms to 1500ms, a 3s delay followed. The participants were invited to verbally estimate the tone duration in milliseconds and were instructed to press the spacebar to commence the next trial. The stimuli durations to be estimated were 500 Hz tones delivered through two personal computer speakers. The tone stimuli were presented one at a time. In each block of trials, each of the above duration values was presented once after three seconds of silence. The seven duration stimuli were randomly presented to avoid repetition of target durations across blocks. Within each block the order of presentation was pseudo-randomized. The participants completed seven blocks of 14 trials, giving a total of 98 trials. The task took approximately 10 minutes to complete. No feedback was given on performance. After each stimulus had been presented, the participant called out their verbal estimation in milliseconds, and this value was typed into the computer by the experimenter. The next trial followed when the participant indicated that he or she was ready.

5.9.1 Results

5.9.1.1 Two-way repeated measures ANOVA on task performance

There was a non-significant main effect of participant group $F\,(1, 51) = .051$, $p = .48$, $\eta_p^2 = .01$. Tone duration as the within-subject factor (see Figure 5.8) produced a significant main effect and revealed a significant effect of tones on verbal estimates, F (3.69, 188.22) = 2.53, p = .05, η_p^2 = .05. The test of sphericity showed a violation of group mean variance. Therefore, Greenhouse-Geisser corrected degrees of freedom values were reported. Upon inspection of the data, this effect of tone duration can be observed in the general increase in gradients of given verbal estimates from the shortest tone duration to the fourth longest (see Figure 5.7). Post hoc tests (Bonferroni corrected) indicated significant ($p < .05$) variances in tone duration estimates for all pairwise comparisons, except for the tone duration comparisons (1*7, 2*5, 2*7, 3*5, 3*6) which did not reach statistical significance ($p > .05$).

There was non-significant interaction effect between tone duration and participant group, F (3.69, 188.22) = 2.12, p = .09. η_p^2 = .04.

Table 5.4 shows the means and SDs of mean verbal estimates given against each of the seven standard durations employed in the task.

Table 5.4 Descriptive statistics for Verbal estimation task for tones

	Group with dyslexia (N=28)		Group without dyslexia (N=25)	
Duration Range	Means	SD	Means	SD
325-ms	189.16	89.04	189.44	85.01
475-ms	224.71	128.82	240.98	121.11
625-ms	235.38	162.54	236.40	130.50
775-ms	263.18	162.73	236.40	130.50
925-ms	280.55	137.05	213.62	135.20
1075-ms	274.63	180.58	214.00	153.36
1174-ms	253.14	154.85	206.36	159.52

Figure 5.7 shows the resulting gradient with data from the group with dyslexia and those without dyslexia in their given mean verbal estimates plotted against the seven stimuli comparison tones.

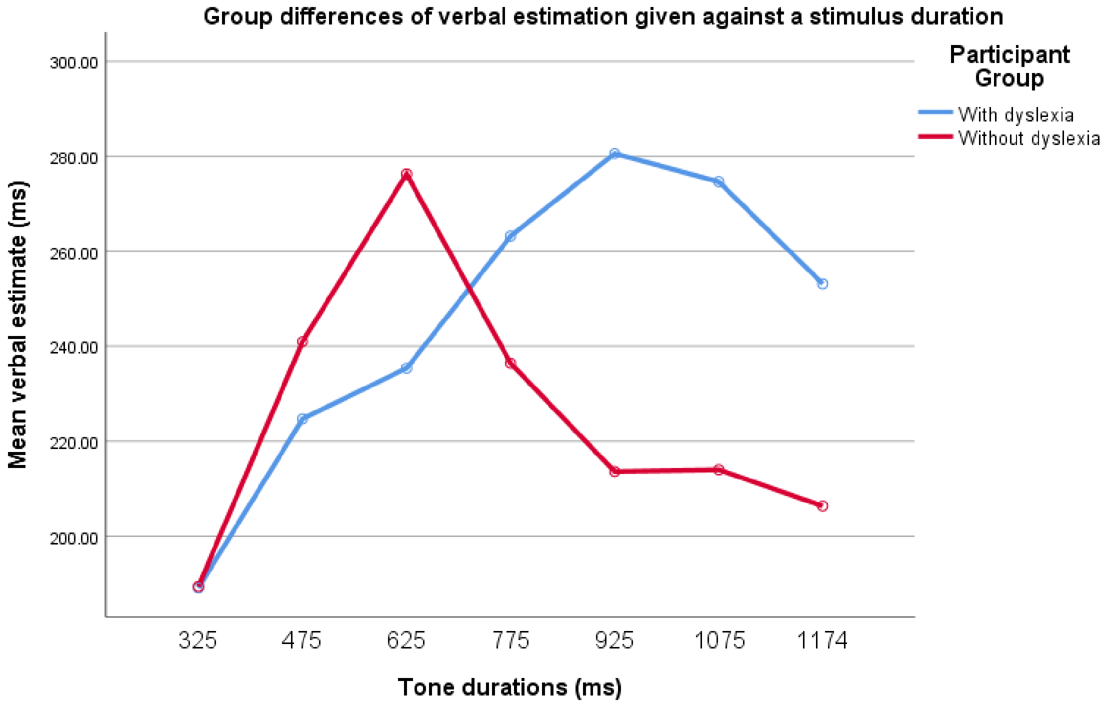

Figure 5.7 Mean verbal estimates (ms) plotted against stimulus duration comprising of 7 tones ranging from short (325-ms) to long (1174-ms).

Figure 5.8 shows the mean verbal estimates plotted against seven stimulus durations varying between 325ms and 1174ms.

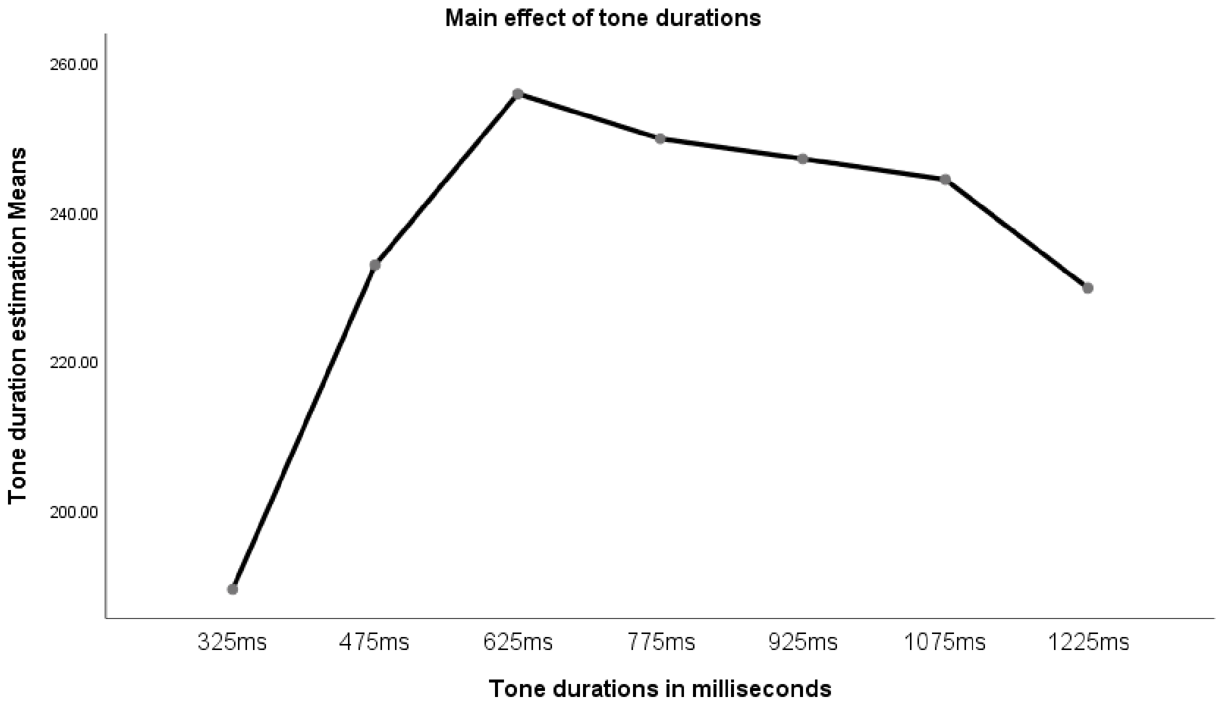

Figure 5.8 The main effect of tone duration expressed as mean accuracy of responses given as verbal estimates

5.9.1.2 Discussion

Overall, the lack of effect found for participant group indicates that the difference in performance on the verbal estimation task between adults with dyslexia and those without did not reach statistical significance. However, tone duration as the within-subjects-factor revealed a significant main effect of given verbal estimates. The effect of tone duration of given verbal estimates showed an augmented linear increase in gradients from the shortest tone duration to the third longest. Verbal estimates from the fourth tone duration to the seventh tone duration showed a consistent gradual decrement in accuracy of given verbal estimates performance. The interaction effect between tone duration and participant group did not reach statistical significance. The results attained from the verbal estimation task are inconsistent with the hypothesis which stated that the effect of dyslexia in adults would significantly negatively hinder their performance on the verbal estimation task in comparison to those without dyslexia. The findings obtained are consistent with Khan et al. (2014) who reported increased accuracy of performance in children with and without dyslexia on the verbal estimation task. The Khan et al’s findings suggest that whilst there may be a potential vulnerability of temporal reproduction task performance in children, this proneness is absent in temporal verbal estimation task performance. As indicated, the results obtained in the current work suggest the absence of temporal verbal estimation deficits in adults with dyslexia. Khan et al. have previously suggested the involvement of modality specific processes in the management of tone duration stimuli in different temporal judgement tasks. Accordingly, Khan et al. have indicated that temporal duration judgment estimations in verbal estimation tasks have greater degree of accuracy compared with the temporal reproduction tasks.

Despite this trend, Ogden, Wearden and Montgomery (2014) have indicated that in verbal estimation tasks, executive function abilities related to updating resources (see Section 5.4.3) are employed to monitor a to-be-timed stimulus. Giving updating working memory problems in dyslexia (e.g., Smith-Spark, Henry, et. al., 2016a); it would be reasonable to expect this limitation to interfere with performance on the verbal estimation task. An alternative proposal put forward by Wearden, Todd and Jones (2006) indicated that reference to long-term memory representations of durations can be carried out when verbal estimations are required. Accordingly, Wearden et al. suggested that this places an increased demand on attention and memory processes. Nevertheless, in the current study, adults with dyslexia did not demonstrate any evidence of processing-related difficulties, and thus, appear to be fall in line with Khan et al. in indicating the absence of temporal verbal estimation difficulties in dyslexia.

5.10 Study 2: Introduction – Longer durations - Prospective and Retrospective time perception

The subjective perception of time can be stimulated through the retrospective and prospective paradigms implicated in the perception of time (see Section 5.2). In the retrospective paradigm, one is not aware of or has access to a time keeping apparatus to refer to in a given task to complete. In the retrospective paradigm, experimentally, a participant is given an untimed task. At the end of the task, the participants are asked to estimate the duration of two points of the task duration. The estimated duration of the passage of time is retrospectively constructed from memory. In retrospective paradigms, retroactive duration judgements are informed by the extent of complexity a given stimulus necessitates processing. An increase in the expanse of stimuli in more difficult tasks results in the perception of time to be judged as briefer. Conversely, an increase in cognitive load leads to an increase in judgement of the passage of time (Block et al., 2010). In the prospective paradigm, however, one is typically aware of the presence of a time keeping device that can be used to track the trajectory of time. Experimental prospective timing tasks typically necessitate frequent surveillance. This is because, participants are prewarned of the need to pay attention to the passage of time in order to achieve task accuracy (Mangels & Ivry, 2001). Typically, in a prospective paradigm experimental task, participants are engaged in a concurrent task in tandem with the prospective time estimation task. In such instances, the passage of time is estimated as being briefer in comparison to when participants are not occupied with a concurrent task. A participant’s conscious awareness (prospective paradigm) or unawareness (retrospective paradigm) of the track of time impacts on how time is perceived. In prospective paradigms, time estimations tend to be overestimated but closer to the literal time compared with retrospective paradigms (Block, 1992). In a meta-analysis by Block and Zakay (1997), prospective time estimations were generally perceived to be superior by 16% in comparison with retrospective time estimations. Specifically, prospective time judgements tended to be estimated as longer and were less variable but with greater accuracy of estimations. In comparison, retrospective judgments tended to be underestimated and were more variable with lesser degree of accuracy. The explanation for the observed disparity in performance in the two paradigms have been argued to involve different cognitive processes Block and Zakay (1997). Characteristically, in the prospective paradigm, one’s awareness of the need to estimate a time portion means that temporal information is purposely encoded as an important fragment of encountering the length of a time epoch – and so requires attentional resources. Differently, in the retrospective paradigm, Block and Zakay (1997) have indicated that the likelihood of encoding temporal information may occur by chance – since typically, in such tasks, one is not forewarned of the need to estimate a forthcoming time portion. Thus, an unexpected prompt for an estimation of a specific segment of time to be given is primarily reliant on memory processes. Additionally, the complexity of task-related information processing is indicated to influence the perception of time judgements such that they are typically judged as being longer (Block, 1992). Hitherto, time perception in dyslexia has been investigated in the milliseconds range and these studies have not assessed time-perception comprehensively. This is despite that in adulthood, most duration judgements that are negotiated in daily life are more likely to be in minutes and hours range. As previously mentioned, Droit-Volet, Wearden, and Zélanti (2015) have indicated that the cognitive processes implicated in the performance of temporal judgments - differ according to the type of task utilized. Tobin, Bisson, and Grondin (2010) have indicated that short duration judgements have been employed in prospective and retrospective studies for practical reasons - with some interval durations lasting 42 seconds (e.g., Hicks et al., 1976). Methodological challenges include inconsistencies in the use of non-ecological tasks (e.g., number searching Bakan, 1955, sorting cards (Hicks, Miller, & Kinsbourne, 1976), and light bulb watching (Zakay, 1992), and only a few in ecological tasks such as watching movies, playing games on the computer, browsing the Internet for several hours (Tobin, et al., 2010). Accordingly, with such methodological discrepancies, caveats are presented when extrapolating investigative findings. The control of the quantity of information processed by the participants have also been raised as another methodological challenge. For example, in Hicks et al. (1976), whilst in one condition, the participants were instructed to only place the cards in piles – and so had no information to process; In another condition, other participants were instructed to sort the cards by colour- and so they processed one level of information. In a third condition, the participants were asked to sort the cards by colour and suit – therefore two levels of information were processed. Other methodological challenges raised by Tobin et al. include that longer interval durations (e.g., several hours) may well cause boredom which may interfere with attentional processes. For that reason, in Tobin et al. (2010), it has been proposed that a systemic way to study longer durations should consider the use of ecological tasks that are interesting in order to motivate endurance in task engagement for lengthy periods of time. However, Tobin, et al. have indicated that the use of the abovementioned tasks come with a trade-off – being that it may be challenging to monitor the exact attentional demands that are implicated. The rationale for assessing retrospective and prospective time perception paradigms are discussed in the next section.

5.11 Study 2 Rationale - short duration minutes interval measures

In dyslexia, there is a lack of research focus on long duration time perception measures in the minutes range. Time perception duration judgements in the long duration range can be implemented under retrospective and prospective paradigms. Therefore, the objective was to assess retrospective time perception and prospective time perception in the minutes range in adults with and without dyslexia. Accordingly, data were generated from a long duration prospective time perception measure and a long duration retrospective time perception measure in the minutes range. In comparison to adults without dyslexia, adults without dyslexia were expected to perform significantly weaker in the long duration retrospective and long duration prospective time perception tasks respectively. The abovementioned predictions were established on the basis that memory and attentional processes have been differently delineated in retrospective and prospective time estimation processes (Block & Zakay, 1997). In prospective duration judgements, a greater demand of attentional resources is required in order to monitor the flow of time. Furthermore, the employment of executive functions to periodically break out of the ongoing task from time to time in order to monitor the passage of time is also required.

Attentional resource allocation and executive function deficits have been shown in adults with dyslexia (e.g., Brosnan et al., 2002; Smith-Spark, Henry et al., 2016) and is thus expected to hinder on their prospective time awareness. Problems in prospective time awareness over forty minutes intervals have previously been reported in adults with dyslexia (e.g., Smith-Spark, Ziecik et al., 2016 b). Differently, retrospective memory duration judgement is deemed to rely mainly on memory representations of an event associated with temporal units that must be retrieved from long term memory to assist with a temporal judgement recall. Dyslexia-related problems have been reported in retrospective memory retrievals from long-term memory (e.g., forgetting names of people, books and films; Smith-Spark & Moore, 2009); and self-reports of forgetting previous actions, and remembering details of events (Smith-Spark, 2000). The latter point is related to sequential order of the occurrence of events which may be relied upon to assist with the retrospective estimation of a time portion. Increased retrospective or episodic memory difficulties in dyslexia have been reported in the short-term (e.g., Menghini et al., 2010) and over the long-term (e.g., McNamara & Wong, 2003; Smith-Spark, 2000; Smith-Spark et al., 2016a). In the retrospective timing task employed in the current study, adults with dyslexia were anticipated to perform significantly weaker than adults without dyslexia. An independent-samples t-test was used to analyse between-group difference in performance. This expectation was hypothesized on the basis that, anchor points that symbolize time markers of the information are entwined with the information entailed in the intervening event up until a retrospective time estimation was required; are likely to be consulted from memory processes in order to assist with the assessment of elapsed time. It is foreseeable for dyslexia-related difficulties to show up in task performance.

The current study's strategy to investigate time perception from a broader perspective, allows for a comparative analysis of long duration processes involved in time perception to be compared with those implicated in short durations judgements. This may potentially contribute to a better understanding of time perception difficulties in dyslexia. Furthermore, investigating time perception from a broader perspective, allows for a comparative analysis of short duration processes involved in time perception to be compared with those implicated in long durations judgements as well as a prospective versus retrospective consideration. This may potentially contribute to a better understanding of time perception difficulties in dyslexia.

5.12 Retrospective and prospective time perception measures design and procedures

5.13 Retrospective time perception measure design and procedure

Retrospective time perception tasks are non-standard memory recall tasks usually devised in-house and are a measure of an individual's ability to assess the passage of time in retrospect (e.g., Csikszentmihalyi & Larson, 2014). In the long duration retrospective time perception task, participants were asked to estimate how much time had passed between two timing points of a past event in the testing session. The participants were not forewarned of any requirement regarding time awareness. The passage of time which had to be judged equated to seven minutes 30 seconds. The rationale for choosing this duration of time is that such a duration is unlikely to be guessed by participants in comparison to (e.g., five minutes). The participants carried out an ongoing filler task (reading a simple passage) in the meantime and recall the contents - prior to being asked to provide a retrospective estimate of the passage of time. The participants' estimations were compared against the true passage of time as a measure of accuracy. The stated hypothesis for retrospective time perception (see Section 5.11) was analysed using an independent-samples t-test.

5.13.1 Results

The duration of the actual elapsed time was 7 minutes 30 seconds. Each participant's over-estimations or under estimations of the elapsed time was collapsed to create an absolute deviation score. There was a non-significant difference in the scores for the group with dyslexia (M = 3.35, *SD* = 3.10) and the group without dyslexia (M = 2.23, *SD* = 2.03), *t* (48) = 1.51, *p* = .14. d = .43. Despite the lack of significance between-groups, on average, the estimations of adults with dyslexia were further from true as well as being more varied.

5.13.1.2 Discussion

The long duration retrospective time perception measure was used to assess accuracy of retrospective time estimation in the minutes range. The results showed no evidence of processing-related problems in retrospective duration judgement in adults with dyslexia. The results are inconsistent with the hypothesis in postulating that adults with dyslexia would perform significantly weaker in their retrospective estimations of elapsed time. Examination of the means showed that behaviourally, adults with dyslexia tended to overestimate their retrospective estimations of elapsed time. In comparison to adults without dyslexia, the estimations of adults with dyslexia tended to be varied and further away from true elapsed interval. To clarify, Block and Zakay (1997) have argued that in retrospective timing tasks, the propensity of encoding temporal information can transpire accidentally on the basis that, participants are not pre-warned of a requirement to give an estimation of a preceding time passage. Therefore, when a time estimation in retrospect is requested, accuracy of estimation is largely reliant on information retrieval processes from memory. Dyslexia-related difficulties have previously been indicated in Smith-Spark et al. (2017) and is related to storage, maintenance, and access of verbal information in long-term memory.

To contextualize, in the current work, access to long-term memory was required in order to retrieve the interim information (a simple reading task with recall) which in turn informs the ability to estimate its temporal span. The related temporal units are entwined with the extent of information processed in the interim and can be relied upon as time markers. Temporal units of elapsed time could then be derived from this. Although group-related performance did not reach statistical significance, indications of variation of given overestimations which were typically further away from the true elapsed time by adults with dyslexia may be attributable to problems linked to access of verbal information but also its storage and maintenance in long-term memory. On the one hand, it is tempting to raise the question of potentially weakening statistical power owing to the relatively small sample size which comprised of adults with dyslexia *N* = 25, adults without dyslexia *N* = 25). However, timing research in dyslexia have consistently found effects (e.g., Chiappe et al., 2002; Grinblat & Rosenblum, 2016) with relatively small sample sizes that are similar to the sample size employed in the current study. On that basis, it can be regarded with confidence that statistical power did not influence the lack of effect owing to the small sample size. Generally, there is a lack of dyslexia-related research focus on long duration time perception measures in the minutes range specifically looking at retrospective time estimation abilities. The current finding, indicate no evidence of dyslexia-related deficits in retrospective time estimations. Despite obtaining a non-significant finding, the results extend the current body of dyslexia-related research by supplementing the existing body of retrospective timing findings with long duration timing range in minutes. Furthermore, the current work has highlighted observed behavioural patterns of adults with dyslexia in their retrospective time ability at the seven minutes, thirty seconds span that may be of interest for future research. See section 6.0 for a broader discussion of the findings.

5.14 Prospective time perception Longer interval design and procedure

The task involved the estimation of an upcoming elapsed time of a testing session. In this task, the participants were pre-warned of a requirement to make a prospective time judgement. Whilst engaged in ongoing filler tasks, the investigator asked the participants to estimate how much time had elapsed based on one event between two timing points - that is, the total duration of the testing session which equated to 30 minutes. The investigator timed the duration of the task for later comparisons between participant estimates against true time as a measure of accuracy. The stated hypothesis for prospective time perception (see Section 5.11) was analysed using an independent-samples t-test. After performing the temporal generalization, verbal estimation, bisection, long duration retrospective and long duration prospective time perception tasks, the participants were debriefed about the nature of the research.

5.14.1 Results

Each participant's over-estimations or under estimations was collapsed to create an absolute deviation score. There was a non-significant difference in the scores for the group with dyslexia (M = 5.07, *SD* = 4.49) and the group without dyslexia (M = 5.27, *SD* = 4.43), *t* (53) = -.16, *p* = .87, d = .04.

5.14.1.2 Discussion

The long duration prospective time perception measure was used to assess accuracy of prospective time estimation in the minutes range. The results indicated no evidence of retrospective duration judgement problems in adults with dyslexia. Therefore, the hypothesis was not supported by the results. Despite the performance of the groups not differing significantly, there were observed behavioural characteristics displayed by the group with dyslexia who tended to underestimate their prospective time judgements compared with adults without dyslexia. The specified estimations by adults with dyslexia for their retrospective time estimation were widely overestimated across three standard deviations. In the following section, a summation of the findings obtained from the time perception measures are discussed from the perspectives of existing theories of time perception.

5.15 General discussion for shorter and longer time perception durations.

Table 5.5 presents a summary table indicating findings of short and long duration time perception measures

Short duration measures (ms)	**Main effects**	***p* value**	**η_p^2**
Temporal Generalization Task	Tone duration	*p*<.001	.40
	Group	*p*=.80	.001

	Interaction effect		
	Group * Tone duration	$p=.63$	.01
	Main effects		
Bisection Task	Tone duration	$p<.001$	.79
	Group	$p=.77$	.002
	Interaction effect		
	Group * Tone duration	$p=.84$	.005
	Main effects		
Verbal Estimation Task	Tone duration	$p=.05$	.05
	Group	$p=.48$	.01
	Interaction effect		
	Group * Tone duration	$p=.09$	.04
Long duration measures in minutes	**Group differences**	***p* value**	**d**
Prospective time estimation	Between group	$p=.87$	.04
Retrospective time estimation	Between group	$p=.14$	.43

Table 5.5 summarizes the results of the short and long duration time perception tasks

A variety of measures were employed in the current chapter to investigate time perception in adults with dyslexia. These measures encompassed both durations in the milliseconds range and longer duration assessments in the minutes range. Performance was also assessed through retrospective and prospective paradigms. With regards to the short duration temporal judgement tasks (namely the temporal generalization, verbal estimation and bisection tasks), the interpretations can be drawn. Across all the three tasks, indications showed that the performance of adults with dyslexia did not indicate temporal processing difficulties. With regards to the data compiled from the temporal generalization and the bisection tasks, the performance of adults with dyslexia were comparable to those without dyslexia. With reference to the verbal estimation task, the group without dyslexia performed marginally better between the first and third tone duration judgements. However, this advantage oddly diminished between the fourth and seventh tone respectively. The performance of adults with dyslexia on the other hand, showed a linear increase in accuracy and thus show no indications of dyslexia-related processing difficulties. In relation to the SET model which describes three processing points namely, the clock, memory and decision-making stages (see section 5.3), it appears as though adults with dyslexia process temporal tone durations effectually across the three processing stages. In light of the SET model, it appears that the encoding, storing and retrieving of the standard auditory temporal tone duration did not present difficulty for adults with dyslexia. Additionally, the comparative stage at which the standard duration stimulus was compared to a grouping of tone durations respectively also did not present any problems for adults with dyslexia. Moreover, the decision-making stage at which duration judgements are required – also did not indicate dyslexia-related temporal processing problems in the milliseconds range in a variety of tasks. It is possible that there are simply no processing-related differences between adults with and without dyslexia adults with dyslexia.

Alternatively, it is likely that adults with dyslexia are able to use compensatory tactics to manage temporal judgements in the milliseconds range. To elaborate, Nicolson and Fawcett (1994) have previously put forward that, individuals with dyslexia deploy compensatory strategies to overcome moderate difficulty. Chiappe et al. (2002) findings indicated that adults with dyslexia may employ compensatory duration discrimination abilities in the milliseconds range that may be superior to those of children with dyslexia, and comparable to neurotypically functioning adults. These tactics have been deployed in non-linguistic task processing in visual memory processing, declarative memory (e.g., Ullman & Pullman, 2015), as well as conscious effort (Nicolson & Fawcett, 1994). In the case of adults with dyslexia, it has been argued that they may continue to use compensatory strategies unlike neurotypically functioning adults with normal reading abilities (Cowan et al., 2017; Hancock et al., 2017).

Two long duration measures were used to assess time perception in the minutes range through the retrospective and prospective paradigms. The results for the retrospective long duration time perception task indicated that adults with dyslexia showed no evidence of retrospective time estimation difficulties. The trend in the data revealed that they were more likely to overestimate their retrospective time estimations compared to adults without dyslexia. Adults with dyslexia were more likely to give less accurate estimates and varied overestimations.

In comparison, Khan (2014) reported that time estimation errors in children with dyslexia with tendencies of overestimations rather than underestimations. The distinction between the behavioural patterns found in the current study (tendencies to overestimate retrospective estimations) in comparison to Khan et al. (tendency to underestimate retrospective estimations) might be explained by the level of attentional resources deployed in the ongoing task. In the current study, participants were asked to read three simple passages in the interim and asked to recall as much information as they could immediately after the reading exercise. The immersive nature of the ongoing task in terms of the attentional resources may have contributed to an inflation of the passage of time.

The observed behavioural pattern by adults with dyslexia can be explained from a phonological processing and visuo-attentional standpoint. In the retrospective task employed in the current study, speed and accuracy were not emphasized in the undertaking of the ongoing task that transpired in the interim. It is plausible that adults with dyslexia may have found it somewhat demanding to pay attention to words contained in the passages – given their difficulties with reading (see Section 1.1). The ongoing reading task demanded visuo-attentional and adequate phonological processes in order to sustain visual focus and to cope with phonological processing of the reading task. Hitherto, the ongoing reading task has been presented as a potential extent of difficulty that may have been experienced by adults with dyslexia. Block (1992) has indicated that retrospective duration judgements are primed by the expanse of difficulty the presented stimuli in the interim demands processing. The occurrence of this is such that, when complex task-related information processing is experienced in the intervening period, judgements are often estimated as being longer (Block, 1992). In relation to the current work, adults with dyslexia generated overestimations of retrospective timings that spanned across three standard deviations. This fluctuation in given estimates may well have been influenced by the different extents of processing problems in the visuo-attentional and/or phonological processing interferences.

In the long prospective time estimation measure, adults with dyslexia generally demonstrated a greater likelihood of underestimating elapsed time – although their performance compared with those without dyslexia indicated no evidence of difficulties in their prospective paradigm time estimations. Hicks, Miller, and Kinsbourne (1976) have argued that awareness of the passage of time can be assumed as the reason for generating relatively accurate prospective time estimations. Hicks et al.'s view is based on the premise that subjective time inflates with one's attentiveness to time. Ergo, attention to the passage of time initiates the storage of subjective temporal units. In the current study, in the absence of salient environmental cues, participants depended on self-initiating processes in order to perform the prospective time estimation task. Self-initiating processes necessitate greater attentional resources. Performance of time-based PM (TBPM) necessitates the remembering to execute an intention at a particular future timepoint - without the presence of prominent environmental cues that may be relied upon to inform task performance. Experimentally, successful enactment of TBPM tasks has been linked to self-initiating and monitoring processes (e.g., Martin, Kliegel, & McDaniel, 2003; McDaniel & Einstein, 2000; Smith-Spark, Ziecik et al., 2016b). These self-initiating and monitoring processes are closely associated with EF ability and their requirement in the activation of TBPM task performance has indicated a greater association of EFs to TBPM relative to EBPM. For example, Martin, Kliegel, and McDaniel (2003) have indicated that EFs are involved at the intention formation stage of PM – at which point, the awareness of the need to be attentive to the flow of time is necessitated. Van den Berg, Aarts, Midden and Verplanken (2004) have indicated that inhibition facet of EF is activated to facilitate with the breaking out of an ongoing task in order to perform a PM task or clock checking. Mäntylä, (2003), McDaniel, Glisky, Rubin, Guynn and Routhieaux (1999) have indicated that Updating working memory facet of EF (i.e., the storing and manipulating of information) may initiate a key function in remembering the planned deed and activating its action into consciousness. Schnitzspahn et al. (2013) found that the distinct EF variables namely, Inhibition, Set shifting, and Updating working-memory, can predict TBPM performance in the neuro-typical population; although see Altgassen et al., 2014 for an alternative account). In the current study, in the case of adults with dyslexia, it may be that their tendency of deflating elapsed time; may be explained by the relatively high demands that may have been placed on the attentional resources required to execute the ongoing task whilst concurrently trying to keep in mind a requirement to remember to prompt the investigator after 30 minutes have elapsed.

Taken together, null findings were attained for the short duration tasks and the long duration tasks. Despite this, the implications merit some consideration in terms of what it adds to the existing body of research findings. These are discussed from the stance of sample size, and statistical power and a rigorous methodological design with reference to Chiappe et al. (2002) owing to the similarity of participant age group classifications employed. In Chiappe et al. (2002), short duration time perception tasks in the milliseconds range were explored in adults. The study employed a relatively small sample size comprising adults with reading difficulty, normally achieving adults and normally achieving children. The group of adults with reading difficulty were found to be statistically inferior on nearly all the timing tasks employed. The Chiappe et al. methodological design lacked a rigorous approach in that; It is not indicated as to whether participants with reading problems were previously diagnosed by an educational psychologist report or not. Such verification of status would indicate the severity of the reading difficulties which in turn can shed light on inferences that can be drawn from observed performance behavioural patterns. In light of the aforesaid, a more meticulous recruitment design with precision in the selection of participants with dyslexia was deemed important in the current work to address the lose methodology in participants selection in the Chiappe at al. study. The previous authors used a relatively small sample size and yet reported significant findings on almost all timing tasks. Although in the current study, the lack of effect was found across temporal duration judgement tasks in the milliseconds range, it can be confidently argued that the tasks themselves functioned effectively and worked more or less. Having assessed the extent of PM functioning in dyslexia through a wide-range of tasks that encompass laboratory-based tasks, ecologically-valid PM task and a naturalistic PM task, conclusion of the general findings is explained in line with theory (see Section 6.2.1).

Chapter 6.0 General conclusions

6.0.1 Overview of the concluding chapter

This chapter concludes the investigation by providing a summary of the main research findings in relation to the research question and objectives. Next, specific details of each of the studies on prospective memory, executive functions and time perception is presented in turn. Afterwards, a dimensional approach of understanding dyslexia in which correlations between measures of dyslexia severity and scores on PM, EF and time perception is presented. This are followed by a consideration of how well the current investigation's findings answers the research question and its contributions to research in line with theory. Next, the practical implications of this investigation are considered, followed by a review of limitations and recommendations for future research.

6.0.1.2 Outline of overall findings

The objective of the thesis was to investigate whether adults with dyslexia show differences in cognitive performance across a variety of PM, EF and time perception (TP) tasks. The approach taken to address the research question was to assess PM, EF, and TP performance extensively in order to determine the existence of and the extent of dyslexia-related deficits across a broad range of cognitive functions. Before summarising the results in more details in the following sections, it is worth noting the major findings of the thesis in the following order PM, EF, followed by TP. Firstly, the PM findings indicated dyslexia-related deficits in adults when PM tasks relied on time-based cues and necessitated episodic and one-off PM responses, but not when time-based cues required a habitual TBPM response. Moreover, no dyslexia-related difficulties were observed in EBPM tasks whether event-based cues required episodic and one-off PM responses or a habitual PM response. In relation to PM, additional RM findings involving both immediate and delayed recall indicated no evidence of dyslexia-related deficits pertaining to the following sensory processing modalities - spatial memory, verbal memory, verbal memory for face recognition, memory for everyday objects, verbal episodic memory and memory for episodic memory (see Section 6.0.1.3). Secondly, the EF findings indicated that adults with dyslexia also showed difficulties in a range of EF abilities related to set-shifting, phonemic fluency, dual-task performance and planning, but not in inhibitory control. Due to a computer error, the data for the updating working-memory task were not logged and thus, no analysis could be carried out (see Section 6.0.1.4). Thirdly, the TP findings showed no evidence of dyslexia-related difficulties in time perception were found, either in time perception for the short duration (milliseconds) range or for the long duration (minutes) range (see Section 6.0.1.5). Brief summaries of the specific details of each of the studies will now be considered beginning with PM.

6.0.1.3 Prospective memory: summary of findings

Chapter 3 investigated PM performance objectively using a wide-range of tasks to measure EBPM and TBPM in adults with and without dyslexia. Despite the extent of PM problems in dyslexia, only a limited number of studies have assessed PM with ecologically valid tasks that depict PM-related performance like those experienced in real-life. To address this issue, and to expand more generally on a small literature (e.g., Smith-Spark, Ziecik, et al., 2016,b; Smith-Spark, Ziecik, et al., 2017,a,b), this study assessed PM using a range of PM measures that encompassed laboratory-based PM tasks, a naturalistic-outside of lab-setting PM task and an ecologically valid breakfast preparation task (Altgassen et al., 2012). In line with previous findings, the results indicated TBPM performance-related difficulties in dyslexia that were associated with set-shifting task (flexible switching between the dining room and the kitchen and between PM tasks) and can be explained from the perspective of dyslexia-related deficits in EFs. In the laboratory-based computerized PM tasks, consistent with previous research, there was no evidence of dyslexia-related PM problems in the computerized EBPM task. This finding on EBPM task-performance provides additional support for the multi-process theory which postulates that PM tasks that are triggered by event-based cues rely on spontaneous retrieval processes. Spontaneous retrieval processes are supervised in one of two processing trajectories (see Section 3.3; multi-process theory). Accordingly, EBPM performance in adults with dyslexia was not disrupted. With regards to TBPM, inconsistent with previous research, adults with dyslexia did not reveal deficits in the TBPM computerized task or in the naturalistic (outside-the-laboratory setting) TBPM processing task. In relation to TBPM tasks, the multi-process theory proposes a second and distinct processing trajectory that is reliant on self-initiated and monitoring of TBPM cues to assist with PM performance. Accordingly, with monitoring and self-initiated processes requiring additional attentional processes (Einstein & McDaniel, 2000), the effects of dyslexia were expected to negatively impact on the TBPM performance of adults. However, given that the computerized TBPM task required a repetitive PM response, this recurring pattern may have given rise to a relatively involuntary retrieval process of the required PM response. With regards to the naturalistic TBPM task, the lack of evidence for dyslexia-related deficits can be explained by methodological limitations related to a failure to employ a pure time-based cue in the naturalistic task. The lack of dyslexia-related deficits in the Rivermead behavioural task (Wilson et al., 2008) indicate that with the exception of the overall score for everyday memory performance, there was no evidence of dyslexia-related deficits in immediate and delayed memory recall ability across a number of sensory processing modalities. A discussion of the main PM findings are related to theory in terms of their relative contributions in understanding dyslexia in section 6.2.1.

6.0.1.4 Executive functions: summary of findings

Executive functions refer to a set of higher cognitive processes that assist with the distribution of attentional resources in order to manage planned and unplanned behaviours. Executive functions can be categorized into core EFs consisting of inhibitory control, updating working-memory, set shifting, and verbal fluency (Diamond, 2013; Fisk & Sharp, 2004; Miyake et al., 2000) and broader EFs including dual-task performance and planning. Relative to the neurotypical population, individuals with dyslexia have been frequently found to have problems with these EFs. Chapter 4 investigated EF performance objectively by using traditional laboratory-based measures to assess EF performance in adults with and without dyslexia. The core EFs that were assessed were: inhibitory control, updating working-memory, set shifting and phonemic fluency (a measure of verbal fluency). The broader EFs assessed were dual-task performance and planning. The results obtained for the core EFs indicated adult dyslexia-related problems in set-shifting. Specifically, adults with dyslexia were found to have a greater cost of switching between two cognitive operations. The findings for phonemic fluency task showed that verbal access functioning ability in adults with dyslexia was weaker than those without dyslexia. For inhibitory control, the findings indicate no evidence of dyslexia-related deficits (see Section 4.9 for a full discussion on inconsistency of inhibition results relative to previous research). The updating working-memory measure used could not be analysed (see Section 4.8.2 for details). The broader EFs results showed problems in dual-task performance. Specifically, adults with dyslexia revealed difficulty in a motor-controlled task when the task was performed in dual-task mode in tandem with a secondary task in dual-task mode. Planning deficits were found in adults with dyslexia when a requirement to alternate between numbers and letters placed additional demands on central executive processes. The main EF findings are contextualized with theory to better understand the incidence of dyslexia (see Section 6.2.1).

6.0.1.5 Time Perception: summary of findings

Experimentally, time perception tasks have been categorized in the short (milliseconds) range and in the long (minutes, hours) range. There are indications of dyslexia-related time perception difficulties in the milliseconds range – these have been established through a variety of auditory discrimination tasks. Despite this, time perception investigations in the long duration range (minutes, hours) have seemingly been ignored; despite these time durations falling within the long duration range are more representative of the intervals of events that we engage in on a daily basis. Chapter 5 investigated time perception more broadly by employing traditional laboratory-based measures in adults with and without dyslexia. The short duration (milliseconds) range was measured with three tasks comprising temporal generalization, bisection, and verbal estimation auditory discrimination tasks. The long duration (minutes) range was assessed using both retrospective and prospective timing paradigms respectively. The results for all the three short duration range tasks indicated no evidence of temporal processing difficulties in adults with dyslexia. The results for the long duration time perception tasks as measured in the minutes range indicated no evidence of temporal processing problems in either the retrospective or the prospective timing paradigms in adults with dyslexia. The main TP findings are discussed in relation to theory in considering dyslexia in section 6.2.1.

Chapter 6.1 Correlations between measures of dyslexia severity and scores on the PM, EF and TP tasks

The analyses presented earlier in the thesis uses a categorical approach (a participant has or has not got dyslexia), but this does not consider the function of the severity of dyslexia (a dimensional approach) in understanding the variance in performance on PM, EF and TP tasks. On this basis, analyses that made allowance for a dimensional approach was implemented to allow for dyslexia-related variance in performance on PM, EF and TP tasks to be assessed based on the discrepancy of reading, spelling, and IQ scores respectively.

In the current work, despite the lack of significance obtained in TP performance in adults with dyslexia as previously indicated, dyslexia performance-related difficulties were found in EF (i.e., Phonemic fluency, flexible shifting, dual-task performance and planning; see Section 6.0.1.4) and PM (TBPM performance, clock monitoring tendency, room/task switching ability; see Section 6.0.1.3). Generally, findings have shown inconsistencies in dyslexia only and its association with a variety of EF measures (e.g., inhibition (Bental & Tirosh, 2007; Booth, Boyle

& Kelly., 2014), updating (Marzocchi et al., 2008; Willcutt et al., 2005), and switching (Menghini et al., 2010; Poljac et al., 2010). However, EF profiles of (inhibition; updating and switching) have been linked to dyslexia, and the extent to which performance-related scores are linked with reading, spelling and IQ scores presents a more useful system of understanding dyslexia. In PM, TBPM problems revealed in dyslexia (e.g., Smith-Spark, Ziecik, et al., 2016b) and in the current work (see Section 6.0.1.3) necessitate monitoring and self-initiated processes (Einstein & McDaniel, 2000). These monitoring and self-initiated attentional demanding processes are linked to EF abilities (i.e., set-shifting, and inhibition). Dyslexia-related profile from a dimensional outlook of TBPM performance would thus be more informative in explaining the extent to which variations in TBPM performance are related to reading, spelling and IQ scores in adults with dyslexia.

In view of addressing how the cognitive profiles of strengths and weaknesses across PM, EF and TP tasks would be better understood from a dimensional view of dyslexia rather than from a categorical view, a series of correlations assessed the extent to which cognitive task performance were related to reading, spelling and their IQ abilities respectively. This was assessed from the perspective of the whole group (that is adults with and without dyslexia) vs. the group with dyslexia only (adults with dyslexia). Cognitive tasks related to EF and PM that showed significant between-group differences qualified to be included in the correlation analyses to further explore their dimensional relatedness to reading, spelling and IQ abilities. All the time perception tasks indicated lack of between-group performance related difference, and so were not included in the analyses. The correlations analysed the degree to which difficulties in performance found across several cognitive tasks were associated with the reading and spelling scores of the participants. For those tasks that had previously shown significant group differences, correlations between task performance and reading, spelling and IQ were run for the whole sample, and also for just the participants with dyslexia. These two sets of analyses were carried out in order to ascertain whether variation in performance was driven by reading, spelling or IQ respectively were specific to the group with dyslexia contrasted with the whole sample.

6.1.1 Pearson correlations of the performance between the scores on the cognitive tasks and the spelling, reading and IQ abilities of the whole sample

Pearson correlations were used to analyse the extent to which performance on cognitive tasks were correlated with spelling, reading and IQ scores respectively, irrespective of group (i.e., scores from the whole sample were entered into the analyses). In order reduce the likelihood of attaining overstated levels of significance on the multiple correlations of the same data, Bonferroni corrections were thus implemented. The resultant alpha level was .006 (i.e., 05/8).

A weak positive correlation was found between spelling ability and TBPM performance (Dresden Breakfast Task) – PM measure (r = .49, *p* = .001). Additionally, significant and weak negative correlations were found between spelling ability and Set-shifting (r = -.49, *p* <.001), and spelling ability and Planning ability (r = -.43, *p* = .002). See Figures 6.1, 6.2 and 6.3 for scatterplot of all the significant correlations. The correlation between spelling ability and all other cognitive tasks were non-significant. See Table 6.1 for all the assessed correlations and coefficients between spelling ability and a range of cognitive tasks.

All correlations between reading ability and all cognitive the tasks that were eligible for the analysis were found to be non-significant. See table 6.1 for the assessed correlations and coefficients values between reading ability and a variety of cognitive tasks.

All correlations between IQ ability and all qualifying cognitive tasks were found to be non-significant. Table 6.1 presents the values for all the tested correlations and their relative coefficients between IQ and a series of cognitive tasks.

Table 6.1: Table of correlations and coefficients of the whole sample's performance on EF and PM tasks correlated with their spelling, reading and IQ scores respectively.

Whole sample - Correlations between cognitive tasks and spelling, reading and IQ respectively

	Task classification and Task-type	Cognitive test	Spelling	Reading	IQ
1	PM - Dresden breakfast task	TBPM tasks completed	* .489	.350	.120
2	PM - Dresden breakfast task	Clock checking tendency	.200	.350	.360
3	PM - Dresden breakfast task	Task and room switching ability	.210	.250	.150
4	EF - Phonemic Fluency	Verbal fluency ability	.190	.250	.110
5	EF - Set-shifting	Plus-Minus task (Cost of switching)	* -.490	-.290	.110
6	EF - Planning ability	Trail making task	* -.430	-.170	.120
7	EF - Dual task performance	Pursuit rotor task	.320	.270	.350
8	EF - Dual task performance	Semantic fluency task	-.100	.010	.190

***. Correlation is significant at .006 or <.006 (2-tailed) after applied Bonferroni-adjusted alpha level (0.05/8) = .006**

Significant positive correlations

Significant negative correlations

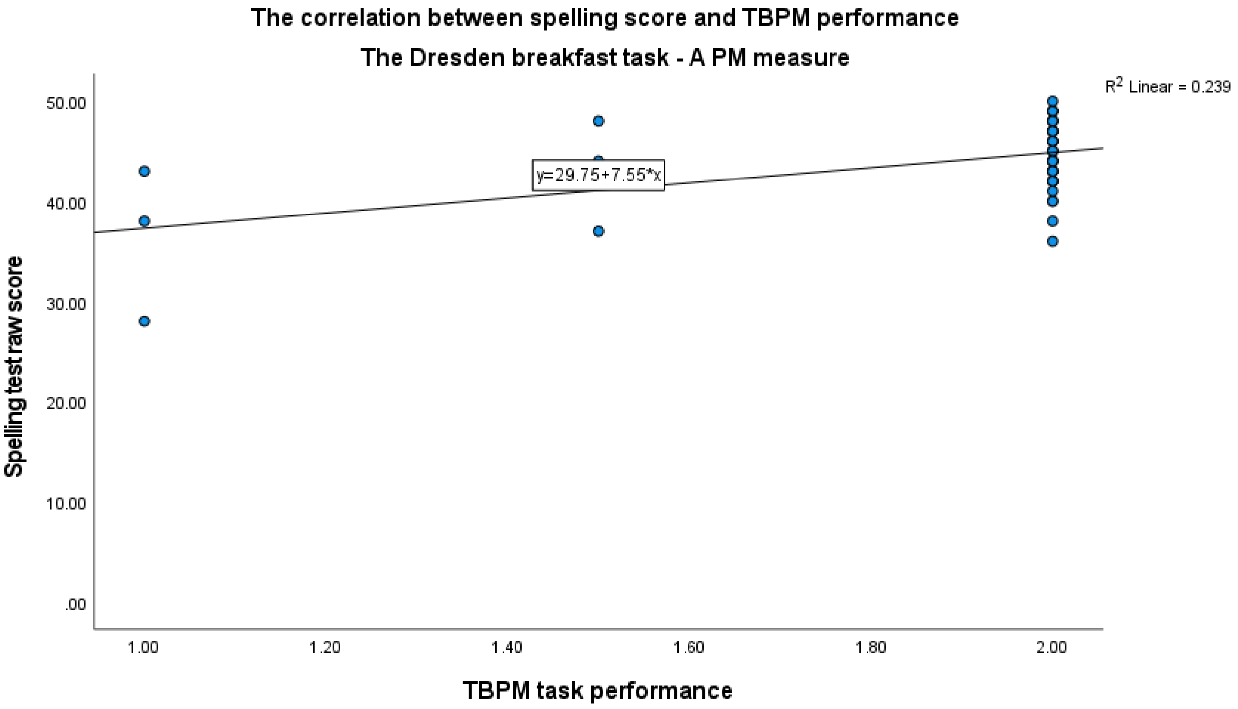

Figure 6.1 A whole sample correlation between spelling score and TBPM performance (The Dresden breakfast task – PM measure)

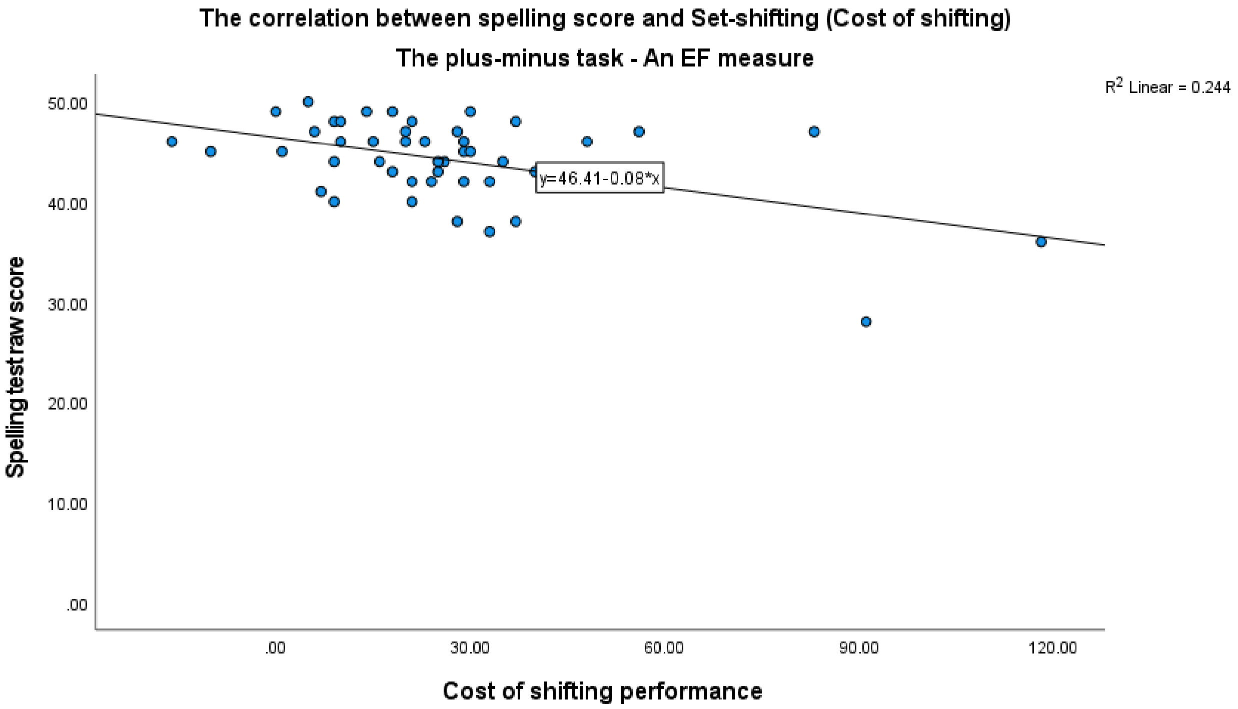

Figure 6.2 A whole sample correlation between spelling score and Set-shifting (Cost of switching - EF measure)

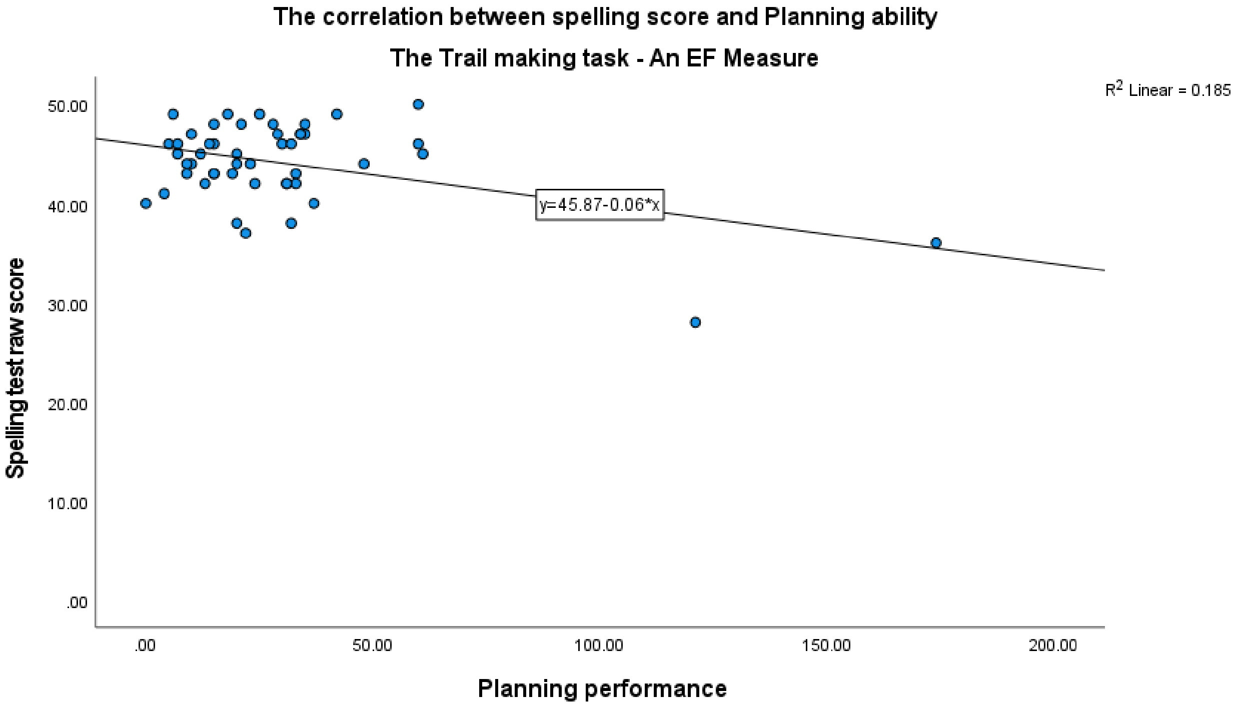

Figure 6.3 A whole sample correlation between spelling score planning ability (EF measure)

6.1.2 Pearson correlations of the performance between the scores on the cognitive tasks and the spelling, reading and IQ abilities of the dyslexia only

Pearson correlations were used to analyse the relationship between the scope of performance on cognitive tasks and respective scores for spelling, reading and IQ. In order reduce the likelihood of attaining overstated levels of significance on the multiple correlations of the same data, Bonferroni corrections were thus implemented. The resultant alpha level was .006 (i.e., 05/8).

All the correlations between spelling ability and the cognitive tasks that met the selection criteria were non-significant. See table 6.2 for a summary of all the analysed correlations with their coefficients between spelling ability and a variety of cognitive tasks.

The correlations between reading ability and cognitive tasks across PM and EF tasks were found to be non-significant. Table 6.2 presents the values for all the tested correlations including their coefficients between reading ability and an array of cognitive tests.

The correlations between IQ and all the cognitive tasks were found to be non-significant. See table 6.2 for an overview of all correlations and coefficients between IQ and the assessed cognitive tasks.

Table 6.2: Table of correlations and coefficients of the dyslexia-group's performance on EF and PM tasks correlated with their spelling, reading and IQ scores.

The group with dyslexia only - Correlations between cognitive tasks and spelling, reading and IQ respectively

	Task classification and Task-type	**Cognitive test**	**Spelling**	**Reading**	**IQ**
1	PM - Dresden breakfast task	TBPM tasks completed	.510	.220	.090
2	PM - Dresden breakfast task	Clock checking tendency	.230	.080	.430
3	PM - Dresden breakfast task	Task and room switching ability	.120	.320	.190
4	EF - Phonemic Fluency	Verbal fluency ability	-.140	-.100	.090
5	EF - Set-shifting	Plus-Minus task (Cost of switching)	-.380	.240	.450
6	EF - Planning ability	Trail making task	-.530	.020	.260
7	EF - Dual task performance	Pursuit rotor task	.300	.060	.440
8	EF - Dual task performance	Semantic fluency task	-.290	-.300	.250

***. Correlation is significant at .006 or <.006 (2-tailed) after applied Bonferroni-adjusted alpha level (0.05/8) = .006**

6.1.3 Discussion

Dyslexia-related EF and PM problems indicated in the current work's findings (see Table 6.2) were further explored to investigate whether variation in performance on cognitive tasks were associated with severity of dyslexia. This was investigated with a series of Pearson correlations with an objective to ascertain whether spelling, reading or IQ abilities were significantly correlated with the EF and PM difficulties adults with dyslexia showed in their performance. The results for the whole sample were presented with the group with dyslexia.

In the group with dyslexia, a series of Pearson correlations indicated that out of the eight measures related to PM and EF (see Table 6.2), none of their indicated performance-related problems correlated significantly with spelling, reading or IQ abilities respectively. In contrast, when the whole sample was considered, the Pearson correlation analyses showed that task performance difficulties on one PM measure (i.e., TBPM task performance) and two EF measures (i.e., Set-shifting, and planning) were significantly correlated with spelling ability. However, performance on PM and EF measures did not correlate significantly with reading or IQ abilities.

In the current work, it was expected that literacy abilities would influence the range of EF and PM measures that were analysed. This prospect was founded on the premise that phonological processing deficit is regarded as a core deficiency in dyslexia (e.g., Ramus, 2003; Snowling, 2000; Vellutino, Fletcher, Snowling, & Scanlon., 2004) and its occurrence coincides with dyslexia-related difficulties in TBPM (e.g., Smith-Spark, Ziecik et al., 2016b), Set-shifting (e.g., Poljac et al., 2010), phonemic fluency (e.g., Smith-Spark, Henry et al., 2017), dual-task performance (e.g., Nicolson & Fawcett, 1990) and planning (e.g., Smith-Spark, Henry et al., 2016).

When the whole sample was considered, spelling ability correlated significantly with TBPM, (a PM measure) and Set-shifting, phonemic fluency and planning (the latter three area all EF measures). Spelling ability was found to be significantly correlated with performance-related difficulties in TBPM and Set-shifting and planning. Surprisingly, when the group with dyslexia only was considered, spelling also did not hold out as a significant motivator of the PM and EF performance-related difficulties. This trend was anticipated to hold out in the dyslexia-group, yet this was not evident. In fact, none of the correlations between the respective EF and PM measures and reading and IQ achieved statistical significance. It may simply be that with the dyslexia-group, being a smaller sample size may have weakened the likelihood of respective spelling, reading and IQ ability being significantly correlated with TBPM, set-shifting and planning performance.

Alternatively, the lack of significant correlations may be due to the specific phonemic awareness measure employed as part of the screening assessments (see Section 2.1.3.4). Having adopted a more categorical approach rather than a dimensional approach to understanding dyslexia-related performance on cognitive tasks (i.e., PM, EF, and TP), the DAST reading test was employed and deemed suitable as a standard measure of phonemic awareness. An alternative, the Spoonerism task (Marotta, Trasciani, & Vicari, 2008) has been shown to be robust predictors of word and nonword reading deficits (e.g., Herman, Kyle, & Roy., 2019) and EF deficits (e.g., Varvara, et al., 2014).

Besides the abovementioned discussed points, it may be worthwhile to consider that since multiple correlations were considered (see table 6.1), the Bonferroni-adjusted alpha level was applied. Though the test is intended to reduce the occurrence of attaining false statistical significance, it is noteworthy to consider that the test reduces the power of attaining statistical significance and consequently increases the possibility of obtaining false negatives. In light of the aforementioned, it would be worthwhile to consider increasing sample size of adults with dyslexia in the first instance to ascertain whether potential significant correlations could be attained between the respective spelling, reading and IQ measures and the range of EF and PM measures assessed.

6.2 An overview of a dimensional view of profiles of strengths and weaknesses in dyslexia versus non-dyslexia PM and EF task performance

The current work explored performance-related strengths and weaknesses of adults with and without dyslexia across PM and EF tasks. The manner in which strengths and weaknesses across the aforementioned tasks can be considered in a more informative manner is more compatible with a dimensional view of dyslexia and less so from a categorical outlook. Sections 6.1 and 6.2 explored the extent to which performance-related cognitive problems in the whole sample (adults with and without dyslexia) and the dyslexia group (i.e., adults with dyslexia only) were influenced by the respective abilities in reading, spelling and IQ. The approach facilitated the extent to which the dyslexia vs non-dyslexia dimension is more relevant in driving individual differences across PM and EF tasks. In the PM performance (the Dresden breakfast task) these measures were eligible to be analysed (i) TBPM tasks completed, (ii) clock checking tendency, and (iii) task and room flexible-switching. In EF performance, the tasks that were eligible to be analysed were the EF tasks that showed between-group difference in performance. Based on the eligibility criteria, The following tasks were included (i) phonemic fluency, (ii) set-shifting, (iii) planning, and (iv) dual-task performance. When the whole group was considered, spelling ability was found to be significantly correlated with TBPM task performance, set-shifting and planning abilities respectively. Reading and IQ were not found to influence PM and EF task performance. In the dyslexia-group, it was revealed that neither spelling, reading or IQ were significantly correlated with any of the assessed PM and EF measures.

6.2.1 Linking the findings to previous research and theory

The current research question investigated prospective memory, executive functions and time perception in adults with dyslexia. The lack of deficits in EBPM performance in adults with dyslexia is in line with previous research (e.g., Khan, 2014, Smith-Spark, Ziecik et al., 2016a). In relation to PM, the current study findings extend this line of work by indicating that, irrespective of the type of PM response required being mundane (undemanding) or episodic and one-off (i.e., more cognitively demanding; multi-process theory McDaniel & Einstein, 2000), EBPM performance in adults with dyslexia did not show evidence of impairment and was in fact comparable to adults without dyslexia. In line with the multi-process theory of PM (Einstein & McDaniel, 2005), when PM responses depend on event-based cues, retrieval of the PM intention to assist with PM performance is spontaneous and automatic. This retrieval system appeared to be uninterrupted in adults with dyslexia. The TBPM deficits found in adults with dyslexia were observed in a meal preparation task that depended on episodic-one-off PM responses. Consistent with the multi-process model, Einstein and McDaniel (2005), when time-based cues are integrated in PM performance, increased attentional resources are needed in order to monitor for target and time-based cues. It is thus unsurprising that attentional resource allocation problems present in adults with dyslexia were experienced in the Dresden breakfast task when episodic and one-off PM responses and time-based cues were required.

The practical implications for the overall findings for TBPM and EBPM types present the scope for real-world application for educational settings and workplaces. Specifically, suitable support should be considered for adults with dyslexia on TBPM activities that rely on PM responses that are sporadic or one-off in nature. Failure to replicate TBPM problems in a laboratory-based computerized task was perhaps not surprising as repetitive TBPM responses were necessitated. It would be worthwhile for future work in this line of research to modify the task to assess performance in adults with dyslexia when episodic and one-off TBPM responses to important tasks are required in comparison to mundane kinds – giving that the former would be expected to require greater attentional resources than the latter. The lack of TBPM problems in adults with dyslexia in the naturalistic TBPM task employed in the current work ought to be interpreted with caution. This is because the TBPM response that was required at a specific timepoint was not based on a purely time-based cue. Indeed, the TBPM response cue was actually at least partly based on the occurrence of an event. The naturalistic TBPM task employed required participants to remember to look at the newspaper headline on the day they were scheduled to attend their next test session and remember to tell the investigator what the headline was. Despite the PM cue (the newspaper board) being devised to occur in certain timeframe en-route to the test session, the occurrence of the news headline board is essentially event-based. This thus meant that the PM response required within a certain timeframe was also assisted by an event-based cue (the newspaper headline board). It would be advantageous, therefore, for future research to meticulously ensure that purely time-based cues are used. As an example, a pure time-based cue could be generated by changing the PM response from requiring the participants to look at the newspaper headline" to "sending a blank email to the investigator 30 minutes before the scheduled appointment for the next test session. By so doing, this removes obvious event-based cues that could otherwise assist remembering through automatic processes. It is possible that dyslexia-related deficits may be evident in task performance once the recommended adjustments are applied.

A further objective of the current research was to assess an extensive range of EF abilities in adults with dyslexia to ascertain the extent of presence of dyslexia and broader cognitive problems. With the exception of Inhibitory control and updating working-memory (where data were not able to be retrieved), the effects of dyslexia observed in core EF abilities were set shifting and verbal fluency subset (phonemic fluency) and in the broader EF abilities of dual-task performance and planning. In each case, the group with dyslexia showed lower levels of performance. The dyslexia-related deficits revealed in dual-task performance provides further support for the dyslexia automatization deficit hypothesis (DAD; Nicolson & Fawcett, 1990; see Section 1.3) which argues for dyslexia-related deficits in attaining automaticity in cognitive and motor skills during dual-task performance. These findings add further support to the small number of studies that have reported the broad range of EF problems in adults with dyslexia (e.g., Smith-Spark, Henry et al., 2016a). The attributions of EF deficits to dyslexia-related problems in the supervisory attentional system (SAS - Norman and Shallice, 1986; see Section 4.5.1) have been pointed out on the basis of its function as an attentional resource allocator to control, assimilate, and coordinate information from varied sources.

The current work's findings are valuable in that, even with the exception of inhibition, they provide further substantiation that adults with dyslexia experience deficits in traditional laboratory-based EF measures that are pervasive across a broad range of EF deficits such as set-shifting, phonemic fluency, planning and dual-task performance. In addition to these findings, dyslexia-related deficits in set-shifting were evident in the Dresden breakfast task (see Section 3.13.4). Although no other EF measure was assessed in the task, dyslexia-related deficits in set-shifting in a meal preparation task provides an insight into the possibility that extending the study of EFs to naturalistic tasks may be useful to broaden current understandings of EF deficits. It may be worthwhile for future research to consider this prospect in different naturalistic tasks. Whilst the Dresden Breakfast Task is a suitable example of a more naturalistic task, it incorporates an assessment of only one EF, namely – set-shifting. Even so, dyslexia-related problems found in one of the core EF facets – set-shifting in a meal preparation is suggestive of the importance of examining whether problems in other EF facets manifest in real-life-like naturalistic tasks in adults with dyslexia. The implications of these findings point to the possibility that these dyslexia-related EF difficulties observed in laboratory-based EF tasks extend to more naturalistic tasks. However, the extent of deficits across the range of EF measures are not yet known. Future research could thus, explore whether dyslexia-related problems in an extensive range of EF facets are evident in naturalistic tasks.

Another aim of the current research was to assess a broad range of time perception performance in adults with dyslexia. The tasks that assessed auditory time perception processing in the milliseconds range namely, temporal generalization, bisection, and verbal estimation revealed no evidence of time perception deficits in adults with dyslexia in these short duration tasks. In context with the SET model of psychological timing (Gibbon, Church, & Meck, 1984), adults with dyslexia successfully encoded, stored and were able to retrieve the standard auditory temporal tone duration from memory for multiple comparisons from the clock, memory and decision-making stages respectively. These findings are contrary to previous research (e.g., Khan et al., 2014; Gooch, Snowling, & Hulme, 2011; Nicolson, Fawcett & Dean, 1995; Wolff, 2002). The aforementioned studies employed children with typical age range between 10 and 16 years old and very little has been reported on adults with dyslexia (e.g., Chiappe et al., 2002). The lack of dyslexia-related problems in the short duration time perception tasks may be that adults with dyslexia may simply have had more efficient coping ability to regulate the demands that the temporal judgement tasks presented – a point made by Nicolson et al. (1995). Furthermore, it may be that the temporal units that were utilized in the tasks fall below the threshold of the cognitive range and were simply not taxing enough to interrupt the attentional and memory processes in older adults with dyslexia.

In the current work, despite the lack of evidence for time perception deficits in adults with dyslexia, these findings further enhance the current literature in that, the findings supplement the few investigations (e.g., Chiappe et al., 2002; Nicolson et al., 1995) that have investigated auditory time perception in adults with dyslexia. Furthermore, the current work has contributed to this line of research by assessing short duration time perception performance with a variety of tasks. This bridges a gap in the small body of existing literature which has tended to investigate time perception in the milliseconds range with different tasks and often with only one task. A further contribution of the current work that is lacking in the existing research pertains to a thorough systematic methodological approach that was employed to select participants with dyslexia (see Sections 5.5 and 5.6). This approach was systematic on the basis that the inclusion criteria for participants with dyslexia required them to present a copy of an educational psychologists' reports to confirm their dyslexia status.

Additionally, adults with and without dyslexia were administered to the short-form IQ screening tests (Wechsler, 2010) in order to confirm that the participants in the two groups had similar IQ levels (see Sections 2.1.3.1 and 2.1.3.4). Moreover, a reading test (Nonsense Word Reading Passage; Fawcett & Nicolson, 1998) was administered to both groups to confirm the presence of and severity of dyslexia. Finally, a spelling test (the WORD spelling test; Wechsler, 1993) was administered to both groups to check spelling ability and age (see Sections 2.1.3.2, 2.1.3.3, and 2.1.3.4 respectively). The implication of employing a systemic methodological approach for participant selection is that the effects of dyslexia on tasks that are susceptible to the condition (i.e., temporal processing) have a greater likelihood of being revealed if they are apparent (Turner, 1997). This approach has not been employed by previous investigations and as a recommendation, future research on dyslexia-related time perception performance that fall into the milliseconds timing range should adapt to this approach to ensure methodological rigidity in the participant selection process. The findings on the long duration time perception measures on prospective and retrospective time estimations revealed no evidence of difficulties in adults with dyslexia. Yet still, the behavioural trend revealed that adults with dyslexia tended to overestimate their retrospective time estimations whilst their prospective time estimations tended to be underestimated. Block and Zakay (1997) have argued that retrospective duration time estimations, accuracy of the estimated time is mainly contingent on temporal information retrieval processes from long-term memory. Given the trend of dyslexia-related deficits linked to storage, maintenance, and access of verbal information in long-term memory (e.g., Smith-Spark, Henry et al., 2017), the behavioural characteristics observed in the current work may well be linked to long-term memory problems. In context with the retrospective time estimation findings, adults with dyslexia were found to have greater error proneness and revealed increased variability in their estimations. These findings obtained in the current thesis should be interpreted with caution owing to the abovementioned observed trend.

In addition to the reading and spelling problems that were reported in the sample of adults with dyslexia, the consensus from the main findings indicates dyslexia-related difficulties across different domains of cognition. With the exception of TP (see Section 6.0.1.5), the findings pertaining to EF (see Section 6.0.1.4) and PM (see Section 6.0.1.3) point to problems that span across verbal and non-verbal abilities in adults with dyslexia. In context with dyslexia theory, dyslexia-related problems indicated in PM in the current work (i.e., TBPM performance, clock checking tendencies, and room plus task switching performance) and EF (i.e., set-Shifting, phonemic fluency, dual-task performance, planning) present problems for the phonological deficit hypothesis in terms of its capacity to account for the extent of cognitive difficulties that extend beyond reading and spelling problems. The phonological deficit hypothesis (see Section 1.3) postulates that the core deficit in dyslexia that results in poor reading of phonemes is owed to a domain specific impediment related to compromised awareness of, access to, or insufficient representations of basic speech sounds. In this way, the phonological deficit hypothesis seems to be more readily able to account for dyslexia-related verbal abilities rather than non-verbal abilities that are similar to those indicated in EF and PM performance in the current study. The phonological deficit hypothesis can thus not explicate the EF and PM deficits found in the current work that appear to occur together with reading and spelling problems in adults with dyslexia.

Likewise, the magnocellular deficit hypothesis (see Section 1.3) asserts that impaired visual input attributable to weakened binocular fixation impedes reading ability (e.g., Stein, 2001). This model would not be able to account for the wider cognitive problems that the current work’s findings indicated in both EF and PM performance in adults with dyslexia.

Alternatively, the DAD which stems from the cerebellar dysfunction (see Section 1.3; Cerebellar deficit hypothesis) ascribes cerebellar impairments to the weakness in the ability to attain fluency in motor skills and implicit learning (a process wherein skills become automatic; Doyle, 2017). In relation to the current work, when considering the extent of EF and PM difficulties showed by adults with dyslexia, the dyslexia automatization deficit offers an account of dyslexia that indeed extends beyond reading and spelling difficulties that are characteristic of dyslexia. As a function of cerebellar impairment, whilst motor-related deficits are linked to motor control difficulties and hinders writing ability (e.g., Nicolson, Fawcett & Dean, 2001), deficiencies linked to implicit learning negatively impacts on the acquisition of skill automaticity. Impairment in skill automatization ability in dyslexia interrupts grapheme-to-phoneme conversions and impedes reading skill as well as the capacity to automatize expertise in cognitive abilities. In context with the dyslexia-related EF and PM problems indicated in the current work, the dyslexia automatization deficit hypothesis can palpably account for cognitive weaknesses that surpass dyslexia-related reading and spelling problems that characterised the sample of adults with dyslexia employed in the current work. The dyslexia automatization deficit can account to some extent for fluency-related and/or motor-related difficulties that were demonstrated by adults with dyslexia in the current work. For instance, in the dual-task performance, when the pursuit rotor task (a task reliant on motor-skills) was performed in tandem with a semantic fluency task (a task that does not induce the effects of dyslexia), supplementary processing power that was not utilized in the semantic fluency task was unavailable to adults with dyslexia to attain fluency in the motor-related task. Additionally, to a degree, phonemic fluency performance requires fluency to enable automaticity in the retrieval of words beginning with a certain letter, and so adeptness in task performance can be explained by the automatization deficit hypothesis.

Despite that, considerations are not given for the involvement of inhibition ability which functions to impede on the selectivity of invalid words and Set-shifting EF ability which can be utilised to shift from a cluster of words that with similar rhyme endings to another. This extent of regard is considered by the SAS (Norman & Shallice, 1986; see Section 4.5.1). The SAS offers a partial explanation for phonemic fluency ability in terms of the selectivity of activation or inhibitory response schemas. These response schemas are managed by the SAS which draws on attentional resources to assist with the selectivity of the preferred response through initiating or impeding specific behavioural schemas.

With regards to the dyslexia-related TBPM problems indicated in the current work, the SAS can be argued to be involved in its task performance to a large extent. For instance, successful TBPM performance relies on self-initiating (the ability to assist with prompting oneself to activate task performance), monitoring (clock checking tendencies), inhibitory control (the ability to prevent replication of previous task actions) and switching processes (the ability to flexibly shift between different operations during task performance) are implicated in the successful performance of TBPM tasks. Thus, dyslexia-related TBPM difficulties can be couched in terms of SAS dysfunction in dyslexia.

The broad consensus that can be drawn from contextualizing the dyslexia-related problems in EF and PM in the current work with dyslexia theory is that a fuller understanding of the indicated cognitive problems can be drawn from a number of dyslexia theories. The phonological deficit hypothesis offers a limited understanding of the range of cognitive problems observed, the automaticity deficit hypothesis. On the other hand, the dyslexia automaticity deficit hypothesis offers an extended view of dyslexia that encompasses cognitive motor-related and fluency attainment problems. In the current work, this theory can account for dual-task performance, but cannot adequately explain in particular EF performance-related problems indicated. Alternatively, the SAS proposes a theory that considers the processes that are involved in literacy attainment (i.e., inhibition, flexible-shifting, Updating-working memory). These processes are involved in general cognitive functions, and inhibition and flexible-shifting have been shown to be involved in TBPM performance. Despite this, fluency (automaticity) attainment can be more precisely explicated by the dyslexia automaticity deficit hypothesis. It is thus apparent that not one dyslexia theory by itself accounts for all the identified EF and PM performance-related deficits in the current work.

6.3 Conclusion

Taking the overall findings into consideration, the current work has shown that the effects of dyslexia extend to broader cognitive deficits related to executive function abilities (i.e., set-shifting, phonemic fluency, dual-task performance and planning), and prospective memory (i.e., TBPM) when greater foci of attention is required for successful PM performance. The dyslexia-related deficits in the areas identified (i.e., executive functions and time-based prospective memory appears to persevere into adulthood. In the current work, the dyslexia-related deficits identified in cognition does not seem to extend to EBPM irrespective of whether the PM response required greater cognitive demands (episodic) or lesser cognitive demands (habitual) over relatively short intervals. This is consistent with the findings of Smith-Spark, Ziecik et al., 2017a) who also reported similar results. Additionally, the time perception experiments did not show any problems in adults with dyslexia in both short and long durations. In the short duration tasks, adults with dyslexia appeared to have been able to successfully cope with the task demands. Moreover, the pattern of performance was similar on the long duration prospective and retrospective time estimation tasks in adults with dyslexia. It may be worthwhile for future research in this area to manipulate the cognitive demands of the ongoing task that participants engage with in the interim. Such manipulations may possibly reveal performance-related difficulties in both prospective but more so in retrospective time estimations – considering that retrospective time estimation relies on retrieval of temporal units from long-term memory and less reliant on attentional processes. Adults with dyslexia appeared to be able to cope with the task demand of the inhibition facet of executive functions. Despite this finding, it may be useful for future dyslexia-related work to explore differing task complexities to assess whether greater levels of difficulty impact on the task's performance.

The current work looked at executive function, time perception and prospective memory in adults with dyslexia. It was important to examine adults with the condition to assess the extent that the effects of dyslexia impact on day-to-day living. The extent of deficits found in the same group of adults with dyslexia appear to be evident over different areas of cognition. The observed range of cognitive deficits were prevalent in both core EFs (i.e., set-shifting, phonemic fluency) and broader EFs (i.e., dual-task performance, and planning). Moreover, additional problems were found in PM when time-based responses were needed (i.e., TBPM in an ecologically-valid breakfast preparation task – The Dresden breakfast task; Altgassen et al., 2012). The overall profile of adults with dyslexia indicates the persistent nature of cognitive problems that occur and negatively impacts on individuals with dyslexia in adulthood.

References

Ahissar, M. (2007). Dyslexia and the anchoring-deficit hypothesis. *Trends in cognitive sciences, 11*(11), 458-465.

Ahissar, M., Lubin, Y., Putter-Katz, H., & Banai, K. (2006). Dyslexia and the failure to form a perceptual anchor. *Nature neuroscience, 9*(12), 1558-1564.

Ahissar, M., Protopapas, A., Reid, M., & Merzenich, M. M. (2000). Auditory processing parallels reading abilities in adults*. Proceedings of the National Academy of Sciences, 97*(12), 6832-6837.

Allan, L. G. (1998). The influence of the scalar timing model on human timing research. *Behavioural Processes*, *44*(2), 101-117.

Alloway, T. P., Gathercole, S. E., & Pickering, S. J. (2006). Verbal and visuospatial short-term and working memory in children: Are they separable?. *Child development, 77*(6), 1698-1716.

Altemeier, L. E., Abbott, R. D., & Berninger, V. W. (2008). Executive functions for reading and writing in typical literacy development and dyslexia. *Journal of clinical and experimental neuropsychology, 30*(5), 588-606.

Altgassen, M., Koban, N., & Kliegel, M. (2012). Do adults with autism spectrum disorders compensate in naturalistic prospective memory tasks?. *Journal of Autism and Developmental Disorders, 42*(10), 2141-2151.

Altgassen, M., Vetter, N. C., Phillips, L. H., Akguen, C., & Kliegel, M. (2014). Theory of mind and switching predict prospective memory performance in adolescents. *Journal of experimental child psychology, 127*, 163-175.

Amitay, S., Ben-Yehudah, G., Banai, K., & Ahissar, M. (2002). Disabled readers suffer from visual and auditory impairments but not from a specific magnocellular deficit. *Brain*, *125*(10), 2272-2285.

Anderson, J. R. (1987). Skill acquisition: Compilation of weak-method problem situations. *Psychological review*, *94*(2), 192.

Augur, J. (1985). Guidelines for teachers, parents and learners. In M. Snowling (Ed.), Children’s Written Language Difficulties (pp. 147-170). Windsor, Berkshire: NFER-Nelson.

Bacon, A. M., Parmentier, F. B., & Barr, P. (2013). Visuospatial memory in dyslexia: Evidence for strategic deficits. *Memory*, *21*(2), 189-209.

Baddeley, A. (1986). Oxford psychology series, No. 11. Working memory.

Baddeley, A. (1996). The fractionation of working memory. *Proceedings of the National Academy of Sciences*, *93*(24), 13468-13472.

Baddeley, A.D., & Hitch, G.J. (1994). Developments in the concept of working memory. *Neuropsychology, 8*(4), 485.

Baddeley, A., Logie, R., Bressi, S., Sala, S. D., & Spinnler, H. (1986). Dementia and working memory. *The Quarterly Journal of Experimental Psychology Section A*, *38*(4), 603-618.

Badian, N. A. (1984). Reading disability in an epidemiological context incidence and environmental correlates. *Journal of Learning Disabilities, 17*(3), 129-136.

Bakan, P. (1955). Effect of set and work speed on time estimation. *Perceptual and Motor Skills*.

Baldo, J. V., & Shimamura, A. P. (1998). Letter and category fluency in patients with frontal lobe lesions. *Neuropsychology, 12*(2), 259.

Banai, K., & Ahissar, M. (2006). Auditory processing deficits in dyslexia: task or stimulus related?. *Cerebral Cortex, 16*(12), 1718-1728.

Banai, K., & Ahissar, M. (2009). Perceptual learning as a tool for boosting working memory among individuals with reading and learning disability. *Learning & Perception, 1*(1), 115-134.

Banich, M. T. (2009). Executive function the search for an integrated account. *Current Directions in Psychological Science, 18*(2), 89-94.

Baudouin, A., Vanneste, S., Pouthas, V., & Isingrini, M. (2006). Age related changes in duration reproduction: Involvement of working memory processes. *Brain and Cognition, 62*(1), 17-23.

Bayliss, D. M., Jarrold, C., Baddeley, A. D., & Gunn, D. M. (2005). The relationship between short-term memory and working memory: Complex span made simple?. *Memory, 13*(3-4), 414-421.

Bental, B., & Tirosh, E. (2007). The relationship between attention, executive functions and reading domain abilities in attention deficit hyperactivity disorder and reading disorder: A comparative study. *Journal of Child Psychology and Psychiatry*, *48*(5), 455-463.

Benton, A. L. (1968). Differential behavioral effects in frontal lobe disease. *Neuropsychologia, 6*(1), 53-60.

Berry, D. C., Berry, D., & Dienes, Z. (1993). *Implicit learning: Theoretical and empirical issues*. Psychology Press.

Binkofski, F., & Buccino, G. (2004). Motor functions of the Broca's region. *Brain and language*, *89*(2), 362-369.

Bishop, D. V., McDonald, D., Bird, S., & Hayiou-Thomas, M. E. (2009). - Children who read words accurately despite language impairment: Who are they and how do they do it?. *Child development*, *80*(2), 593-605.

Bishop, D. V., & Snowling, M. J. (2004). Developmental dyslexia and specific language impairment: Same or different?. *Psychological bulletin, 130*(6), 858.

Bisson, N., Tobin, S., & Grondin, S. (2012). Prospective and retrospective time estimates of children: a comparison based on ecological tasks. *PLoS One, 7*(3), e33049.

Bizo, L. A., & White, K. G. (1997). Training with controlled reinforcer density: Implications for models of timing. *Journal of Experimental Psychology: Animal Behavior Processes*, *23*(1), 44.

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child development, 78(*2), 647-663.

Blau, V., Reithler, J., van Atteveldt, N., Seitz, J., Gerretsen, P., Goebel, R., & Blomert, L. (2010). Deviant processing of letters and speech sounds as proximate cause of reading failure: a functional magnetic resonance imaging study of dyslexic children. *Brain, 133*(3), 868-879.

Block, R.A. (1990). Models of psychological time. In R.A. Block (Ed.), Cognitive models of psychological time (pp. 1-35). Hillsdale,· NJ: Erlbaul1l.

Block, R. A. (1992). Prospective and retrospective duration judgment: The role of information processing and memory. In *Time, action and cognition* (pp.141-152). Springer, Dordrecht.

Block, R. A., George, E. J., & Reed, M. A. (1980). A watched pot sometimes boils: A study of duration experience. *Acta psychologica*, *46*(2), 81-94.

Block, R. A., Grondin, S., & Zakay, D. (2018). Prospective and retrospective timing processes: Theories, methods, and findings. Timing and Time Perception: Procedures, measures.

Block, R. A., Hancock, P. A., & Zakay, D. (2010). How cognitive load affects duration judgments: A meta-analytic review. *Acta psychologica*, *134*(3), 330-343.

Block, R. A., & Zakay, D. (1996). Models of psychological time revisited. *Time and mind*, *33*(9), 171-195.

Block, R. A., & Zakay, D. (1997). Prospective and retrospective duration judgments: A meta-analytic review. *Psychonomic bulletin & review*, *4*(2), 184-197.

Blomert, L. (2011). The neural signature of orthographic–phonological binding in successful and failing reading development. *Neuroimage, 57*(3), 695-703.

Boets, B., Wouters, J., Van Wieringen, A., & Ghesquiere, P. (2007). Auditory processing, speech perception and phonological ability in pre-school children at high-risk for dyslexia: A longitudinal study of the auditory temporal processing theory. *Neuropsychologia*, *45*(8), 1608-1620.

Bogaerts, L., Szmalec, A., Hachmann, W. M., Page, M. P., Woumans, E., & Duyck, W. (2015). Increased susceptibility to proactive interference in adults with dyslexia?. *Memory, 23*(2), 268-277.

Booth, J. N., Boyle, J. M., & Kelly, S. W. (2014). The relationship between inhibition and working memory in predicting children's reading difficulties. *Journal of research in reading*, *37*(1), 84-101.

Brachacki, G. W., Fawcett, A. J., & Nicolson, R. I. (1994). Adults with dyslexia have a deficit in voice recognition. *Perceptual and motor skills*, *78*(1), 304-306.

Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read—a causal connection. *Nature, 301*(5899), 419-421.

Brandimonte, M. A., & Passolunghi, M. C. (1994). The effect of cue familiarity, cue-distinctiveness, and retention interval on prospective remembering. *The Quarterly Journal of Experimental Psychology, 47*(3), 565-587.

Bretherton, L., & Holmes, V. M. (2003). The relationship between auditory temporal processing, phonemic awareness, and reading disability. *Journal of experimental child psychology*, *84*(3), 218-243.

Broadbent, D. E., Cooper, P. F., FitzGerald, P., & Parkes, K. R. (1982). The cognitive failures questionnaire (CFQ) and its correlates. *British journal of clinical psychology*, *21*(1), 1-16.

Brosnan, M., Demetre, J., Hamill, S., Robson, K., Shepherd, H., & Cody, G. (2002). Executive functioning in adults and children with developmental dyslexia. Neuropsychologia, 40, 2144–2155.

Brown, S. W. (1997). Attentional resources in timing: Interference effects in concurrent temporal and nontemporal working memory tasks. *Perception & psychophysics*, *59*(7), 1118-1140.

Bruno, J. E., & Maguire, S. R. (1993). Perception and allocation of time by dyslexic children. *Perceptual and motor skills, 77*(2), 419-432.

Brunswick, N., McDougall, S., & de Mornay Davies, P. (Eds.). (2010). *Reading and dyslexia in different orthographies*. Psychology Press.

Brustio, P. R., Magistro, D., Zecca, M., Rabaglietti, E., & Liubicich, M. E. (2017). Age-related decrements in dual-task performance: Comparison of different mobility and cognitive tasks. A cross sectional study. *PLoS One*, *12*(7), e0181698.

Buhusi, C. V., & Meck, W. H. (2005). What makes us tick? Functional and neural mechanisms of interval timing. *Nature Reviews Neuroscience, 6*(10), 755-765.

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child development*, *72*(4), 1032-1053.

Carlson, S. M., & Wang, T. S. (2007). Inhibitory control and emotion regulation in preschool children. *Cognitive Development, 22*(4), 489-510.

Cassim, R., Talcott, J. B., & Moores, E. (2014). Adults with dyslexia demonstrate large effects of crowding and detrimental effects of distractors in a visual tilt discrimination task. PloS one, 9(9).

Catts, H. W., & Adlof, S. (2011). Phonological and other language deficits associated with dyslexia. *Individual differences in reading: Theory and evidence*, 137-151.

Catts, H. W., Nielsen, D. C., Bridges, M. S., Liu, Y. S., & Bontempo, D. E. (2015). Early identification of reading disabilities within an RTI framework. *Journal of learning disabilities*, *48*(3), 281-297.

Chiappe, P., Stringer, R., Siegel, L. S., & Stanovich, K. E. (2002). Why the timing deficit hypothesis does not explain reading disability in adults. *Reading and Writing*, *15*(1), 73-107.

Chein, J. M., Moore, A. B., & Conway, A. R. (2011). Domain-general mechanisms of complex working memory span. *NeuroImage, 54(*1), 550-559.

Cockburn, J. (1995). Task interruption in prospective memory: A frontal lobe function?. *Cortex, 31*(1), 87-97.

Collins, A., & Koechlin, E. (2012). Reasoning, learning, and creativity: frontal lobe function and human decision-making. *PLoS biology*, *10*(3), e1001293.

Conway, C. M., & Christiansen, M. H. (2001). Sequential learning in non-human primates. *Trends in cognitive sciences*, *5*(12), 539-546.

Cowan, N., Hogan, T. P., Alt, M., Green, S., Cabbage, K. L., Brinkley, S., & Gray, S. (2017). Short-term memory in childhood dyslexia: Deficient serial order in multiple modalities. *Dyslexia*, *23*(3), 209-233.

Conway, A. R., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic bulletin & review, 12*(5), 769-786.

Criaud, M., & Boulinguez, P. (2013). Have we been asking the right questions when assessing response inhibition in go/no-go tasks with fMRI? A meta analysis and critical review. *Neuroscience & biobehavioral reviews*, *37*(1), 11-23.

Csikszentmihalyi, M., & Larson, R. (2014). Validity and reliability of the experience-sampling method. In Flow and the foundations of positive psychology (pp. 35-54). Springer Netherlands.

Daneman, M., & Carpenter, P. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 450-466.

Dawes, P., Sirimanna, T., Burton, M., Vanniasegaram, I., Tweedy, F., & Bishop, D. V. (2009). Temporal auditory and visual motion processing of children diagnosed with auditory processing disorder and dyslexia. *Ear and hearing, 30*(6), 675-686.

Dehaene, S., Pegado, F., Braga, L. W., Ventura, P., Nunes Filho, G., Jobert, A., ... & Cohen, L. (2010). How learning to read changes the cortical networks for vision and language. *science, 330*(6009), 1359-1364.

Denckla, M. B., & Rudel, R. G. (1976). Rapid 'automatized'naming (RAN): Dyslexia differentiated from other learning disabilities. *Neuropsychologia*, *14*(4), 471-479.

de Lima, R. F., Azoni, C. A. S., & Ciasca, S. M. (2013). Attentional and executive deficits in Brazilian children with developmental dyslexia. *Psychology*, *4*(10), 1.

Diamond, A. (2013). Executive functions. *Annual review of psychology, 64*, 135.

Doyle, C. (2017). *Executive function (EF) in dyslexia: examining an EF profile associated with dyslexia and comorbid dyslexia-ADHD and exploring the near and far transfer effects of EF training in dyslexia alone* (Doctoral dissertation, Dublin City University).

Droit-Volet, S., Wearden, J. H., & Zélanti, P. S. (2015). Cognitive abilities required in time judgment depending on the temporal tasks used: a comparison of children and adults. *The Quarterly Journal of Experimental Psychology, 68*(11), 2216-2242.

Eckert, M. A., Leonard, C. M., Richards, T. L., Aylward, E. H., Thomson, J., & Berninger, V. W. (2003). Anatomical correlates of dyslexia: frontal and cerebellar findings. *Brain*, *126*(2), 482-494.

Einstein, G. O., & McDaniel, M. A. (1990). Normal aging and prospective memory. Journal of Experimental Psychology: Learning, Memory, and Cognition,16(4), 717.

Einstein, G. O., & McDaniel, M. A. (1996). Retrieval processes in prospective memory: Theoretical approaches and some new empirical findings. Prospective memory: Theory and applications, 115-141.

Einstein, G.O., & McDaniel, M.A. (2000). Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. Applied cognitive psychology, 14(7), S127-S144.

Einstein, G. O., & McDaniel, M. A. (2005). Prospective memory: Multiple retrieval processes. Current Directions in Psychological Science, 14(6), 286-290.

Einstein, G. O., McDaniel, M. A., Thomas, R., Mayfield, S., Shank, H., Morrisette, N., & Breneiser, J. (2005). Multiple processes in prospective memory retrieval: factors determining monitoring versus spontaneous retrieval. Journal of Experimental Psychology: General, 134(3), 327.

Elliot, J.G., & Grigorenko, E.L. (2014). The dyslexia debate (No. 14). Cambridge University Press.

Ellis, J., & Kvavilashvili, L. (2000). Prospective memory in 2000: Past, present, and future directions. *Applied Cognitive Psychology, 14*(7), S1-S9.

Eloranta, A. K., Närhi, V. M., Eklund, K. M., Ahonen, T. P., & Aro, T. I. (2019). Resolving reading disability — Childhood predictors and adult-age outcomes. *Dyslexia*, *25*(1), 20-37.

Fawcett, A. J., & Nicolson, R. I. (1992). Automatisation deficits in balance for dyslexic children. *Perceptual and motor skills*, *75*(2), 507-529.

Fawcett, A. J., & Nicolson, R. I. (1998). The Dyslexia Adult Screening Test (DAST): Complete Kit. Psychological Corporation.

Fawcett, A. J., & Nicolson, R. I. (1999). Performance of dyslexic children on cerebellar and cognitive tests. *Journal of motor behavior*, *31*(1), 68-78.

Fawcett, A. J., Nicolson, R. I., & Dean, P. (1996). Impaired performance of children with dyslexia on a range of cerebellar tasks. *Annals of Dyslexia*, *46*(1), 259-283.

Federmeier, K. D., Kutas, M., & Schul, R. (2010). Age-related and individual differences in the use of prediction during language comprehension. *Brain and language, 115*(3), 149-161.

Fischbach, A., Könen, T., Rietz, C. S., & Hasselhorn, M. (2014). What is not working in working memory of children with literacy disorders? Evidence from a three-year-longitudinal study. *Reading and Writing, 27*(2), 267-286.

Fisher, S. E., & DeFries, J. C. (2002). Developmental dyslexia: genetic dissection of a complex cognitive trait. *Nature Reviews Neuroscience*, *3*(10), 767.

Fisk, J.E., & Sharp, C.A (2004). Age-related impairment in executive functioning: Updating, inhibition, shifting, and access. Journal of Clinical and Experimental Neuropsychology, 26(7), 874-890.

Fitzpatrick, S., Gilbert, S., & Serpell, L. (2013). Systematic review: are overweight and obese individuals impaired on behavioural tasks of executive functioning*?. Neuropsychology review, 23*(2), 138-156.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition an interference control functions: a latent-variable analysis. *Journal of experimental psychology: General*, *133*(1), 101.

Friedman, N. P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. *Cortex, 86*, 186-204.

Friston, K. (2010). The free-energy principle: a unified brain theory*?. Nature reviews neuroscience, 11*(2), 127.

Frith, U., Landerl, K., & Frith, C. D. (1995). Verbal fluency in dyslexia: Further evidence for a phonological deficit. *Dyslexia*, *1*, 2-11.

Gabay, Y., Schiff, R., & Vakil, E. (2012). Attentional requirements during acquisition and consolidation of a skill in normal readers and developmental dyslexics. *Neuropsychology*, *26*(6), 744.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection?. *Journal of memory and language, 29*(3), 336-360.

Gibbon, J., Church, R. M., & Meck, W.H. (1984). Scaler timing in memory. In J.Gibbon & L. Allan(Eds.), Animals of the New York Academy of Science: Vol. 423. Timing and time perception (pp. 52-77).

Glicksohn, J. (2001). Temporal cognition and the phenomenology of time: A multiplicative function for apparent duration. *Consciousness and Cognition*, *10*(1), 1-25.

Glicksohn, J., & Myslobodsky, M. S. (2006). What it takes to remember the future. *Timing the future: The case for a time-based prospective memory*, 263-306.

Gooch, D., Snowling, M., & Hulme, C. (2011). Time perception, phonological skills and executive function in children with dyslexia and/or ADHD symptoms. *Journal of child psychology and psychiatry*, *52*(2), 195-203.

Goswami, U. (2003). Why theories about developmental dyslexia require developmental designs. *Trends in Cognitive Sciences, 7,* 534–554.

Graf, P., & Grondin, S. (2006). Time perception and time-based prospective memory. Timing the future: The case for a time-based prospective memory, 1-24.

Grinblat, N., & Rosenblum, S. (2016). Why are they late? Timing abilities and executive control among students with learning disabilities. *Research in developmental disabilities*, *59*, 105-114.

Grondin, S. (2001). From physical time to the first and second moments of psychological time. *Psychological bulletin, 127*(1), 22.

Grondin, S. (Ed.). (2008). *Psychology of time*. Emerald Group Publishing.

Grondin, S. (2010). Timing and time perception: a review of recent behavioral and neuroscience findings and theoretical directions. *Attention, Perception, & Psychophysics, 72*(3), 561-582.

Grondin, S. (2012). Violation of the scalar property for time perception between 1 and 2 seconds: evidence from interval discrimination, reproduction, and categorization. *Journal of Experimental Psychology: Human Perception and Performance, 38* (4), 880.

Groth, K., Lachmann, T., Riecker, A., Muthmann, I., & Steinbrink, C. (2011). Developmental dyslexics show deficits in the processing of temporal auditory information in German vowel length discrimination. *Reading and Writing*, *24*(3), 285-303.

Guynn, M. J., & McDaniel, M. A. (2007). Target preexposure eliminates the effect of distraction on event-based prospective memory. *Psychonomic Bulletin & Review*, *14*(3), 484-488.

Guynn, M. J., McDaniel, M. A., & Einstein, G. O. (2001). Remembering to Perform Actions. *Memory for action: A distinct form of episodic memory?*, 25.

Hachmann, W. M., Bogaerts, L., Szmalec, A., Woumans, E., Duyck, W., & Job, R. (2014). Short-term memory for order but not for item information is impaired in developmental dyslexia. *Annals of dyslexia*, *64*(2), 121-136).

Hancock, R., Pugh, K. R., & Hoeft, F. (2017). Neural noise hypothesis of developmental dyslexia. *Trends in cognitive sciences*, *21*(6), 434-448.

Hannon, R., Adams, P., Harrington, S., Fries-Dias, C., & Gipson, M. T. (1995). Effects of brain injury and age on prospective memory self-rating and performance. *Rehabilitation Psychology*, *40*(4), 289.

Hatcher, J., Snowling, M. J., & Griffiths, Y. M. (2002). Cognitive assessment of dyslexic students in higher education. *British journal of educational psychology*, *72*(1), 119-133.

Hebb, D. O. (1961). Distinctive features of learning in the higher animal. *Brain mechanisms and learning*, *37*, 46.

Henderson, L. M., & Warmington, M. (2017). A sequence learning impairment in dyslexia? It depends on the task. *Research in Developmental Disabilities*, *60*, 198-210.

Henry, J. D., & Crawford, J. R. (2004). Verbal fluency deficits in Parkinson's disease: a meta-analysis. Journal of the International *Neuropsychological Society, 10* (04), 608-622.

Hepper, P. G., Scott, D., & Shahidullah, S. (1993). Newborn and fetal response to maternal voice. *Journal of Reproductive and Infant Psychology*, *11*(3), 147-153.

Herman, R., E. Kyle, F., & Roy, P. (2019). Literacy and phonological skills in oral deaf children and hearing children with a history of dyslexia. *Reading Research Quarterly*, *54*(4), 553-575.

Hicks, R. E., Miller, G. W., & Kinsbourne, M. (1976). Prospective and retrospective judgments of time as a function of amount of information processed. *The American journal of psychology*, 719-730.

Huizinga, M., Dolan, C.V., & van der Molen, M.W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropschologia, 44*(11), 2017-2036.

Isaki, E., Spaulding, T. J., & Plante, E. (2008). Contributions of language and memory demands to verbal memory performance in language learning disabilities. *Journal of Communication Disorders, 41*(6), 512-530.

Jersild, A. T. (1927). Mental set and shift. Archives of psychology.

Jones, M. R., & Boltz, M. (1989). Dynamic attending and responses to time. *Psychological review, 96*(3), 459.

Jones, M. W., Branigan, H. P., Parra, M. A., & Logie, R. H. (2013). Cross modal binding in developmental dyslexia. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *39*(6), 1807.

Jones, M. W., Kuipers, J. R., & Thierry, G. (2016). ERPs Reveal theTime Course of Aberrant Visual-Phonological Binding in Developmental Dyslexia. *Frontiers in human neuroscience, 10.*

Jorm, A. F. (1983). Specific reading retardation and working memory: A review. *British journal of Psychology, 74*(3), 311-342.

Kadesjö, B., & Gillberg, C. (2001). The comorbidity of ADHD in the general population of Swedish school-age children. *Journal of Child Psychology and Psychiatry, 42*(4), 487-492.

Kapoula, Z., Lê, T. T., Bonnet, A., Bourtoire, P., Demule, E., Fauvel, C., ... & Yang, Q. (2010). Poor Stroop performances in 15-year-old dyslexic teenagers. *Experimental brain research, 203*(2), 419-425.

Kastenbaum, R. (1994). Time perspective. In (R. J. Corsini, Ed.) Encyclopedia of Psychology. New York: John Wiley.

Katusic, S. K., Colligan, R. C., Barbaresi, W. J., Schaid, D. J., & Jacobsen, S.J. (2001, November). Incidence of reading disability in a population-based birth cohort, 1976–1982, Rochester, Minn. In Mayo Clinic Proceedings (Vol. 76, No. 11, pp. 1081-1092). Elsevier.

Khan, A. (2014). An investigation into prospective memory in children with developmental dyslexia. *Frontiers in psychology, 5.*

Khan, A., Abdal-hay, A., Qazi, T., Calle, C. L., & Castillo, R. C. (2014). Time estimation in developmental dyslexia: An experimental investigation. Open *Journal of Medical Psychology, 3*(05), 373.

Kibby, M. Y., Fancher, J. B., Markanen, R., & Hynd, G. W. (2008). A quantitative magnetic resonance imaging analysis of the cerebellar deficit hypothesis of dyslexia. *Journal of child neurology*, *23*(4), 368-380.

Kopec, C. D., & Brody, C. D. (2010). Human performance on the temporal bisection task. *Brain and Cognition, 74*(3), 262-272.

Kramer, J. H., Knee, K., & Delis, D. C. (2000). Verbal memory impairments in dyslexia. *Archives of Clinical Neuropsychology, 15*(1), 83-93.

Krishnan, S., Watkins, K. E., & Bishop, D. V. (2016). Neurobiological Basis of Language Learning Difficulties. *Trends in Cognitive Sciences, 20*(9), 701-714.

Kronbichler, M., Hutzler, F., & Wimmer, H. (2002). Dyslexia: Verbal impairments in the absence of magnocellular impairments. *Neuroreport*, *13*(5), 617 620.

Labelle, M. A., Graf, P., Grondin, S., & Gagne-Roy, L. (2009). Time related processes in time-based prospective memory and in time interval production. *European Journal of Cognitive Psychology, 21*(4), 501-521.

Landerl, K., & Wimmer, H. (2000). Deficits in phoneme segmentation are not the core problem of dyslexia: Evidence from German and English children. *Applied psycholinguistics, 21*(02), 243-262.

Law, J. M., Vandermosten, M., Ghesquiere, P., & Wouters, J. (2014). The relationship of phonological ability, speech perception, and auditory perception in adults with dyslexia. *Frontiers in human neuroscience, 8,* 482.

Leclercq, A. L., & Majerus, S. (2010). Serial-order short-term memory predicts vocabulary development: Evidence from a longitudinal study. *Developmental Psychology*, *46*(2), 417.

Lehongre, K., Ramus, F., Villiermet, N., Schwartz, D., & Giraud, A. L. (2011). Altered low-gamma sampling in auditory cortex accounts for the three main facets of dyslexia. *Neuron, 72*(6), 1080-1090.

Lehto, J. E., Juujärvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British journal of developmental psychology*, *21*(1), 59-80.

Levin, B. E. (1990). Organizational deficits in dyslexia: Possible frontal lobe dysfunction. *Developmental Neuropsychology, 6*(2), 95-110.

Lewis, P. A., & Miall, R. C. (2006). Remembering the time: a continuous clock. *Trends in cognitive sciences, 10*(9), 401-406.

Lezak, M. D. (1995). Neuropsychological assessment, (3rd edition). New York: Oxford University Press.

Lezak, M., Howieson, D., Bigler, E., and Tranel, D. (2012). Neuropsychological Assessment. New York, NY: Oxford University Press.

Liberman, A. M. (1993). In speech perception, time is not what it seems. ANNALS NEW YORK ACADEMY OF SCIENCES, 682, 264-264.

Lima, R. F. D., Azoni, C. A. S., & Ciasca, S. M. (2011). Attentional performance and executive functions in children with learning difficulties. *Psicologia: Reflexão e Crítica, 24*(4), 685-691.

Livingstone, M. S., Rosen, G. D., Drislane, F. W., & Galaburda, A. M. (1991). Physiological and anatomical evidence for a magnocellular defect in developmental dyslexia. *Proceedings of the National Academy of Sciences*, *88*(18), 7943-7947.

Lobier, M., & Valdois, S. (2015). Visual attention deficits in developmental dyslexia cannot be ascribed solely to poor reading experience. *Nature Reviews Neuroscience, 16*(4), 225-225.

Lovegrove, W. (1993). Weakness in the transient visual system: A causal factor in dyslexia?.

Lunt, L., Bramham, J., Morris, R. G., Bullock, P. R., Selway, R. P., Xenitidis, K., & David, A. S. (2012). Prefrontal cortex dysfunction and 'jumping to conclusions': bias or deficit?. Journal of *Neuropsychology, 6*(1), 65-78.

Lyon, G. R. (1996). Learning disabilities. *Future Child, 6*, 54 –76.

Mackinlay, R. J., Kliegel, M., & Mäntylä, T. (2009). Predictors of time based prospective memory in children. *Journal of Experimental Child Psychology, 102*(3), 251-264.

Maguire, M. J., Brier, M. R., Moore, P. S., Ferree, T. C., Ray, D., Mostofsky, S., .. & Kraut, M. A. (2009). The influence of perceptual and semantic categorization on inhibitory processing as measured by the N2–P3 response. *Brain and cognition*, *71*(3), 196-203.

Mahone, E. M., Koth, C. W., Cutting, L., Singer, H. S., & Denckla, M. B. (2001). Executive function in fluency and recall measures among children with Tourette syndrome or ADHD. Journal of the International *Neuropsychological Society, 7*(1), 102-111.

Mahy, C. E., & Moses, L. J. (2011). Executive functioning and prospective memory in young children. *Cognitive Development, 26(*3), 269-281.

Mangels, J. A., & Ivry, R. B. (2001). Time perception. *The handbook of cognitive neuropsychology: What deficits reveal about the human mind*, 467-493.

Mann, V. A., & Liberman, I. Y. (1984). Phonological awareness and verbal short term memory. *Journal of learning disabilities*, *17*(10), 592-599.

Mäntylä, T. (2003). Assessing absentmindedness: Prospective memory complaint and impairment in middle-aged adults. *Memory & Cognition, 31*(1), 15-25.

Martin, M., Kliegel, M., & McDaniel, M. A. (2003). The involvement of executive functions in prospective memory performance of adults. *International Journal of Psychology, 38*(4), 195-206.

Martinez Perez, T., Poncelet, M., Salmon, E., & Majerus, S. (2015). Functional alterations in order short-term memory networks in adults with dyslexia. *Developmental Neuropsychology*, *40*(7-8), 407-429.

Marotta, L., Trasciani, M., & Vicari, S. (2008). *CMF test. Evaluation of metaphonological skills. With CD-ROM.* Erickson Editions.

Marzocchi, G. M., Oosterlaan, J., Zuddas, A., Cavolina, P., Geurts, H., Redigolo, D., Vio,C. & Sergeant, J. A. (2008). Contrasting deficits on executive functions between ADHD and reading disabled children. *Journal of Child Psychology and Psychiatry, 49*, 543 552.

Matthews, A. J., & Martin, F. H. (2015). Spatial attention and reading ability: ERP correlates of flanker and cue-size effects in good and poor adult phonological decoders. *Brain and language, 151*, 1-11.

McDaniel, M. A., & Einstein, G. O. (2000). Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. Applied cognitive psychology, 14(7), S127-S144.

McDaniel, M. A., & Einstein, G. O. (2007). Prospective Memory: An Overview and Synthesis of an Emerging Field: An Overview andSynthesis of an Emerging Field. Sage Publications.

McDaniel, M. A., Glisky, E. L., Rubin, S. R., Guynn, M. J., & Routhieaux, B. C. (1999). Prospective memory: A neuropsychological study. *Neuropsychology, 13,* 103–110.

McDaniel, M. A., Guynn, M. J., Einstein, G. O., & Breneiser, J. (2004). Cue focused and reflexive-associative processes in prospective memory retrieval. Journal of Experimental Psychology*: Learning, Memory, and Cognition, 30*(3), 605.

McFarland, C. P., & Glisky, E. L. (2009). Frontal lobe involvement in a task of time-based prospective memory. *Neuropsychologia, 47*(7), 1660-1669.

McGrath, L. M., Pennington, B. F., Shanahan, M. A., Santerre-Lemmon, L. E., Barnard, H. D., Willcutt, E. G., … Olson, R. K. (2011). A multiple deficit model of reading disability and attention deficit/hyperactivity disorder: Searching for shared cognitive deficits. *Journal of Child Psychology and Psychiatry, 52,* 547-557.

McLean, G. M., Stuart, G. W., Coltheart, V., & Castles, A. (2011). Visual temporal processing in dyslexia and the magnocellular deficit theory: The need for speed? *Journal of Experimental Psychology: Human Perception and Performance, 37*, 1957–1975.

McLoughlin, D., Fitzgibbon, G., & Young, V. (1994). Adult Dyslexia: Assessment. *Counselling and Training. London: Whurr*.

McNamara, J. K., & Wong, B. (2003). Memory for everyday information in students with learning disabilities. *Journal of Learning Disabilities, 36(5), 394-406*.

Meltzer, L. (1991). Problem-solving Strategies and Academic Performance in Learning-disabled Students: Do Subtypes. *Subtypes of learning disabilities: Theoretical perspectives and research*, 163.

Menghini, D., Carlesimo, G. A., Marotta, L., Finzi, A., & Vicari, S. (2010). Developmental dyslexia and explicit long-term memory. *Dyslexia*, *16*(3), 213-225.

Menghini, D., Finzi, A., Benassi, M., Bolzani, R., Facoetti, A., Giovagnoli, S., ... & Vicari, S. (2010). Different underlying neurocognitive deficits in developmental dyslexia: a comparative study. *Neuropsychologia*, *48*(4), 863 872.

Menghini, D., Finzi, A., Carlesimo, G. A., & Vicari, S. (2011). Working memory impairment in children with developmental dyslexia: is it just a phonological deficity?. *Developmental Neuropsychology, 36*(2), 199-213.

Miles, T. R. (1982). The Bangor Dyslexia Test. Cambridge: Learning Development Aids.

Miles, T. R., Gilroy, D., & Du Pre, E. A. (2007). *Dyslexia at college*. Routledge.

Miller-Shaul, S. (2005). The characteristics of young and adult dyslexics readers on reading and reading related cognitive tasks as compared to normal readers. *Dyslexia*, *11*(2), 132-151.

Mioni, G., Santon, S., Stablum, F., & Cornoldi, C. (2016). Time-based prospective memory difficulties in children with ADHD and the role of time perception and working memory. *Child Neuropsychology, 121*.

Mioni, G., & Stablum, F. (2014). Monitoring behaviour in a time-based prospective memory task: The involvement of executive functions and time perception. *Memory, 22*(5), 536-552.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current directions in psychological science*, *21*(1), 8-14.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive psychology, 41*(1), 49-100.

Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding?. *Journal of experimental child psychology, 64*(2), 199-231.

Moll, K., Loff, A., & Snowling, M. J. (2013). Cognitive endophenotypes of dyslexia. *Scientific Studies of Reading, 17*, 385-397.

Monsell, S. (2003). Task switching. *Trends in cognitive sciences, 7*(3), 134-140.

Montgomery, C., Hatton, N. P., Fisk, J. E., Ogden, R. S., & Jansari, A. (2010). Assessing the functional significance of ecstasy-related memory deficits using a virtual paradigm. *Human Psychopharmacology: Clinical and Experimental*, *25*(4), 318-325.

Moores, E., Nicolson, R., & Fawcett, A. (2003). Attention deficits in dyslexia: Evidence for an automatisation deficit?. *European Journal of Cognitive Psychology, 15(*3), 321-348.

Morris, R. G., Miotto, E. C., Feigenbaum, J. D., Bullock, P., & Polkey, C. E. (1997). The effect of goal-subgoal conflict on planning ability after frontal and temporal-lobe lesions in humans. *Neuropsychologia, 35*(8), 1147-1157.

Moura, O., Simões, M. R., & Pereira, M. (2015). Executive functioning in children with developmental dyslexia. *The Clinical Neuropsychologist, 28* (sup1), 20-41.

Närhi, V., Räsänen, P., Metsäpelto, R. L., & Ahonen, T. (1997). Trail Making Test in assessing children with reading disabilities: A test of executive functions or content information. *Perceptual and Motor Skills, 84*(3_suppl), 1355-1362.

Nergård-Nilssen, T., & Hulme, C. (2014). Developmental dyslexia inadults: Behavioural manifestations and cognitive correlates. *Dyslexia, 20*(3), 191-207.

Newcombe, F. (1969). Missile wounds of the brain: A study of psychological deficits.

Nicolson, R. I., & Fawcett, A. J. (1990). Automaticity: A new framework for dyslexia research?. *Cognition, 35*(2), 159-182.

Nicolson, R. I., & Fawcett, A. J. (1994). Comparison of deficits in cognitive and motor skills among children with dyslexia. *Annals of dyslexia, 44*(1), 147-164.

Nicolson, R. I., Fawcett, A. J., Berry, E. L., Jenkins, I. H., Dean, P., & Brooks, D. J. (1999). Association of abnormal cerebellar activation with motor learning difficulties in dyslexic adults. *The Lancet, 353*(9165), 1662-1667.

Nicolson, R. I., Fawcett, A. J., & Dean, P. (1995). Time estimation deficits in developmental dyslexia: evidence of cerebellar involvement. Proceedings of the Royal Society of London B: *Biological Sciences, 259*(1354), 43-47.

Nicolson, R. I., Fawcett, A. J., & Dean, P. (2001). Developmental dyslexia: the cerebellar deficit hypothesis. Trends in neurosciences, 24(9), 508-511.

Nielsen, K., Abbott, R., Griffin, W., Lott, J., Raskind, W., & Berninger, V. W. (2016). Evidence-Based Reading and Writing Assessment for Dyslexia in Adolescents and Young Adults. *Learning disabilities (Pittsburgh, Pa.), 21*(1), 38.

Nigg, J. T. (2017). Annual Research Review: On the relations among self regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology. *Journal of child psychology and psychiatry, 58*(4), 361-383.

Nittrouer, S. (1999). Do temporal processing deficits cause phonological processing problems?. *Journal of Speech, Language, and Hearing Research*, *42*(4), 925-942.

Norman, D. A., & Shallice, T. (1980). Attention to Action: Willed and Automatic Control of Behavior Technical Report No. 8006.

Norman, D. A., & Shallice, T. (1986). Attention to action. In Consciousness and self-regulation (pp. 1-18). Springer US.

Ober, T. M., Brooks, P. J., Plass, J. L., & Homer, B. D. (2019). Distinguishing Direct and Indirect Effects of Executive Functions on Reading Comprehension in Adolescents. *Reading Psychology, 40*(6), 551-581.

Ogden, R. S., Wearden, J. H., & Montgomery, C. (2014). The differential contribution of executive functions to temporal generalisation, reproduction and verbal estimation. *Acta Psychologica*, *152*, 84-94.

Olulade, O. A., Napoliello, E. M., & Eden, G. F. (2013). Abnormal visual motion processing is not a cause of dyslexia. *Neuron*, *79*(1), 180-190.

Oriá, R. B., Costa, C. M. C., Lima, A. A., Patrick, P. D., & Guerrant, R. L. (2009). Semantic fluency: A sensitive marker for cognitive impairment in children with heavy diarrhea burdens?. *Medical hypotheses, 73*(5), 682-686.

Orton Dyslexia Society Research Committee (1994). Operational definition of dyslexia. In C. Scruggs (Ed.), Perspectives, 20, 4.

Page, M. P., & Norris, D. (2008). Is there a common mechanism underlying word-form learning and the Hebb repetition effect? Experimental data and a modelling framework. In *Interactions between short-term and long-term memory in the verbal domain* (pp. 148-168). Psychology Press.

Page, M. P. A., & Norris, D. (2009). A model linking immediate serial recall, the Hebb repetition effect and the learning of phonological word forms. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1536), 3737-3753.

Pennington, B. F. (2006). From single to multiple deficit models of developmental disorders. *Cognition*, *101*(2), 385-413.

Pennington, B. F., Santerre–Lemmon, L., Rosenberg, J., MacDonald, B., Boada, R., Friend, A. … Olson, R. K. (2012). Individual prediction of dyslexia by single versus multiple deficit models. *Journal of Abnormal Psychology, 121*, 212-224.

Perez, T. M., Majerus, S., Mahot, A., & Poncelet, M. (2012). Evidence for a specific impairment of serial order short-term memory in dyslexic children. *Dyslexia, 18*(2), 94-109.

Peterson, R. L., Pennington, B. F., Shriberg, L. D., & Boada, R. (2009). What influences literacy outcome in children with speech sound disorder?.

Plummer, P., & Eskes, G. (2015). Measuring treatment effects on dual task performance: a framework for research and clinical practice. *Frontiers in human neuroscience, 9*, 225.

Poljac, E., Simon, S., Ringlever, L., Kalcik, D., Groen, W. B., Buitelaar, J. K., & Bekkering, H. (2010). Impaired task switching performance in children with dyslexia but not in children with autism. *The Quarterly Journal of Experimental Psychology*, *63*(2), 401-416.

Prado, C., Dubois, M., & Valdois, S. (2007). The eye movements of dyslexic children during reading and visual search: impact of the visual attention span. *Vision research*, *47*(19), 2521-2530.

Rae, C., Lee, M. A., Dixon, R. M., Blamire, A. M., Thompson, C. H., Styles, P., ... & Stein, J. F. (1998). Metabolic abnormalities in developmental dyslexia detected by 1H magnetic resonance spectroscopy. *The Lancet*, *351*(9119), 1849-1852.

Rakitin, B. C., Gibbon, J., Penney, T. B., Malapani, C., Hinton, S. C., & Meck, W. H. (1998). Scalar expectancy theory and peak-interval timing in humans. *Journal of Experimental Psychology: Animal Behavior Processes*, *24*(1),15.

Rammsayer, T. H., & Lima, S. D. (1991). Duration discrimination of filled and empty auditory intervals: Cognitive and perceptual factors. *Perception & Psychophysics*, *50*(6), 565-574.

Ramus, F. (2003). Developmental dyslexia: specific phonological deficit or general sensorimotor dysfunction?. *Current opinion in neurobiology, 13 (*2), 212-218.

Raskin, S., Buckheit, C., & Sherrod, C. (2010). Memory for intentions test (MIST). *Lutz, FL: Psychological Assessment Resources*.

Rattat, A. C., & Droit-Volet, S. (2012). What is the best and easiest method of preventing counting in different temporal tasks?. *Behavior Research Methods, 44*(1), 67-80.

Reid, A. A., Szczerbinski, M., Iskierka-Kasperek, E., & Hansen, P. (2007). Cognitive profiles of adult developmental dyslexics: theoretical implications. *Dyslexia*, *13*(1), 1-24.

Reitan, R. M., & Wolfson, D. (1985). *The Halstead-Reitan neuropsychological test battery: Theory and clinical interpretation* (Vol. 4). Reitan Neuropsychology.

Reiter, A., Tucha, O., & Lange, K. W. (2005). Executive functions in children with dyslexia. *Dyslexia, 11*(2), 116–131.

Requena, C., Alvarez-Merino, P., & Rebok, G. W. (2019). Age-and education adjusted normative data for the Rivermead Behavioural Memory Test (RBMT). *European journal of ageing*, *16*(4), 473-480.

Richardson, F. M., Ramsden, S., Ellis, C., Burnett, S., Megnin, O., Catmur, C., .. & Price, C. J. (2011). Auditory short-term memory capacity correlates with gray matter density in the left posterior STS in cognitively normal and dyslexic adults. *Journal of Cognitive Neuroscience, 23*(12), 3746-3756.

Richlan, F. (2014). Functional neuroanatomy of developmental dyslexia: the role of orthographic depth. *Frontiers in human neuroscience*, *8*, 347.

Rosen, S. (2003). Auditory processing in dyslexia and specific language impairment: Is there a deficit? What is its nature? Does it explain anything?. *Journal of phonetics*, *31*(3-4), 509-527.

Roth, R. M., Isquith, P. K., & Gioia, G. A. (2005). BRIEF-A: Behavior rating inventory of executive function--adult version: Professional manual. Psychological Assessment Resources.

Rutter, M., Caspi, A., Fergusson, D., Horwood, L. J., Goodman, R., Maughan, B., ... & Carroll, J. (2004). Sex differences in developmental reading disability: new findings from 4 epidemiological studies. *Jama*, *291*(16), 2007-2012.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8 month-old infants. *Science*, *274*(5294), 1926-1928.

Schiavone, G., Linkenkaer-Hansen, K., Maurits, N. M., Plakas, A., Maassen, B. A., Mansvelder, H. D., ... & van Zuijen, T. L. (2014). Preliteracy signatures of poor-reading abilities in resting-state EEG. *Frontiers in human neuroscience, 8.*

Schnitzspahn, K. M., Stahl, C., Zeintl, M., Kaller, C. P., & Kliegel, M. 2013). The role of shifting, updating, and inhibition in prospective memory performance in young and older adults. *Developmental psychology, 49*(8), 1544.

Schwartz, S., & Baldo, J. (2001). Distinct patterns of word retrieval in right and left frontal lobe patients: a multidimensional perspective *Neuropsychologia, 39*(11), 1209-1217.

Sellen, A. J., Louie, G., Harris, J. E., & Wilkins, A. J. (1997). What brings intentions to mind? An in situ study of prospective memory. Memory, 4, 483-507.

Shallice, T. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, *298*(1089), 199-209.

Shallice, T., & Burgess, P. (1993). Supervisory control of action and thought selection.

Shao, Z., Janse, E., Visser, K., & Meyer, A. S. (2014). What do verbal fluency tasks measure? Predictors of verbal fluency performance in older adults. *Frontiers in psychology, 5*, 772.

Shaywitz, S. E. (1998). Dyslexia. *New England Journal of Medicine*, *338*(5), 307-312.

Shaywitz, S. E., Shaywitz, B. A., Fletcher, J. M., & Escobar, M. D. (1990). Prevalence of reading disability in boys and girls: Results of the Connecticut Longitudinal Study. *Jama, 264*(8), 998-1002.

Shaywitz, S. E., & Shaywitz, B. A. (2003). The science of reading and dyslexia. *Journal of American Association for Pediatric Ophthalmology and Strabismus {JAAPOS}*, *7*(3), 158-166.

Shehata, G. A., & Hassan, H. S. (2014). Assessment of cognitive functions psychomotor performance and attention deficit hyperactivity disorders among students with dyslexia.

Shi, Z., Church, R. M., & Meck, W. H. (2013). Bayesian optimization of time perception. *Trends in Cognitive Sciences, 17*(11), 556-564.

Shum, D., Ungvari, G. S., Tang, W. K., & Leung, J. P. (2004). Performance of schizophrenia patients on time-, event-, and activity-based prospective memory tasks. *Schizophrenia Bulletin*, *30*(4), 693-702.

Sigmundsson, H. (2005). Do visual processing deficits cause problem on response time task for dyslexics?. *Brain and cognition, 58*(2), 213-216.

Smith, G., Del Sala, S., Logie, R. H., & Maylor, E. A. (2000). Prospective and retrospective memory in normal ageing and dementia: A questionnaire study. *Memory*, *8*(5), 311-321.

Smith, R. E., Hunt, R. R., McVay, J. C., & McConnell, M. D. (2007). The cost of event-based prospective memory: Salient target events. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 734–746.

Smith-Spark, J. H. (2000). *Memory in adult dyslexics: An exploration of the working memory system* (Doctoral dissertation, University of Sheffield).

Smith-Spark, J. H. (2017). A review of prospective memory impairments in developmental dyslexia: evidence, explanations, and future directions. *The Clinical Neuropsychologist, 1-20.*

Smith-Spark, J. H. (2018). A review of prospective memory impairments in developmental dyslexia: Evidence, explanations, and future directions. *The Clinical Neuropsychologist*, *32*(5), 816-835.

Smith-Spark, J., Fawcett, A., Nicolson, R., & Fisk, J. (2004). Dyslexic students have more everyday cognitive lapses*. Memory, 12(*2), 174-182.

Smith-Spark, J. H., & Fisk, J. E. (2007). Working memory functioning developmental dyslexia*. Memory, 15*(1), 34-56.

Smith-Spark, J., Fisk, J., Fawcett, A., & Nicolson, R. (2003). Investigating the central executive in adult dyslexics: Evidence from phonological and visuospatial working memory performance. *European Journal of Cognitive Psychology, 15*(4), 567-587.

Smith-Spark, J. H., Henry, L. A., Messer, D. J., Edvardsdottir, E., & Zięcik, A. P. (2016). Executive functions in adults with developmental dyslexia. *Research in developmental disabilities, 53*, 323-341.

Smith-Spark, J. H., Henry, L. A., Messer, D. J., & Zięcik, A. P. (2017). Verbal and non-verbal fluency in adults with developmental dyslexia: Phonological processing or executive control problems?. *Dyslexia*, *23*(3), 234-250.

Smith-Spark, J. H., & Moore, V. (2009). The representation and processing of familiar faces in dyslexia: differences in age of acquisition effects. *Dyslexia, 15*(2), 129-146.

Smith-Spark, J. H., Zięcik, A. P., & Sterling, C. (2016a). Self-Reports of Increased Prospective and Retrospective Memory Problems in Adults with Developmental Dyslexia. *Dyslexia*, *22*(3), 245-262.

Smith-Spark, J. H., Zięcik, A. P., & Sterling, C. (2016b). Time-based prospective memory in adults with developmental dyslexia. *Research in Developmental Disabilities*, *49*, 34-46.

Smith-Spark, J. H., Zięcik, A. P., & Sterling, C. (2017a). Adults with developmental dyslexia show selective impairments in time-based and self-initiated prospective memory: Self-report and clinical evidence. *Research in Developmental Disabilities, 62,* 247-258. doi:10.1016/j.ridd.2016.12.011.

Smith-Spark, J. H., Zięcik, A. P., & Sterling, C. (2017b). The event based prospective memory of adults with developmental dyslexia under naturalistic conditions. *Asia Pacific Journal of Developmental Differences, 4*(1), 17-33.

Snowling, M. (1987). Developmental Dyslexia-A Cognitive Developmental Perspective. In Bulletin of The British Psychological Society (Vol. 40, pp. A23-A23).

Snowling, M. J. (2000). Dyslexia. Blackwell publishing.

Snowling, M. J. (2008). Specific disorders and broader phenotypes: The case of dyslexia. The Quarterly Journal of Experimental Psychology, 61, 142-156.

Snowling, M. J., Gallagher, A., & Frith, U. (2003). Family risk of dyslexia is continuous: Individual differences in the precursors of reading skill. *Child development*, *74*(2), 358-373.

Snyder, H. R., Miyake, A., & Hankin, B. L. (2015). Advancing understanding of executive function impairments and psychopathology: bridging the gap between clinical and cognitive approaches. *Frontiers in psychology, 6*, 328.

Stanovich, K. E. (2000). *Progress in understanding reading: Scientific foundations and new frontiers*. Guilford Press.

Stein, J. (2001). The magnocellular theory of developmental dyslexia. *Dyslexia*, *7*(1), 12-36.

Stein, J., & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia. *Trends in neurosciences*, *20*(4), 147-152.

Stoet, G., Markey, H., & López, B. (2007). Dyslexia and attentional shifting. *Neuroscience letters*, *427*(1), 61-65.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental psychology*, *18*(6), 643.

Szmalec, A., Loncke, M., Page, M., & Duyck, W. (2011). Order or disorder? Impaired Hebb learning in dyslexia. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(5), 1270.

Taatgen, N., & van Rijn, H. (2011). Traces of times past: representations of temporal intervals in memory. *Memory &cognition, 39*(8), 1546-1560.

Takács, Á., Kóbor, A., Tárnok, Z., and Csépe, V. (2013). Verbal fluency in children with ADHD: strategy using and temporal properties. *Child Neuropsychol. 20*, 415–429. doi:10.1080/09297049.2013.799645.

Takács, Á., Kóbor, A., Tárnok, Z., & Csépe, V. (2014). Verbal fluency in children with ADHD: strategy using and temporal properties. *Child Neuropsychology*, *20*(4), 415-429.

Talbot, K. D. S., & Kerns, K. A. (2014). Event-and time-triggered remembering: The impact of attention deficit hyperactivity disorder on prospective memory performance in children. *Journal of Experimental Child Psychology*, *127*, 126-143.

Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in children. *Brain and language, 9*(2), 182-198.

Tallal, P., Miller, S., & Fitch, R. H. (1993). Neurobiological basis of speech: a case for the preeminence of temporal processing. *Annals of the New York academy of sciences, 682*(1), 27-47.

Taylor, S. J., Barker, L. A., Heavey, L., & McHale, S. (2015). The longitudinal development of social and executive functions in late adolescence and early adulthood. *Frontiers in behavioral neuroscience*, *9*, 252.

Thomas, E. A., & Weaver, W. B. (1975). Cognitive processing and time perception. *Perception & Psychophysics, 17(*4), 363-367.

Titz, C., & Karbach, J. (2014). Working memory and executive functions: effects of training on academic achievement. *Psychological research, 78*(6), 852 868.

Tobin, S., Bisson, N., & Grondin, S. (2010). An ecological approach to prospective and retrospective timing of long durations: a study involving gamers. *PloS one*, *5*(2), e9271.

Torppa, M., Parrila, R., Niemi, P., Lerkkanen, M. K., Poikkeus, A. M., & Nurmi, J. E. (2013). The double deficit hypothesis in the transparent Finnish orthography: A longitudinal study from kindergarten to Grade 2. *Reading and Writing*, *26*(8), 1353-1380.

Torgesen, J. K. (1977). Memorization processes in reading-disabled children. *Journal of Educational Psychology, 69*(5), 571.

Turner, M. (1997). Psychological assessment of dyslexia. London: Whurr.

Ullman, M. T., & Pullman, M. Y. (2015). A compensatory role for declarative memory in neurodevelopmental disorders. *Neuroscience & Biobehavioral Reviews*, *51*, 205-222.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods, 37*, 498-505.

Valdois, S., Lassus-Sangosse, D., & Lobier, M. (2012). Impaired Letter String Processing in Developmental Dyslexia: What Visual-to Phonology Code Mapping Disorder?. *Dyslexia, 18*(2), 77-93.

Van Bergen, E., De Jong, P. F., Maassen, B., & van der Leij, A. (2014). The effect of parents' literacy skills and children's preliteracy skills on the risk of dyslexia. *Journal of abnormal child psychology*, *42*(7), 1187-1200.

Van Bergen, E., de Jong, P. F., Regtvoort, A., Oort, F., van Otterloo, S., & van der Leij, A. (2011). Dutch children at family risk of dyslexia: Precursors, reading development, and parental effects. *Dyslexia, 17*, 2-18.

van Bergen, E., van der Leij, A., & de Jong, P. F. (2014). The intergenerational multiple deficit model and the case of dyslexia. *Frontiers in human neuroscience*, 346.

van den Berg, S., Aarts, H., Midden, C., & Verplanken, B. (2004). The role of executive processes in prospective memory tasks. *European Journal of Cognitive Psychology, 16*(4), 511-533.

van der Sluis, S., de Jong, P. F., & van der Leij, A. (2007). Executive functioning in children, and its relations with reasoning, reading, and arithmetic. *Intelligence, 35*(5), 427-449.

Vanneste, S., Baudouin, A., Bouazzaoui, B., & Taconnat, L. (2016). Age-related differences in time-based prospective memory: The role of time estimation in the clock monitoring strategy. *Memory*, *24*(6), 812-825.

Varvara, P., Varuzza, C., Sorrentino, A. C., Vicari, S., & Menghini, D. (2014). Executive functions in developmental dyslexia. *Frontiers in human neuroscience, 8*, 120.

Vellutino, F. R. (1979). Dyslexia: Theory and research. Cambridge, MA: MIT Press.

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades?. *Journal of child psychology and psychiatry*, *45*(1), 2-40.

Waldum, E. R., & McDaniel, M. A. (2016). Why are you late? Investigating the role of time management in time-based prospective memory. *Journal of Experimental Psychology: General*, *145*(8), 1049.

Wang, S., & Gathercole, S. E. (2013). Working memory deficits in children with reading difficulties: Memory span and dual task coordination. *Journal of experimental child psychology*, *115*(1), 188-197.

Wang, L. C., Tasi, H. J., & Yang, H. M. (2012). Cognitive inhibition in students with and without dyslexia and dyscalculia. *Research in Developmental Disabilities, 33*, 1453–1461.

Warmington, M., & Hulme, C. (2012). Phoneme awareness, visual verbal paired associate learning, and rapid automatized naming as predictors of individual differences in reading ability*. Scientific Studies of Reading,16* (1), 45-62.

Wearden, J. H. (1991). Do humans possess an internal clock with scalar timing properties?. *Learning and motivation*, *22*(1-2), 59-83.

Wearden, J. H. (1991). Human performance on an analogue of an interval bisection task. *The Quarterly Journal of Experimental Psychology Section B, 43*(1b), 59-81.

Wearden, J. H. (1992). Temporal generalization in humans. *Journal of Experimental Psychology: Animal Behavior Processes*, *18*(2), 134.

Wearden, J. H. (2003). Applying the scalar timing model to human time psychology: Progress and challenges. Time and mind II: Information processing perspectives, 21-39.

Wearden, J., & Bray, S. (2001). Scaler timing without reference: Episodic temporal generalization and bisection in humans*. Quarterly Journal of Experimental Psychology, 54B*, 289-310.

Wearden, J. H., Denovan, L., & Haworth, R. (1997). Scalar timing in temporal generalization in humans with longer stimulus durations. *Journal of Experimental Psychology: Animal Behavior Processes*, *23*(4), 502.

Wearden, J. H., & McShane, B. (1988). Interval production as an analogue of the peak procedure: Evidence for similarity of human and animal timing processes. *The Quarterly Journal of Experimental Psychology*, *40*(4), 363-375.

Wearden, J. H., Smith-Spark, J. H., Cousins, R., Edelstyn, N. M., Cody, F. W., & O'Boyle, D. J. (2009). Effect of click trains on duration estimates by people with Parkinson's disease. *The Quarterly Journal of Experimental Psychology, 62*(1), 33-40.

Wearden, J. H., Todd, N. P. M., & Jones, L. A. (2006). When do auditory/ visual differences in duration judgements occur?. *The Quarterly Journal of Experimental Psychology, 59*(10), 1709-1724.

Wechsler, D. (1993). The Wechsler Objective Reading Dimensions. London: The Psychological Corporation.

Wechsler, D. (2010). *Wechsler Adult Intelligence Scale – Fourth UK Edition*. San Antonio, TX: The Psychological Corporation.

Wester, A. J. (2014). The RBMT as a measure of everyday memory in patients with Korsakoff's syndrome. *Rivermead Behavioural Memory Test*, *1*, 31.

White, S., Milne, E., Rosen, S., Hansen, P., Swettenham, J., Frith, U., & Ramus, F. (2006). The role of sensorimotor impairments in dyslexia: a multiple case study of dyslexic children. *Developmental science*, *9*(3), 237-255.

Wilson, B. A., Greenfield, E., Clare, L., Baddeley, A., Cockburn, J., Watson, P. Tate, R., Sopena, S., Nannery, R., & Crawford, J. R. (2008). The Rivermead Behavioural Memory Test – Third Edition. London: Pearson Education Ltd.

Willcutt, E. G., Pennington, B. F., Olson, R. K., Chhabildas, N., & Hulslander, J. (2005). Neuropsychological analyses of comorbidity between reading disability and attention deficit hyperactivity disorder: In search of the common deficit. *Developmental neuropsychology*, *27*(1), 35-78.

Winograd, E. (1988). Some observations on prospective remembering. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), Practical aspects of memory: Current research and issues (Vol. 1, pp. 348-353). Chichester, UK: Wiley.

Wittmann, M. (2013). The inner sense of time: how the brain creates a representation of duration. *Nature Reviews Neuroscience, 14*(3), 217-223.

Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental dyslexias. *Journal of educational psychology*, *91*(3), 415.

Wolff, P. H. (2002). Timing precision and rhythm in developmental dyslexia. *Reading and Writing, 15*(1-2), 179-206.

World Federation of Neurology (1968). Report of research group on dyslexia and word literacy. Dallas, TX: WFN.

World Health Organization, 2011. International Statistical Classification of Diseases and Related Health Problems – 10th Revision, 4th ed. World Health Organization, Geneva.

Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2008). The role of executive function and attention in gait. *Movement disorders: official journal of the Movement Disorder Society*, *23*(3), 329-342.

Zakay, D. (1990). The evasive art of subjective time measurement: Some methodological dilemmas.

Zakay, D. (1992). On prospective time estimation, temporal relevance and temporal uncertainty. In *Time, action and cognition* (pp. 109-117). Springer, Dordrecht.

Zakay, D. (2000). Gating or switching? Gating is a better model of prospective timing (a response to 'switching or gating? 'by Lejeune). *Behavioural processes*, *52*(2-3), 63-69.

Zakay, D., & Block, R. A. (1995). An attentional-gate model of prospective time estimation. *Time and the dynamic control of behavior, 167-178*.

Zakay, D., & Block, R. A. (1996). The role of attention in time estimation processes. In *Advances in psychology* (Vol. 115, pp. 143-164). North Holland.

Zakay, D., & Block, R. A. (1997). Temporal cognition. Current Directions in *Psychological Science, 6*(1), 12-16.