Executive functions and children's reading difficulties: The effects of task modality, cognitive ability and comorbid conditions.

Josephine N. Booth

University of Strathclyde

School of Psychological Sciences and Health

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Author's Declaration

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

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Previously published work

A paper from Chapter Two has been published as:

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My role as first author involved study conceptualisation, data collection, analysis and writing up. The second author, as my first supervisor, was involved in consultation regarding study conceptualisation, advice regarding analysis and manuscript preparation. The third author, as second supervisor, was involved in discussion regarding conceptualisation and manuscript preparation. This paper can be found in Appendix A.

In addition, results from Chapters Four, Five, Six and Seven have been presented at a number of national and international conferences with my role as first author and presenter involving study design, participant recruitment, data collection, analysis and presentation.

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Date:

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List of Abbreviations

ADHD	Attention Deficit/Hyperactivity Disorder
ADHD group	Children with significantly high levels of ADHD symptoms
AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
CA	Chronological age matched group
CAS	Cognitive Assessment System
CELF	Clinical Evaluation of Language Fundamentals
CFI	Comparative Fit Index
CPT	Continuous Performance Task
DCD	Developmental Coordination Disorder
DRC	Dual Route Cascaded model
EFA	Exploratory Factor Analysis
ERP	Event-related Potential
Expressive LI	Expressive language problems
Expressive SLI	Specific Language Impairment with Expressive language problems
FSIQ	Full scale IQ
g	General intelligence
GPC	Grapheme-Phoneme Correspondence
HCSM	Hierarchical Competing Systems Model
I NV	Inhibition non-verbal
I V	Inhibition verbal
IAC	Interactive Activation and Competition
IQ	Intelligence Quotient
LEA	Local Education Authority
LI	Language Impairment
LTM	Long term memory
MFFT	Matching Familiar Figures Test

MIMIC	Multiple indicators and multiple causes model
Mixed LI	Mixed expressive and/or receptive language problems
Mixed SLI	Specific Language Impairment with Mixed expressive and/or receptive language problems
ML	Maximum Likelihood
MLR	Robust Maximum Likelihood
No LI	No Language Impairment
NVIQ	Non-verbal IQ
PDP	Parallel Distributed Processing model
RAN	Rapid Automatized Naming
RD	Reading Difficulties
RD-RC	Reading comprehension difficulties
RD-WR	Word reading difficulties
RL	Reading level matched group
RMSEA	Root Mean Square Error of Approximation
S-CPT	Swanson Cognitive Processing Test
SD	Standard Deviation
SE	Standard Error
SEM	Structural Equation Modelling
SLI	Specific Language Impairment
SRMR	Standardised Root Mean Square Residual
SSRT	Stop-signal Reaction Time
STM	Short-term memory
TDC	Typically Developing Controls
TLI	Tucker-Lewis Index
TOH	Tower of Hanoi
TOL	Tower of London
VIF	Variance Inflation Factor
WASI	Wechsler Abbreviated Scale of Intelligence
WCST	Wisconsin Card Sorting Task

WIAT	Wechsler Individual Achievement Test
WISC	Wechsler Intelligence Scale for Children
Without ADHD	Children without significantly high levels of ADHD symptoms
WM NV	Working memory non-verbal
WM V	Working memory verbal
WMTB-C	Working Memory Test Battery for Children

Abstract

This thesis examines the extent to which executive functions have an explanatory role in children's reading difficulties (RD) and explores inconsistent findings in the literature. Three studies are reported, the first of which is a meta-analysis which concluded that children with RD have a general impairment with executive functioning. Effect sizes varied as a function of assessment task, with task modality and definitional criteria moderating the magnitude of effect. The second study examined the extent to which inhibition and working memory predicted reading ability and whether this is independent of non-verbal IQ (NVIQ). Results from multiple regression found that inhibition and NVIQ predicted word reading; however with reading comprehension as the dependent variable, both inhibition and working memory made unique contributions, but not when NVIQ was included in the model. Furthermore, when multinomial logistic regression was employed, performance on tasks of inhibition and working memory requiring a verbal response discriminated children with RD from both age-, and reading-level matched control groups, with lower task performance being associated with the RD group. When non-verbal tasks were employed, only inhibition performance discriminated between the groups. The final study explored the influence of conditions comorbid with RD, specifically Attention Deficit Hyperactivity Disorder (ADHD) and language impairment (LI). 213 children with RD participated and the results from structural equation modelling revealed that while comorbidities did not influence the relationship between executive functions and reading, that differences in latent means were observed depending on the nature of the comorbidity. Furthermore, NVIQ did not mediate or moderate the relationship between executive functions and reading. Together, these findings indicate children with RD have profound difficulties with inhibition and working memory which both explain and predict the severity of RD. This relationship is not attributable to IQ, or influenced by comorbid conditions, however, but is impacted by underlying task demands. These results have implications for both the assessment and treatment of RD.

Chapter One

Introduction

It is estimated that between 10% and 15% of school children have difficulties with reading (Velluntino & Fletcher, 2005) which are persistent into adulthood (Hulme & Snowling, 2009) and which can have a number of negative consequences (Rutter, Yule, et al., 1975). While theoretical accounts of reading difficulties (RD) posit the primary deficit to be in the phonological system (Hulme & Snowling, 2009; Velluntino, Fletcher, Snowling, & Scanlon, 2004), deficiencies in the executive system have also been identified (Gathercole, Tiffany, Briscoe, Thorn, & Alspac-team, 2005; Pickering & Gathercole, 2004; Swanson, 2006) and it has been suggested that these problems could be "above and beyond their deficits in the phonological system" (Swanson, 2006, p. 58). Swanson (2006) highlights several executive areas where children with RD have difficulties, including maintaining relevant information in working memory, inhibition of irrelevant information and accessing material in long term memory (LTM). Furthermore, theoretical accounts of difficulties with reading comprehension implicate working memory skills, comprehension monitoring and inference making (Hulme & Snowling, 2009; Nation, 2005; Vukovic & Siegel, 2006b), and the ability to update information and inhibit distractors has been implicated in research(e.g. Palladino, Cornoldi, De Beni, & Pazzaglia, 2001). These "higher order" cognitive processes (Rayner & Pollatsek, 1989) all fall under the rubric of executive functions and may have implications for differential responsivity to reading intervention (Sesma, Mahone, Levine, Eason, & Cutting, 2009). The aim of this thesis is to examine the extent to which executive functions have an underpinning explanatory role in regard to children's RD.

1.1 Reading

Reading is the process of "transforming print to speech, or print to meaning"(Coltheart, 2005, p. 6). That is, orthographic representations (print) are converted to combinations of phonemes (speech sounds) or semantic representations (meaning). Thus, reading involves the combination of a number of skills and processes of considerable complexity (Cain, 2010). With regard to theoretical accounts, Gough and colleagues (1986; Hoover & Gough, 1990) proposed the "Simple View" of reading. This model holds that reading (R) is a product of decoding ability (D) and linguistic comprehension (C): R= D x C. That is, the interaction between the ability to successfully recognise words with no contextual cues and the ability to access semantic properties of words and interpret them constitutes reading capability. Thus if decoding ability is poor then reading ability will also be poor; however some level of reading can take place where there is poor comprehension but good decoding, and vice versa. In addition to highlighting the necessity of at least basic levels of both of these processes in order to read successfully, this model also distinguishes between the two components; thus illustrating the differential nature of these abilities. As such then, models regarding each of these processes will be examined separately.

1.1.1 Word reading.

Perfetti (1984, p. 57) argued that " the heart of reading is the access of word representations". Therefore, accessing word representations, which can be conceptualised as the ability to decode an orthographic representation, is central to the reading process. The ability to decode successfully is influenced by a number of factors such as: (a) orthographic regularity, that is whether a word can successfully be decoded using conventional grapheme-phoneme correspondence (GPC) rules or not; (b) consistency of spelling, i.e. whether a word's spelling is generally pronounced in the same way or not (e.g. deaf and leaf are inconsistent), and indeed the number of other words with similar spellings which conform to that pronunciation (i.e. a word's orthographic neighbours), for example, cash, mash and bash are all pronounced in the same way but wash differs; (c) morphology, that is, words which can be primed by prior presentation of a word of similar morphological root, for example like and likely; and indeed (d) frequency with which the word is encountered (Cain, 2010). In contrast to languages such as Finnish, English has a deep orthography (Frost, 2005) and as such is both irregular and inconsistent (Caravolas, 2005) making the process of reading in English more challenging than it is in more transparent orthographies (Paulesu, et al., 2001).

1.1.2 Models of word reading.

A number of different models of visual-word recognition have been proposed and distinctions can generally be made between two broad classes of models; search models and activation models. For example search models, such as the Bin model (Forster, 1976) and the Activation-Verification model (Paap, Newsome, McDonald, & Schvaneveldt, 1982), suggest that the process of reading involves matching a written word with entries in the lexicon, that is, entries contained in an individual's dictionary of words (Cain, 2010). This is achieved by searching specific areas of the lexicon for matches, for example, in orthographic similarity (i.e. the bin model) or feature similarity of individual letters and then individual words in serial order with activation levels determining which words to be searched for matches (i.e. the activation-verification model). Activation models, on the other hand, involve contemporaneous activation and inhibition rather than area searching, with words being selected when this activation reaches a certain limit (Lupker, 2005). A further distinction can be made within activation models, as some activation models, for example, the Logogen Model (Morton, 1969, 1979, 1980) the Interactive Activation and Competition (IAC) model (J. L. McClelland & Rumelhart, 1981) and the Dual Route Cascaded (DRC) model (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), can be conceived as fundamentally opposed to Parallel Distributed Processing (PDP) models, such as the Triangle model (Harm & Seidenberg, 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). PDP models work on the principle that words are not stored as whole representations in a lexicon as they are in other explanatory models; instead the lexical system comprises representations relating to the components of a word, i.e. semantics, phonics and orthographics, which are each activated in order to recognise individual words (Lupker, 2005). Two influential models of word reading are the DRC model and the Triangle model (Cain, 2010); as such these models will be examined in more detail.

1.1.2.1 The Dual-Route Cascaded model.

The Dual-Route Cascaded (DRC) model (Coltheart, et al., 1993; Coltheart, et al., 2001) exemplifies concepts regarding interactivity (Lupker, 2005) and builds upon the development of the Logogen model and the IAC model (see Coltheart, et al., 2001 for a review of the model's development); the DRC model is illustrated in Figure 1.1.

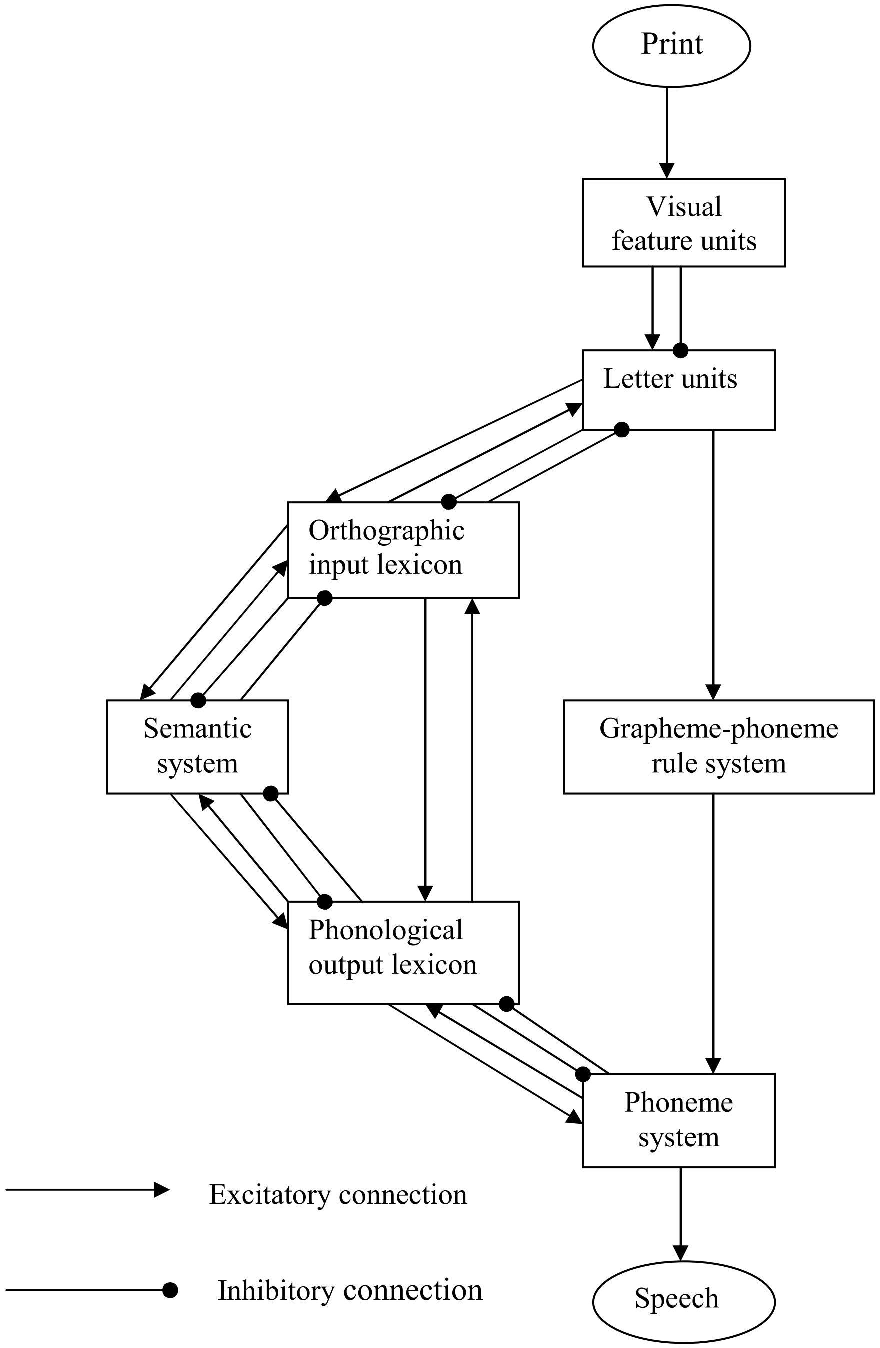

Figure 1.1. The DRC model (Coltheart, 2005).

The model comprises two routes from visual word presentation to decoded output; a direct lexical route and an indirect non-lexical route. Information flows through the model in a continual cascaded manner from print to speech, rather than a sequential stage-like fashion, so that information is being processed throughout the system at once instead of information only passing to the second stage once initial processing is complete, for example. The indirect route is the slower of the two routes (Cain, 2010) and requires the use of GPC rules. Each individual grapheme is converted to its corresponding phoneme and the individual phonemes are subsequently combined in order to decode the word.

The direct route involves accessing the lexicon of stored semantic knowledge (the lexical semantic route) or using the direct lexical route which decodes the word by accessing the lexicon using orthographic-phonological knowledge but without accessing the semantic information. The indirect route can be used for decoding unfamiliar words including non-words; however activation of the direct route and thus similar items stored in the lexicon, will occur simultaneously. Therefore excitatory and inhibitory processes interact in each aspect of the model in order to select an output response. This model is a quintessential representation of a race model; both routes are activated and whichever route is the quickest to reach a threshold level of activation and thus decode the word is the output to be produced (Coltheart, 2005).

1.1.2.2 The Triangle model: a connectionist framework.

The Triangle model is a representation of connectionist models of word reading (Harm & Seidenberg, 2004; Plaut, et al., 1996; Seidenberg, 2005; Seidenberg & McClelland, 1989). Connectionist models use computer simulation techniques to replicate cognitive functioning (McLeod, Plunkett, & Rolls, 1998). A model comprises layers of what can be thought of as networks of neurons which interact using inhibitory and excitatory processing (Plaut, 2005). The presentation of the stimulus (i.e. printed word) constitutes the first layer. A computation is carried out which assesses the difference between the correct level of a unit and that produced by the model and the result is passed to the next layer in the model and so on, with the final layer producing the model's response; thus activation spreads throughout the model. The relative strength or weight of connections between each layer are manipulated using a backpropagation algorithm[1] which consequently influences the computation carried out in that layer; this is the process by which the model learns (McLeod, et al., 1998). These models have been influential for conceptualisations of the word reading process and indeed Lupker (2005, p. 40) went as far as suggesting that the Triangle model " represented what I would argue was the first complete model of word recognition".

The Triangle model is illustrated in Figure 1.2. The large ovals in the model indicate neurons which represent orthographic, phonological and semantic networks or layers. The smaller ovals represent "hidden" units indicating learned representations which mediate the connections between the larger layers and allow more complex relationships to be made (Plaut, 2005; Seidenberg, 2005). Thus presentation of a word activates layers i.e. relating to either orthography, phonology or semantics, which concurrently activate and inhibit other layers, thus activation spreads through the network. The weights of connections are altered using a set of algorithms and learnt so

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[1] Backpropagation involves connections in the model carrying activity signals in one direction and error signals in the other and is used as a way of training connectionist networks (McLeod, et al., 1998).

that certain activation in one layer e.g. orthographics, results in certain levels of activation in other parts of the model e.g. phonology, thus the model learns to respond appropriately to stimulus (Plaut, et al., 1996; Seidenberg, 2005; Seidenberg & McClelland, 1989). Due to this network of connections, similar orthographic representations will activate a number of corresponding phonological representations, for example, from which the incorrect ones will be inhibited and the correct connections will be produced (Lupker, 2005).

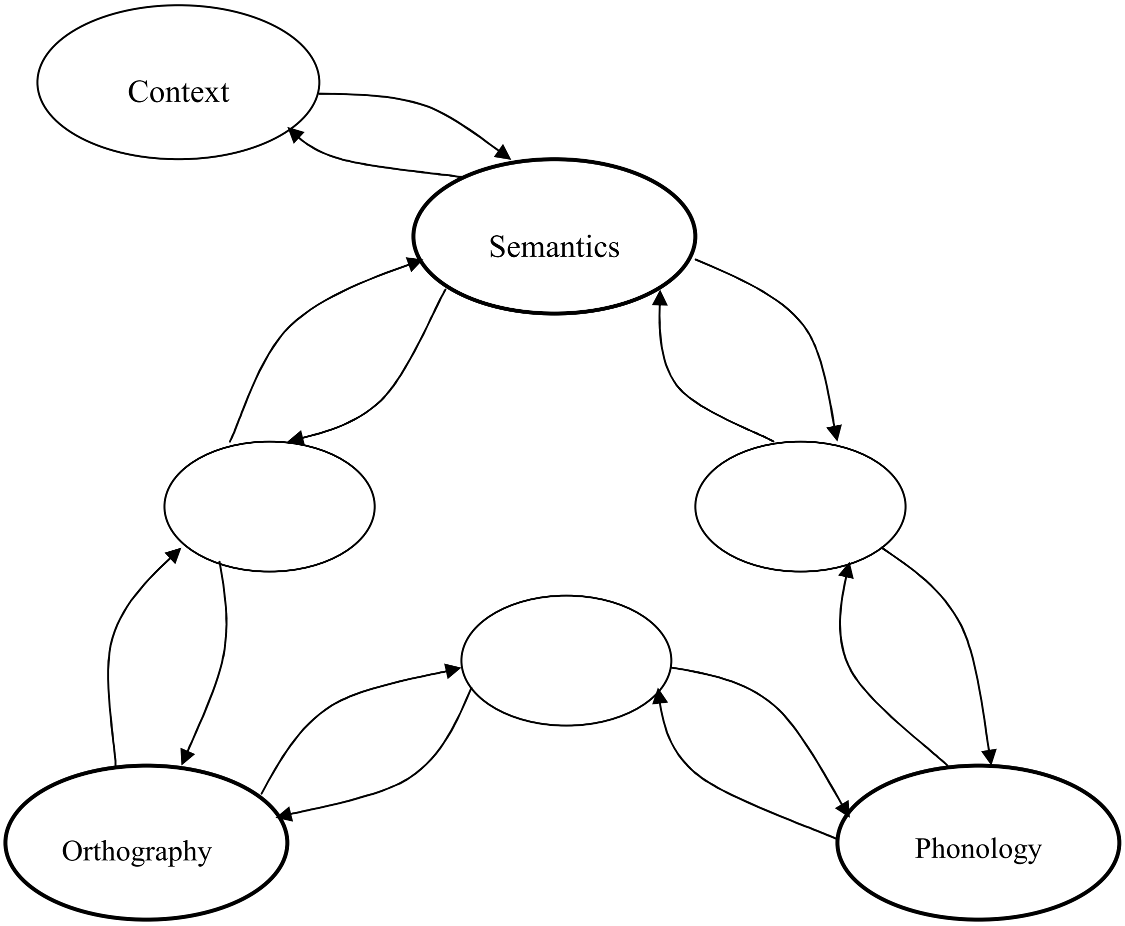

Figure 1.2. The Triangle model (Seidenberg & McClelland, 1989).

While distinctive from the DRC model in that a lexicon is not represented in the Triangle model (Cain, 2010; Lupker, 2005), it is often viewed as being a single route model, however the triangle model also includes dual processing routes: one from orthography to semantics and one from orthography to phonology to semantics (Coltheart, 2005). Indeed this dual-route was investigated by Harm and Seidenberg (2004) who used this connectionist model to disambiguate the relationship between phonology and reading. That is, they examined whether reading is mediated by phonological skills. Results found that, in the early stages of reading, phonology mediated the relationship between orthography and semantics. However, as reading ability improved, direct correspondences between orthography and semantics became more important; both pathways were found to be continual contributors to reading performance at the end of the model training though, depending on the word. For example, homophones (e.g. *bare-bear*) were reliant on semantic representations as the phonological representation does not indicate the meaning. These results therefore suggest that phonological mediation may be more predominant in children who have not yet mastered proficient reading ability either through lack of experience or developmental difficulty. This further suggests that difficulties with reading might be strongly related to deficient phonological skills. This finding is also consistent with the idea that the relationship between decoding and comprehension will change over time as skills develop (Cain, 2010).

While both the Triangle model and the DRC model have their proponents, Lupker (2005) argued that neither model gives an undisputed account of the word reading process. Furthermore, Cain (2010) suggested that neither model can be employed to account for inconsistent pronunciations of morphemes in words such as *sign* and *signature*, for example. Therefore, further work needs to be done in order to fully explain the complexities of the word reading process.

1.1.3 Reading comprehension.

Comprehension is the act of understanding and constructing meaning and can be construed as the "ultimate goal of reading" (Nation, 2005, p. 248). Thus it involves extracting meaning of isolated words, sentences, or passages of text. When comprehension is the intended outcome of the reading process, readers are less likely to retain information about individually decoded words and instead retain information concerning the overall meaning which has to be inferred from the text. Thus comprehension involves extracting meaning from text at a variety of different levels. A number of factors are important in the process of extracting meaning from text. Coherence is the process by which the reader examines (a) the relationship between sentences which are adjacent to each other in order to judge how well they fit, termed local coherence, or (b) the relationship between sentences in a passage or the text as a whole, termed global coherence. In order to judge the global coherence of a passage, existing knowledge must be evaluated and integrated, that is, whether the meaning extracted from the passage is consistent with prior knowledge (Cain, Oakhill, & Bryant, 2004).

Furthermore, prior knowledge is employed to assist in the interpretation of the passage through the process of inference making. That is, given the existing knowledge of the reader, meaning will be attributed and the reader will gain a different sense of understanding from a text than if they had no existing knowledge. Two different types of inferences are thought to be made in the process of comprehension: necessary inferences and elaborative inferences. Necessary inferences are additional pieces of required understanding which the reader must include in order to gain an understanding of the passage as a whole. These can also be termed coherence inferences. Elaborative inferences differ in that they are not required in order to construct meaning from sentences and combine meaning in order to gain a complete understanding of the passage. Instead they are additional inferences, which are generally made after the reading of the text and add to the overall interpretation (Cain, 2010). Indeed it has been suggested that only inferences which are required for local coherence are made at the time of reading the text/passage and indeed that only prior knowledge which was accessible was incorporated initially (McKoon & Ratcliff, 1992). More complex knowledge and that which was more difficult to retrieve are thought to be amalgamated after initial reading in elaborative inferences.

In addition to this, successful comprehension requires the reader continually to monitor or keep track of the understanding which they are gaining from the text as they read new sentences in order to assess their overall understanding (Cain, et al., 2004). Thus comprehension requires information to be held in working memory and be continually updated as the understanding extracted is amended. Therefore comprehension involves the coordination of a wide variety of processes, all of which place heavy demands on higher order cognitive processes (Cain, et al., 2004).

1.1.4 Models of reading comprehension.

A number of alternative models have been proposed to explain the process of reading comprehension. According to Mental Models theory (Johnson-Laird, 1983) a reader constructs a meaning-based representation to give a context for comprehension, that is, a situation model is constructed. Kintsch (1998) expanded the idea of a situation model and proposed the Construction-Integration theory in which it was suggested that the type of representation formed varies at different stages. At the initial stage of processing a piece of text, a surface level representation is formed which incorporates the meaning of individual words. From this initial surface level of representation, the ideas from each sentence are constructed into a textbase which gives the overall meaning of the passage incorporating knowledge from long-term memory (c.f. Kintsch & Rawson, 2005). According to this model, comprehension involves two distinct phases: construction of meaning based on accessing word meanings and making necessary inferences; and integration of the meaning in context to gain an overall understanding. These two phases mean that comprehension is a cyclical process, due to restrictions of working memory capacity (Kintsch & Rawson, 2005).

The Landscape model of reading (van der Broek, Risden, Fletcher, & Thurlow, 1996) also conceptualises comprehension as a cyclical process. In this model different clauses or phrases in the text represent different cycles. Meaning within each cycle will be activated at differing levels depending on the text being processed in each cycle, information being amalgamated from previous cycles, the overall meaning which is currently being held in working memory and the reader's existing knowledge base. Concepts activated in each cycle will be amalgamated to form the overall representation of the text and the level of activation will vary depending on whether concepts have been activated in prior cycles. Thus comprehension of each section influences the overall comprehension which is amended as the next section is processed.

The Structure Building framework proposed by Gernsbacher (1990) differs from the previous models by emphasising the processes used in the construction of the situation model. The model posits that cognitive processes of excitation and inhibition are employed by readers in order to construct a situation model. This framework suggests that when a word is processed multiple meanings are activated including those not relevant for the context. The inappropriate meanings are inhibited and the process of excitation increases activation of the appropriate word meaning for that particular context. Thus the process of comprehension requires a reader to integrate new information with that already processed from the text and amend this information in light of incoming information. These cognitive processes are proposed to be modality independent as despite the differences in modality, comprehension levels related to reading, listening and indeed watching films are highly correlated (r-values ranging from .72 to .92) (Gernsbacher, Varner, & Faust, 1990).

While each of these models of reading comprehension differ, they all emphasise the coordination of incoming information with that currently being held in working memory thus highlighting the integral nature of this process for successful comprehension (Cain, 2010). However given how complex the process of reading is, it is not surprising that the process is fallible.

1.1.5 Reading difficulties.

The Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR; APA, 2000) defines a reading disorder as when reading achievement (in either accuracy or comprehension) is significantly below that which would be expected based on a person’s age, intelligence and education. Given this definition then, the DSM-IV-TR estimates that 4% of school children will have a reading disorder (APA, 2000). However, this definition fails to consider distinctions between children who may have a difficulty with reading accuracy, generally termed dyslexia, or children who have difficulties with reading comprehension in light of adequate word reading abilities, known as poor comprehenders (Hulme & Snowling, 2009). Furthermore, a number of different definitional terms have been used throughout the literature which may influence the estimates of the prevalence of children who have a difficulty with reading, estimates which can vary considerably. For example, Velluntino and Fletcher (2005) estimate that 10-15% of school children will have dyslexia or specific reading disability. Snowling (2000) suggests that 3-10% of children have dyslexia and indeed Hulme and Snowling (2009) estimate that dyslexia affects 3-6% of children. Further to this Swanson (2006) reviews a number of studies involving children with “reading disabilities”. Thus differences in terminology are employed throughout the literature, however it can be argued that each of these terms is used to describe “unexpected and unexplained” difficulties in reading (Wagner & Muse, 2006, p. 41).

When explicit distinctions are made between impairments in word reading and reading comprehension, prevalence estimates are also influenced. For example, Vukovic and Siegel (2006b) suggest that 5-20% of school children have word reading difficulties and 10-15% fulfil criteria for a definition of poor comprehender. Indeed estimates of the prevalence of children who are poor comprehenders have consistently been found to be approximately 10% (Nation & Snowling, 1997; Stothard & Hulme, 1992; Yuill & Oakhill, 1991). Thus while the estimates of word reading difficulties varies from 3% to 20%, the estimates of reading comprehension problems are far more consistent.

Other than the variability in terminology used for word reading difficulties, the definitional criteria used may also influence the prevalence estimates. The definition of reading disorder provided by the DSM-IV-TR (APA, 2000) is reliant on an individual having a significant discrepancy between their Intelligence Quotient (IQ) and reading level; a point which has been the subject of much debate (Hulme & Snowling, 2009). Stanovich (2005) argues against the use of IQ-discrepancy definitions of RD, suggesting that IQ-discrepant readers do not differ from IQ-consistent readers on any of the propositions which would support such a distinction (Stanovich & Siegel, 1994). Indeed there is a growing body of research which argues against the use of an IQ/achievement discrepancy definition of RD (Fletcher, et al., 1994; Hoskyn & Swanson, 2000; Jiménez, Siegel, O'Shanahan, & Ford, 2009; Restori, Katz, & Lee, 2009; Stuebing, et al., 2002; Velluntino, et al., 2004). In light of the argument against use of such definitions, Swanson (2006, p. 61) gives a definition of reading disabilities as "those children who have general IQ scores on standardized tests above 85 and who have reading scores below the 25th percentile on a standardized reading achievement measure". Thus intelligence must be in the average range but a specific 15 point discrepancy is not employed. In addition to this, Hulme and Snowling (2009, p. 39) give an operational definition of dyslexia as "a problem in learning to recognize printed words at a level appropriate for a child's age". Therefore, even out with studies which have employed a "problematic" discrepancy definition, there are still differences in how problems with reading are defined.

One further contributing factor to the inconsistency in the literature is the level of reading which is required to constitute a difficulty. For example, the definition provided by Swanson (2006, p. 61) suggests that reading scores should be below the 25th percentile on a standardised measure of reading, however other researchers use a cut-off of the 16th percentile (Reiter, Tucha, & Lange, 2005). By this very nature, the prevalence of RD will be influenced by the definition, with less stringent criteria leading to the characterisation of a larger number of individuals as having RD. Furthermore, Bishop and colleagues (Bishop, 2001; Bishop & Snowling, 2004) argue that the use of less stringent criteria may lead to the inclusion of participants whose difficulties with reading may be related to environmental factors; thus the use of more stringent inclusion criteria is advocated.

Pickering (2006, p. 9) argued that "one of the major challenges facing researchers and practitioners with an interest in dyslexia is that of establishing who is dyslexic and who is not". Given the variability in terminology and definition found in the literature, the present thesis employs the term "Reading Difficulties" (RD) which is used to encompass all children who have a difficulty with reading regardless of whether they fulfil an IQ/achievement discrepancy definition or not. However as differences have been found between children whose difficulties are with word reading (RD-WR) and those whose problems are with comprehension (RD-RC), distinctions will be made on these principles.

1.1.5.1 Accounts of word reading difficulties.

"Dyslexia" is known to be hereditary (Cain, 2010) and indeed genetics studies suggest that chromosomes 6 and 15 may be vital to the manifestation of dyslexia (for a review, see Hulme & Snowling, 2009; Pennington & Olson, 2005). While these chromosomes are believed to influence the development of brain tissue (Hulme & Snowling, 2009) it is unknown exactly how they may lead to RD, although some studies have shown reduced myelination of areas associated with language abilities in dyslexics (see Velluntino, et al., 2004 for a review). It has been suggested that genetic influences account for approximately half of the deficits in reading observed in those with RD (DeFries & Alarcón, 1996) and indeed it had been argued that the influence of genetics may be mediated by IQ; dyslexics with high IQ may be more profoundly influenced by their genes than those with a lower IQ (Pennington & Olson, 2005). While this demonstrates that genetic influences are vital to RD, it has also been suggested that environmental influences will have an impact (Rutter, 2005). In addition to exploration regarding gene expressions, a number of cognitive theories have been proposed to account for RD.

Language and phonological skills are thought to be crucial for successfully learning to read and it has been suggested that one of the best known predictors for reading ability is phonological awareness task performance (Menn & Stoel-Gammon, 1995). Indeed this proposition is consistent with suggestions that the primary deficit in RD is in the phonological system (Hulme & Snowling, 2009; Velluntino, et al., 2004) and that deficits with phonological representations are causal (Cain, 2010). Phonological representations, that is, the representation that one has of the speech sounds of letters and words, are thought to underlie a number of different areas where children with RD are known to have difficulties: specifically with phonological awareness tasks (Bradley & Bryant, 1978; Swan & Goswami, 1997; Windfuhr & Snowling, 2001), phonological short-term memory (McDougall, Hulme, Ellis, & Monk, 1994), non-word repetition (Herrmann, Matyas, & Pratt, 2006; Snowling, Goulandris, & Defty, 1996), naming (Messer & Dockrell, 2006; Wimmer, 1993) and of course word reading (Cain, 2010;

Hulme & Snowling, 2009; Velluntino & Fletcher, 2005). In addition to this, phonological representations are also thought to be central to visual-verbal learning (Cain, 2010); that is, learning to associate visual information (i.e. orthographics or pictures) with corresponding phonological information. The development of the ability to assign phonological representations to visual stimuli and its importance for reading were investigated by Palmer (2000a) in a study of children aged 5 to 8 years. Results found that while age, IQ and working memory all contributed to reading performance, the capacity to retrieve phonological representations accounted for an additional 18-25%, depending on the reading outcome measure. Further to this however, the ability to inhibit visual representations contributed an additional 10% to the variance in reading ability after 7 years of age. Palmer argued that these findings demonstrate that learning the phonological codes of visual stimuli requires not only the correct phonological associations to be made but also that visual information be inhibited so that the reader is more reliant on phonological information; thus if visual information is not inhibited, phonological recoding may be deficient. In addition, Palmer suggested that children who retain reliance on visual encoding will demonstrate higher incidences of RD. Thus while it is widely accepted that phonological deficits explain difficulties encountered by children with RD (Cain, 2010; Hulme & Snowling, 2009; Velluntino & Fletcher, 2005), the results of Palmer (2000a) suggest that additional cognitive difficulties may exist which lead to these phonological impairments.

However, a deficit in the phonological system is not the only explanation to be posited to account for RD. Tallal (1980) proposed that deficient phonological representations in RD are a consequence of difficulties processing rapidly presented auditory information. By this account, processing difficulties with auditory information which is presented rapidly, such as that found in speech, constrains the ability to distinguish between phonemes thus leading to the impairments in phonological representations which are demonstrated extensively in children with RD. While this account seems plausible, research findings have failed to support it (e.g. Ramus, Pidgeon, & Frith, 2003). In addition, Heath, Hogben and Clark (1999) found that problems with auditory processing were more strongly associated with oral language impairments than RD (although see Chapter Seven for a discussion of this proposition) and in fact in a review of the literature, Troia (2004, p. 285) suggests that research findings "challenge the existence of a pervasive deficit in auditory temporal processing among children with reading disabilities, and suggest that attention is an important variable to consider". Furthermore, a recent meta-analysis (Strong, Torgerson, Torgerson, & Hulme, 2010) failed to find evidence in support of the Fast ForWord remediation programme which is based on the theoretical assumption of a deficit in auditory temporal processing. Conclusions from the review were that the Fast ForWord programme was not effective at treating reading or oral language difficulties and indeed that there was limited support for the premise that training auditory temporal processing skills would lead to improvements in reading and language skill. Thus while it is one possible account for RD, limited support has been gleaned for it.

Further to this, the Magnocellular theory (Stein & Talcott, 1999) suggests that deficits in the magnocellular system lead to visual difficulties which are reported in some cases of RD. The theory states that the magnocellular system acts to inhibit processing of visual stimuli during saccades (eye-movements from one word to another) when reading and deficiencies will lead to blurring and visual confusion of words. In addition, the Cerebellar theory (Nicolson & Fawcett, 1990, 2005) proposes that deficiencies with the cerebellum are causal in RD. That is, impairments in the function of the cerebellum will lead to difficulties in speech articulation and also the automatisation of tasks such as learning orthographic-phonological representations. Furthermore motor skills would also be impaired due to deficient cerebellar functioning. While both of these accounts have their proponents, there is currently a paucity of supportive research for both of these theories (Hulme & Snowling, 2009) leaving the conceptualisation of RD reflecting deficiencies in the phonological system as currently the most widely supported theory (Cain, 2010; Hulme & Snowling, 2009; Velluntino, et al., 2004).

1.1.5.2 Accounts of reading comprehension difficulties.

Hulme and Snowling (2009) argue that while there has been a paucity of research examining the genetic aetiology of RD-RC, it is certainly viable that genetic influences may contribute to the impairment. Keenan and colleagues (Keenan, Betjemann, Wadsworth, DeFries, & Olson, 2006) conducted a twin-study in which Cholesky decomposition was employed to model genetic influences on reading comprehension. One hundred and ninety one twin pairs were administered a battery of tasks assessing word recognition, reading comprehension and listening comprehension and factors representing genetic and environmental influences were created from the phenotypic covariances using the Cholesky model[2]. Results found that genetic influences on word

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[2] This procedure is similar to that used in hierarchical regression and estimates the proportion of genetic variance which is shared between factors (Hulme & Snowling, 2009).

reading and listening comprehension predicted reading comprehension level and in fact accounted for all of the variation in this ability. Furthermore they reported the influence of environment on all aspects, suggesting a role for both genetics and the environment in reading comprehension. While this study involved participants with reading difficulties (one twin in each pair at least), it did not actively recruit participants who had RD-RC; thus while it is suggestive of potential genetic influences on RD-RC, the results cannot be interpreted as conclusive evidence.

The findings reported by Keenan et al. (2006) are consistent with the Simple View of reading (Gough & Tunmer, 1986; Hoover & Gough, 1990) discussed previously, which states that reading comprehension is the product of word reading and listening comprehension. In accordance with this proposition, research evidence involving specific difficulties with reading comprehension has found that children with RD-RC have intact phonological skills but demonstrate deficiencies with listening comprehension (for a review, see Hulme & Snowling, 2009; Nation, 2005); findings which have resulted in the exploration of a number of avenues in order to identify causal mechanisms for this pattern of impairment.

Given the deficits with general comprehension abilities reported for those with RD-RC then, one possibility which has been examined relates to semantics; that is, whether individuals with RD-RC have difficulties with the meanings of words and sentences. A number of studies have reported that RD-RC display deficient performance on tasks assessing semantics, such as judging whether two words are semantically related or not (Landi & Perfetti, 2007; Nation, Marshall, & Snowling, 2001; Nation & Snowling, 1998, 1999). However, Gernsbacher (1993) argued that individuals with RD have difficulties inhibiting irrelevant meaning of ambiguous words and contextual information. Thus their comprehension difficulties are related to inefficient suppression of semantic and contextual information, rather than semantic deficits per se. Further to this, syntactic knowledge has been investigated in order to explain difficulties in comprehension had by this population. However inconsistencies have emerged in the literature with some studies reporting deficient performance for RD-RC (e.g. Cragg & Nation, 2006; Nation, Clarke, Marshall, & Durand, 2004) and other studies reporting performance which is comparable to good comprehenders (e.g. Cain & Oakhill, 2006). These discrepancies reported in the literature indicate a further understanding of RD-RC; that the population is heterogeneous (Cain, 2010). For example, Nation and colleagues (2004) reported that while some children with RD-RC were impaired on sentence recall tasks, some children were not. Thus it was argued that there is no consistent "marker" for this disorder. Furthermore, Cain and Oakhill (2006) examined performance on a number of tasks, however consistent performance was not demonstrated, in that there was not one task on which all of the participants were impaired. Thus identifying underlying causal deficiencies in RD-RC is problematic.

However, individuals with RD-RC have been found to demonstrate difficulties with both inference making (Bowyer-Crane & Snowling, 2005; Cain & Oakhill, 1999; Catts, Adlof, & Weismer, 2006) and integrating information contained in text (Cain, Oakhill, & Elbron, 2003); areas both known to be important for successful reading comprehension (Hulme & Snowling, 2009). Further to this, it can be argued that these difficulties are not due to a lack of knowledge (Cain & Oakhill, 1999), instead RD-RC are unable to employ their background knowledge effectively in order to assist their understanding (Cain, Oakhill, Barnes, & Bryant, 2001). In addition to this, difficulties with comprehension monitoring have also been identified (Ehrlich, Remond, & Tardieu, 1999; Oakhill & Yuill, 1996). Thus these results all indicate a wealth of areas where those with RD-RC have difficulties; although the causal nature of these difficulties has been questioned, with Perfetti and colleagues arguing that these deficits are not causal in the comprehension difficulty but instead represent the difficulty itself (Perfetti, Marron, & Foltz, 1996).

One of the most expansively researched areas in recent years regards the role of working memory in reading comprehension difficulties. The extant literature in this area suggests that those with RD-RC have difficulties in working memory (Cain & Oakhill, 2006; Nation, Adams, Bowyer-Crane, & Snowling, 1999) and indeed in inhibiting distracting or irrelevant information (Cain, 2006; Carretti, Cornoldi, De Beni, & Romano, 2005; De Beni & Palladino, 2000; Palladino, et al., 2001; Pimperton & Nation, 2010). Thus it is plausible that deficits in working memory underlie difficulties on other tasks for which RD-RC demonstrate impairments (Cain, 2010). However, it has been suggested that comprehension difficulties may in fact determine performance on working memory tasks (Hulme & Snowling, 2009). Thus while a number of factors have been proposed to account for the difficulties experienced in RD-RC, no one area can be unequivocally seen as causal.

Lupker (2005) argued that models of word recognition must take account of the concept of interactivity; that is, that there is an interaction between orthographic, semantic and phonological representations whereby processing a word involves reciprocal activation and inhibition between each of these components. One commonality then across each of the theories of reading and theories regarding RD, is the extent to which they implicate certain “higher order” cognitive processes (Rayner & Pollatsek, 1989), processes which all fall under the rubric of executive functions.

1.2 Executive Functions

Executive functions can be defined as the “underlying processes involved in cognitive functioning” (Booth & Boyle, 2009, p. 340). The term “executive functions” is often used as an umbrella term to encompass a wide variety of processes from skills such as inhibition and planning to shifting and updating skills (P. J. Anderson, 2008). For example, Baron (2004) lists 21 different subdomains of executive functions, including processes such as problem solving and attentional control. Anderson (2008, p. 4) suggests that “The key elements of executive function include (a) anticipation and deployment of attention; (b) impulse control and self-regulation; (c) initiation of activity; (d) working memory; (e) mental flexibility and utilisation of feedback; (f) planning ability and organisation; and (g) selection of efficient problem solving strategies.” While theoretical accounts have placed emphasis on different processes within the umbrella of executive functioning it has been suggested that inhibition and working memory may be integral with several theorists highlighting the importance of these processes (Barkley, 1997; Denckla, 1996b; Diamond, Barnett, Thomas, & Munro, 2007; Pennington, Bennetto, McAleer, & Roberts, 1996; Roberts & Pennington, 1996).

1.2.1 Theories of executive functions.

In a review of models of executive functioning, Anderson (2008) argued that while several theoretical accounts of executive functioning have been suggested, no single model has been unequivocally established and that the chances of this happening are unlikely. He suggests that "differences across theoretical models can be partly explained by the motivation for the model's development" (p 18). That is, opposing models have been postulated by theorists from different backgrounds i.e. neuropsychologists deal with the subject of executive functioning differently from developmentalists (Denckla, 1996a). Partly as a function of these different models, emphasis has been placed on different processes within the umbrella of executive functioning. For example, the model described by Barkley (1997) puts behavioural inhibition at its core, while the Supervisory Attention System (Norman & Shallice, 1986) puts attention as its dominant construct.

Furthermore, Lezak (1995) described a framework for executive function involving four areas: volition, that is, the conscious intention to carry out and complete an action or goal; planning, that is, identifying the actions which must be completed in order to achieve the goal; purposive action, that is, carrying out the actions identified in planning; and effective performance, which is monitoring and regulating the actions being performed. Processes such as working memory, attention and control of impulses are all thought to be important for the planning stage, as without them effective planning cannot take place; however the model has been criticised for not placing enough emphasis on these processes (P. J. Anderson, 2008).

Zelazo and colleagues (Zelazo, Carter, Reznick, & Frye, 1997) also proposed a framework for executive functions, but this framework was based around problem-solving. The problem solving framework involves four distinct phases that occur in sequence. The first is problem representation, the second planning, the third is execution which involves the sub-functions of intention and rule use, and the fourth stage is evaluation, which involves error detection and correction. Thus this framework provides a conceptualisation of distinct executive processes which integrate effectively to solve a problem. More recently Zelazo and colleagues (Marcovitch & Zelazo, 2009) proposed the Hierarchical Competing Systems Model (HCSM) within the context of the A-not-B task, a delayed search task which is argued to involve a number of executive processes (Marcovitch & Zelazo, 2009). This computational model suggests that underlying purposeful goal-directed behaviour are a habit system and a representational system which interact to direct such behaviour. While this model is proposed to account for performance by infants on the A-not-B task and thus the development of executive functions in infants, the authors propose that the model serve as a basis for the development of executive function throughout childhood and adolescence; however it is conceded that the model is still in its infancy and that predictions from the model require substantiating through further research.

In addition to this, the Executive Control System was proposed by Anderson (2002). This model contains four independent but inter-related sub-sections of executive function. The first sub-section is cognitive flexibility. This incorporates working memory, divided attention, conceptual transfer and the appropriate utilisation of feedback. The second sub-section is goal setting and involves processes relating to initiative, reasoning, planning and strategic organisation. Information processing is the third sub-section involving efficiency, fluency and speed of processing. Finally the last sub-section in the model is labelled attentional control. This section involves selective attention, self-regulation, self-monitoring and inhibition. The four sub-sections work together in an integral fashion and the nature of the activation of each aspect depends on the requirements of the current task (P. J. Anderson, 2008).

The classic Working Memory model, originally proposed by Baddeley & Hitch (1974), is one of the most dominant conceptualisations associated with executive function research (P. J. Anderson, 2008; Miyake, et al., 2000) and is often seen as central to research in this area (Denckla, 1996a). The model comprises two limited capacity modality specific slave systems, associated with verbal and visuospatial material respectively, the episodic buffer which coordinates information from each of the slave systems and long-term memory and a domain general central executive responsible for the synchronisation of the entire system (Baddeley, 1996, 2000, 2002, 2003; Baddeley & Logie, 1999). While considerable support has been found for the working memory model (e.g. Alloway, Gathercole, Willis, & Adams, 2004; Gathercole, Pickering, Ambridge, & Wearing, 2004), a recent study by Pimperton and Nation (2010) found evidence of domain specific deficits in central executive performance in a sample of children with reading comprehension difficulties. These findings cannot be reconciled by the current understanding of the central executive as domain general in nature, indicating that efforts to further our understanding of this conceptualisation are warranted.

Alternative models of working memory have been proposed however. For example, Engle and colleagues (Engle & Kane, 2003; Engle, Tuholski, Laughlin, & Conway, 1999) propose a model of working memory in which working memory capacity comprises a combination of short-term memory (STM) capacity and controlled attention. The controlled attention component contains mechanisms for the active maintenance of stimuli and the inhibition of distracting information. Furthermore, Cowan (1988) suggested that working memory can be conceptualised as where a subset of information contained in LTM is activated and that a further subset of this activated memory is held in the focus of attention for current processing. Furthering this model, Cowan (1997) suggested that attention is a vital aspect of the model, not only in that it activates aspects of memory to be held in the focus of attention but that it inhibits irrelevant information. In a more recent proposal of a model of working memory, Oberauer (2009) distinguishes between what he terms procedural working memory (“responsible for doing the processing”) and declarative working memory (“responsible for making representations available for processing”) and includes a direct-access region in which small components of information are made accessible and integrated with incoming information and the focus of attention which is used to select information currently in the region of direct access. While the terms procedural and declarative are more synonymous with ideas regarding long-term memory, Oberauer sees them as separate but integrally related. While distinct from the working memory model proposed by Baddeley and Hitch (1974), the model retains the importance of attention and executive processes. Thus while a number of models of working memory have been proposed, one of the commonalities to emerge throughout these conceptualisations is the emphasis on attentional components, including inhibitory functioning.

In concordance with the dominance of the working memory model however, Roberts and Pennington (1996) postulated that inhibition and working memory are the most integral processes of executive functioning and indeed are characteristic of the whole umbrella. Denckla (1996b) also suggested inhibition as underlying other executive functions and in fact Pennington, Bennetto, McAleer and Roberts (1996) postulated that inhibition is fundamental to working memory; indeed the very process of attending to information and holding it in mind requires the inhibition of distracting or inappropriate information.

1.2.1.1 Specifying aspects of executive function.

While inhibition and working memory have been identified as integral to the concept of executive function then, there are indeed distinctions regarding how aspects of executive function are conceptualised. For example, distinctions have been made in the literature concerning behavioural and cognitive inhibition, including differentiation between inhibition which is automatic and that which is intentional (Harnishfeger, 1995). Further to this, Nigg (2000) carried out a comprehensive review of the developmental literature concerning inhibitory processes and differentiated eight different types of inhibition identified in the literature which he argued could be distinguished empirically. The taxonomy of inhibitory processes distinguished: executive inhibition effects including interference control, cognitive inhibition of irrelevant information entering working memory, behavioural inhibition and oculomotor inhibition; motivational inhibition effects which included response to punishment cues and response to novelty; and automatic inhibition of attention which included suppression of recently inspected stimuli and suppression of information at unattended locations. Thus rather than inhibition being a unitary construct it has been viewed as a "family of inhibitory processes" (Harnishfeger, 1995, p. 179). However, it has been argued that children use cognitive inhibition to maintain behavioural control (Mischel, Shoda, & Rodriquez, 1989) thus suggesting the two are necessarily related and dependent on one another.

Attentional abilities have been similarly demarcated. Mirsky and colleagues (Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991) performed a principle component analysis of attentional abilities in adults and children. They found four separable factors of attention which they labelled focus-execute, shift, sustain and encode. Similar factors were found in both adults and children, suggesting that this was not an age-related finding. Furthermore, Goldhammer, Moosbrugger and Schweizer (2007) investigated the separability of attentional abilities. They found factors relating to alertness, spatial attention, focused attention, attentional switching and divided attention. In addition, they found a general factor on to which all the tasks which were assessed loaded. This factor was described as an alertness factor and it was argued that this may underlie all of the other postulated attention abilities.

Thus while a number of theories have been suggested to account for executive functions, there are theoretical differences not only in the conceptualisation but also in the specific type of executive function included e.g. behavioural or response inhibition, factors which add further complication to the overall conceptual understanding.

1.2.1.2 Executive function development across the life span.

While differences have been found pertaining to the theoretical construct of executive function then, there has been more consistent agreement regarding the development of these processes. It is generally agreed that performance on tasks of executive function improves with age throughout childhood and adolescence (P. J. Anderson, 2002; Best, Miller, & Jones, 2009; Davidson, Amso, Anderson, & Diamond, 2006; Garon, Bryson, & Smith, 2008; Leon-Carrion, Garcia-Orza, & Perez-Santamaria, 2004; McAuley & White, in press), peaks during the twenties (De Luca & Leventer, 2008) and then declines with age (Kray, Eber, & Lindenberger, 2004; McCabe, Roediger III, McDaniel, Balota, & Hambrick, 2010; Swanson, 1999b). However different aspects of executive functioning are thought to follow different developmental trajectories, with some aspects reaching maturity before others (V. Anderson, Anderson, Jacobs, & Smith, 2008; De Luca & Leventer, 2008). For example, Garon et al. (2008) reviewed the literature regarding executive function development in pre-school children. They suggested that the ability to attend selectively was required before any other executive function could develop. Their review suggested that following the emergence of the ability to attend selectively, working memory ability emerged during the first six months of life with inhibition beginning to develop from six-months of age. Shifting was believed to be more complex and thus developed later, with evidence that some children could shift by approximately 2-3 years of age. Garon and colleagues argued that there was substantial improvement in executive function between the ages of three and five, but that this reflected the development of more advanced attentional abilities. Thus they argued that by 5 years of age, children have a degree of executive function capability. Further to this, Best et al. (2009) examined executive development after 5 years of age. The conclusions reached from an evaluation of the literature were that inhibitory processes showed most substantial improvements prior to school age with less development later on. However, while working memory and shifting were found to begin to develop in the pre-school period, they improved more significantly after 5 years of age. In addition, planning ability was found to develop most in later childhood and adolescence.

In terms of maturity of these functions, there is some disagreement in the literature. For example, Anderson (P. J. Anderson, 2002) suggested that attentional control reaches adult levels by 11 or 12 years of age, with cognitive flexibility, goal-setting and information processing reaching maturity later, at approximately 15 years of age. In addition, Davidson and colleagues (2006) reported that cognitive flexibility was still not at adult levels at 13 years of age, but that children as young as four had good levels of inhibitory ability. Indeed a recent study by Pritchard and Neumann (2009) found adult levels of inhibitory performance on a negative priming task by 5 years of age. However Leon-Carrion et al. (2004) found continued development of inhibitory processes as assessed by the Stroop task up to 17 years of age, although it was argued that results regarding the maturity of executive functions could be related to task demands. Consistent with this proposal, Harnishfeger (1995) argued that while inhibition develops throughout childhood into adulthood, that it could not be assumed that all types of inhibition followed the same developmental trajectory. Thus the lack of consensus regarding when these abilities reach maturity could be a function of the aspect of inhibition investigated and the assessment task employed.

The concept of executive functioning is thought to be associated with the function of the frontal lobes (Robbins, Weinberger, Taylor, & Morris, 1996) and the inverted U-shaped development of executive functions is believed to mirror the development of these brain regions (V. Anderson, et al., 2008; De Luca & Leventer, 2008). The processes of myelination and synaptic pruning are thought to continue well into adolescence and adulthood (Blakemore & Choudhury, 2006) thus supporting the premise that executive functions may continue developing into adolescence (Luna, Padmanabhan, & O'Hearn, 2010). In addition to this, it has been suggested that gender differences in grey and white matter in the cortex observed at 11 years of age may be related to differences in executive function task performance evident at this time (Blakemore & Choudhury, 2006) however, this has been disputed by studies which have not found such differential performance being associated with gender (e.g. Leon-Carrion, et al., 2004).

Furthermore, different areas of the pre-frontal cortex are believed to show age-related activation when performing executive tasks (Dumontheil, Hassan, Gilbert, & Blakemore, 2010). For example, Tamm and colleagues (Tamm, Menon, & Reiss, 2002) found that younger participants recruited the left superior and middle frontal gyri more than older participants but older participants engaged the left inferior frontal gyrus more. However the validity of employing tasks of executive function as assessments purely of frontal lobe function has been questioned (Alvarez & Emory, 2006). Studies have identified distinct networks of brain regions not restricted to the pre-frontal cortex which appear to be related to differing executive demands. For example, Dosenbach and colleagues (2007) identified a frontoparietal network of the dorsolateral prefrontal cortex and the intraparietal sulcus which was related to initiation and adaption of control and error information and a cinguloopercular network involving the dorsal anterior cingulated/medial superior frontal cortex, anterior insula/frontal operculum and anterior prefrontal cortex which was related to sustained activity. The authors postulated that the second network may be responsible for goal-directed behaviour. In addition, Aron (2008) suggested that inhibition might be related to the right inferior frontal cortex and the right sub-thalamic nucleus and conflict monitoring might be related to the pre-supplementary nucleus. Furthermore, he suggested that the dorsolateral prefrontal cortex is important for rule-governed behaviour. McNab and colleagues (2008) suggested that the parietal region was associated with working memory processes and that the right inferior frontal gyrus with inhibition. However, both aspects of executive function recruited overlapping regions in the prefrontal cortex which the authors suggested may account for the strong relationship between these aspects of executive functioning. Thus executive functions can be seen to be related to a variety of distinct areas in the brain, all of which develop with age thus supporting the idea that executive function performance is related to development of brain regions.

1.2.2 Measurement difficulty.

One possible confound for the theoretical ambiguity and lack of consensus in the literature is the measurement tasks which have been used to assess executive functioning. Zelazo, Qu & Muller (2004) argued that executive functions should be classed as either "hot" or "cool", with "hot" aspects being "affectively laden" (Hughes, 2005, p. 314) and "cool" aspects being more cognitive in nature (De Luca & Leventer, 2008; Denckla, 1996b). In support of this differentiation are criticisms concerning the lack of ecological validity of many tests of executive function (Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Burgess, et al., 2006) due in part to the fact that many commonly used tasks have their roots in research into frontal lobe damage (e.g. Wisconsin Card Sorting Task) and are not representative of real-world situations. In order to detect deficits in executive functions, it is historically agreed that tasks must be novel (P. J. Anderson, 2002; Rabbitt, 1997). As tasks can only be novel once, the reliability of tasks is thus placed into question (Rabbitt, 1997). In addition, the validity of tasks of executive function is queried, at least in part, because of the issue of task impurity (Miyake, et al., 2000; Rabbitt, 1997; Van der Sluis, de Jong, & van der Leij, 2004). That is, that many tasks commonly used to tap executive functions actually involve more than one executive process.

In order to investigate the issue of task impurity Morris (1996) conducted a survey of measures of executive function in the published literature. Six prominent journals were screened for measures of “executive function” (defined by Morris as involving problem-solving skills), attention and memory used with children of school age. It was found that in excess of 20 measures of “executive function” were described, 15 measures of memory and more than 25 measures of attention. One of the most conspicuous findings of this survey was that many of the measures of “executive function” were used by other researchers as measures of attention. That is, that there was little consensus about the underlying processes which are measured by tasks. This finding is also evident in the literature for executive functions other than attention. For example, fluency is often seen as a distinct executive function (Henry & Bettenay, 2010; Phillips & Henry, 2008) however it has been suggested as an assessment of inhibition (McCabe, et al., 2010) and shifting (Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003). Furthermore naming tasks are thought to assess inhibitory functioning (Booth & Vitkovitch, 2008; Gershkoff-Stowe, Connell, & Smith, 2006) however they have also been viewed as a distinct executive function in that they require a number of processes (Baron, 2004). Furthermore, the Wisconsin Card Sorting Task (WCST) is generally employed as a measure of shifting ability (Willcutt, Doyle, Nigg, Farone, & Pennington, 2005) however, it also places strong demands on working memory as sorting rules must be held in mind during task completion (Lehto, 1996). The Tower of London (TOL) and the Tower of Hanoi (TOH) tasks are often employed as comparable measures of planning ability (Baron, 2004). However Bull and colleagues (Bull, Espy, & Senn, 2004) suggested that both tasks require shifting ability but that the TOL also involves inhibition. Indeed a number of studies have reported that the TOL involves inhibitory processes and in some cases working memory (Phillips, Wynn, Gilhooly, Della Sala, & Logie, 1999; Welsh, Satterlee-Cartmell, & Stine, 1999) but that the TOH only places weak demands on inhibitory processes (Welsh, et al., 1999) or indeed no demands at all (Bishop, Aamodt-Leeper, Creswell, McGurk, & Skuse, 2001). Thus the lack of consensus identified by Morris (1996) is evident throughout the research literature.

Further investigation by Morris (1996) of the tasks identified led to the conclusion that "a majority of the tests described as measuring a single construct were actually multidimensional in nature" (p 13). This finding is supported by Ozonoff (1997) who gave examples of several of the most widely used measures of executive function (that is the WCST, the TOH, the Matching Family Figures Test, the Trial Making Test and the Stroop task) as measures which involve more than one executive function. Indeed, Rabbitt (1997, p. 13) suggests that "executive tasks are, necessarily, very complex, and that attempts to fit them into linguistic categories borrowed from everyday discourse such as "inhibition", or "planning", or "monitoring", are necessarily Procrustean". That is, it is inappropriate to attempt to define these tasks as assessing one singular construct. Understandably then this poses problems for the interpretation of poor performance on these tasks and complicates isolating areas of possible executive dysfunction.

Given the issues regarding task impurity and the fact that the same tasks are employed to assess different processes, the interpretation of task performance has proved problematic. In order to address some of these issues, factor analytic techniques have been employed by researchers.

1.2.3 Unity and diversity.

Factor analytic studies have found that tasks of executive function load onto several distinct factors, namely inhibition, working memory and in some cases shifting (Lehto, et al., 2003; Miyake, et al., 2000; St Clair-Thompson & Gathercole, 2006; Willcutt, et al., 2001; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005). However, in addition to finding several distinct factors, research by Miyake and colleagues (Miyake, et al., 2000) found that executive functions are also highly correlated. They focused on three executive functions of shifting, updating of working memory representations and inhibition. Shifting referred to the ability to move back and forth between tasks, updating requires someone to amend known information as and when new information is received and inhibition has been described as “the ability to deliberately inhibit dominant, automatic or prepotent responses” (St Clair-Thompson & Gathercole, 2006, p. 746). They reported evidence for the independent contribution of each of these constructs to performance on tasks commonly used to tap executive function, thereby showing that these three functions are separable constructs. However shifting, updating and inhibition were also found to be significantly correlated with each other and Miyake concluded that this demonstrated both the “unity and diversity” of executive functions and suggested that underlying inhibitory processes may be involved in all three of the executive functions investigated. Further support for this unity and diversity was found by Lehto, Juujärvi, Kooistra and Pulkkinen (2003) who reported a similar pattern of results with a sample of children and indeed this separability has been found to be stable between childhood and adulthood, at least for inhibition and working memory (McAuley & White, in press). Therefore while evidence suggests that executive functions are all distinct constructs it seems that they are not entirely unrelated.

1.2.4 Executive functions and IQ.

Strong correlations have been reported between IQ or general intelligence (*g*) and performance on tasks of executive function (Dempster & Cooney, 1982; Obonsawin, et al., 2002). Indeed Kyllonen and Christal (1990) reported correlations between working memory task performance and reasoning ability ranging from .80 to .88. Furthermore, it has been suggested that *g* reflects frontal lobe function (Duncan, Emslie, Williams, Johnson, & Freer, 1996) and indeed studies have reported that working memory is a strong predictor of *g* (Engle & Kane, 2003; Engle, et al., 1999), a relationship which Engle et al. (1999) attributed to controlled attention ability. This has led to the proposition that working memory and *g* are the same construct (c.f. P. L. Ackerman, Beier, & Boyle, 2005). This strong relationship is unsurprising however when considering measures used to assess IQ. For example, the Wechsler Intelligence Scale for Children (Wechsler, 2004) is one of the most widely employed measures of intelligence and actually includes a working memory component (Cockshott, Marsh, & Hine, 2006). Furthermore, Denckla (1996b) suggested that the processes involved in IQ tasks necessarily relate them to executive function and indeed Miyake and colleagues (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001) found that executive functions were strong predictors of performance on spatial abilities tasks, tasks which they argue are inimitable measures of *g*.

However, a number a studies employing regression analysis have reported the separability of IQ and working memory (Alloway & Alloway, 2010; Alloway, et al., 2004) and indeed a lack of significant relationship between inhibition and IQ has also been reported (Dempster & Corkill, 1999; Michel & Anderson, 2009). Indeed Ackerman and colleagues (2005) reviewed the literature regarding the relationship between working memory and intelligence. They concluded that "working memory is not the same thing as g" (P. L. Ackerman, et al., 2005, p. 51). Thus while executive function performance may be closely related to intelligence, and scores on tasks of executive function may correlate with both verbal and non-verbal IQ scores, the two constructs cannot be viewed as synonymous.

1.2.5 Executive functions in learning.

There is a growing body of research which has implicated executive functions in many areas of learning (Bull, Espy, & Wiebe, 2008; M. M. McClelland, et al., 2007), for example: mathematics (Andersson, 2008; Bull & Scerif, 2001; Passolunghi & Siegel, 2001; Swanson & Kim, 2007), science (Bahar & Hansell, 2000; Chen & Whitehead, 2009; Danili & Reid, 2004; St Clair-Thompson & Gathercole, 2006) and the learning of new vocabulary (Dempster & Cooney, 1982). Indeed a number of studies have demonstrated the importance of executive functions for language related abilities, specifically: language abilities (Ellis Weismer, Evans, & Hesketh, 1999), listening comprehension (Was & Woltz, 2007), literacy (Gathercole & Pickering, 2000), sentence reading (Gernsbacher, 1993) and language and reading comprehension (Booth & Boyle, 2009; M. Daneman & Merikle, 1996; Dempster & Corkill, 1999; Gathercole & Pickering, 2000; Palladino, et al., 2001; Sesma, et al., 2009). Furthermore, depressed performance on tasks of executive function is associated with deficient educational attainment (Gathercole, et al., 2005) and impaired performance in National Curriculum Tests in the areas of both English and Maths (Gathercole & Pickering, 2000). Thus executive functions are important for a wide variety of skills, including reading ability.

1.3 The Role of Executive Functions in Reading Difficulties

Theoretical accounts of reading have implicated executive functions and this relationship has been confirmed in research (Bell, McCallum, & Cox, 2003; M. Daneman & Merikle, 1996). Indeed Troia (2004, p. 279) suggested that "The process of recovering phonological codes from print undoubtedly places significant demands on working memory". Furthermore working memory has been found to predict reading performance above the impact of phonological processes (McCallum, et al., 2006). Given the fact that executive functions are important for reading ability and that theory regarding RD discussed previously emphasises executive processes, it is of little surprise that executive functions have also been found to be important in RD (e.g. Swanson, Howard, & Sáez, 2006), for example: deficits in inhibition (Facoetti, Luisa Lorusso, Paganoni, Umiltà, & Gastone Mascetti, 2003; Gernsbacher, 1993), attention (c.f. Everatt, et al., 1999), updating (Palladino, et al., 2001), planning, (van der Schoot, Licht, Horsley, & Sergeant, 2000) and working memory (McCallum, et al., 2006), to name but a few, are all thought to be related to RD.

Indeed there is a growing body of research which has demonstrated that children with RD are impaired on tasks of executive functions (Altemeier, Abbott, & Berninger, 2008; De Jong, 1998; Everatt, Weeks, & Brooks, 2008; Helland & Asbjornsen, 2000; Martinussen & Tannock, 2006; Swanson, 1999a; Swanson & Alexander, 1997; Swanson

& Jerman, 2007; Willcutt, et al., 2001; Willcutt, Pennington, et al., 2005). For example, Everatt, Warner, Miles and Thomson (1997) found that children with RD were impaired on the Stroop task compared to typically developing controls. Deficits have also been identified for the Stop-signal reaction time task (van der Schoot, et al., 2000; Van der Schoot, Licht, Horsley, & Sergeant, 2002), which like the Stroop, is generally employed as an assessment of inhibition. Impaired performance on tasks of working memory, both verbal and visuospatial, was found by Martinussen and Tannock (2006) in a sample of children with RD. Furthermore, a battery of tasks assessing fluency, naming and inhibition were given to children with RD by Miller-Shaul (2005); results found statistically lower performance for children with RD across all areas. Berninger and colleagues (Berninger, Raskind, Richards, Abbott, & Stock, 2008), reviewed a range of evidence regarding genetic, brain and behavioural studies of dyslexia and executive functions. They suggested that deficits in working memory may be related to a deficit on chromosome 15 and that deficits detected in switching, attention and goal-directed behaviour may be associated with variation on chromosome 6; thus indicating that the executive function deficit observed in children with RD may have a genetic basis. However the results have not always been so consistent and in fact discrepancies have been reported in the literature.

1.3.1 Discrepancies in the literature.

While a number of studies have found that children with RD have difficulties with tasks of executive function in the area of working memory (Berninger, et al., 2006; Gathercole, Alloway, Willis, & Adams, 2006; Jerman & Swanson, 2005; Moore, Kagan, Sahl, &

Grant, 1982), consistent conclusions have not always been reached. For example, Das and colleagues (Das, Bisanz, & Mancini, 1984) found that while there was a trend for children with RD to perform more poorly than average readers of the same age on a number of tasks assessing working memory, that these trends were not statistically significant. Furthermore, when compared with children matched for reading ability there were no significant group differences. The authors thus argued that their results do not support conclusions regarding a working memory deficit in children with RD.

Indeed, the same discrepancies have been found for other areas of executive function. For example, Menghini and colleagues (Menghini, et al., 2009) found that executive function task performance, including a measure assessing attentional skills, accounted for 23% of the variance in word reading in a sample of children with RD, above the impact of age, IQ and a task assessing phonological ability. However, while Hulslander and colleagues (2004) found that a sensory processing task which tapped attention skills was significantly related to word reading ability in a sample of children with RD, regardless of whether it employed visual or auditory stimuli, this relationship was no longer found to be significant when IQ was controlled for. This suggests a strong relationship between attentional aspects of executive function and RD; a relationship which is by no means clear cut.

In addition to this, a number of other studies have found that the performance of children with RD is comparable to that of typically developing controls (e.g. Hall, Halperin, Schwartz, & Newcorn, 1997; Pennington, Groisser, & Welsh, 1993; Pickering & Gathercole, 2004; Stothard & Hulme, 1992; Van der Sluis, van der Leij, & de Jong, 2005). For example, as part of a larger study looking at the dissociation between ADHD and RD, McGee, Brodeur, Symons, Andrade and Fahie (2004) investigated differences between children with RD and clinical control children. No statistically significant difference was found in performance between the RD group and the control group on tasks of working memory and also on the Conners' Continuous Performance Task (CPT; Conners, 1995), which gives an overall index which is indicative of attention problems. However deficits on the CPT task have previously been identified for children with RD (Beale, Matthew, Oliver, & Corballis, 1987). Furthermore, Swanson, Saez and Gerber (2004), conducted a large scale study (*N*=101) assessing the predictive value of phonological and executive processes on later reading performance. Children who scored at least one standard deviation below the mean on a task of word reading were compared to those who scored above this cut off score on a battery of tasks of working memory and also random generation tasks designed to tap inhibitory skills; however no significant difference on task performance was found between these two groups. In addition, Reiter and colleagues (Reiter, et al., 2005) report significantly poorer performance on tasks assessing working memory and fluency for children with RD but performance which was comparable to typically developing controls (TDC) for shifting and concept formation. Interestingly, however, differential performance was identified for two tasks assessing inhibition; performance on the Stroop task was significantly depressed but performance on the Go/No Go tasks was comparable to TDC's. The results, therefore, indicate that any executive function deficit in RD may not be consistent across all aspects of executive function and indeed might be related to the assessment task employed.

Therefore a possible source of confound which may underpin the discrepancies between studies which have found significant differences between RD and control groups and studies which have not, even within the same aspect of executive function, is the variety of tasks of executive function which have been employed. Furthermore the underlying demands of these tasks may have an additional influence on the pattern of results obtained.

1.3.2 Modality.

One possibility is that the discrepancies identified in the literature could be attributed to the verbal demands of the tasks being used to assess executive functions. Russell, Jarrold and Hood (1999) suggested that the use of “inner speech” may assist performance on tasks tapping executive function when a non-verbal response is required, whereby verbalising the demands of tasks make it easier to inhibit responses. It was therefore suggested that children with problematic language skills may exhibit impaired performance due to difficulties with verbalisation. However, Kray, Kipp and Karbach (2009) examined the influence of verbalising on performance on the stop-signal task, a non-verbal task which is employed to assess inhibitory skills. They reported that verbal labelling by children was advantageous for initiating a response, through the mechanisms of maintaining a representation of the task and directing appropriate attentional resources, however it was not beneficial for inhibiting responses. Furthermore, consistent with Russell et al. (Russell, et al., 1999), Bishop and Norbury (2005b) found that whether tasks of inhibition required a verbal or a non-verbal response, the performance of children with poor language skills was still impaired. They suggested that their results demonstrate that impairments of inhibitory skills indicate that language is not being successfully employed as a “tool for thought” (Bishop & Norbury, 2005b, p. 40). However dissociations have been found between verbal and non-verbal tasks of inhibition, with Hamilton and Martin (2005) reporting that a patient with verbal difficulties was impaired on verbal inhibition tasks but not non-verbal tasks. Thus the pattern of results is not consistent.

In regard to children with RD, Nation and colleagues (Nation, et al., 1999) conducted a series of three experiments that compared the working memory spans of children with deficits in reading and language comprehension to those of TDC. They found that the performance of poor comprehenders was worse than TDC on tasks that involved verbal material but not on tasks that were non-verbal in nature. It could therefore be argued that the deficits exhibited by children with RD are related to the verbal demands of working memory tasks (Nation, et al., 1999); a proposition which Savage (Savage, Lavers, & Pillay, 2007) argued, could not currently be refuted. Results such as these have led to the proposition that children with RD demonstrate impairments on tasks of working memory because of the use of stimuli which are language based or indeed that which must be read and not because of any underlying executive function deficit (Hulme & Snowling, 2009).

However, results such as those of Gernsbacher (1993) report that deficits on tasks of inhibition are found in those with RD regardless of whether linguistic or non-linguistic stimuli are used. Indeed, Boden and Brodeur (1999) report deficits for processing both verbal and non-verbal visual stimuli for children with RD. However it can be argued that even tasks which do not require any explicit verbalisation still place demands on participants’ language/reading skills due to the processes of verbal recoding, that is, visual material is recoded in a verbal format (Brandimonte, Hitch, & Bishop, 1992) and indeed any verbal information which may be associated with a visual object will also be encoded (Postle, D'Esposito, & Corkin, 2005; Verhaeghen, Palfai, & Johnson, 2006). It has been suggested that the use of pictorial stimuli in tasks of working memory reduces demands on the phonological loop compared to tasks employing spoken material (Alloway, et al., 2004), thus reducing the reliance on verbal abilities; however contrary to this, it has been suggested that verbal abilities mediate performance on tasks involving pictorial stimuli, at least in a sample of children with Specific Language Impairment (SLI; Newton, Roberts, & Donlan, 2010). Furthermore, it has been suggested that imposing a time limit on visual tasks reduces the availability of verbal codes for visual information (L. A. Brown, Forbes, & McConnell, 2006). Palmer (2000b) reported that the use of verbal encoding develops with age. Children aged 5 years old were found to employ a mostly visual encoding strategy in a working memory task employing pictures, whereas those aged six and seven used a combination of both visual and verbal coding. By age eight, children were mostly reliant on verbal coding strategies, consistent with strategies employed by adults. Palmer argued that use of verbal encoding is related to the ability to inhibit the visual response; and that inefficient inhibition is related to reliance on visual encoding. In terms of children with RD, results reported by Johnston and Anderson (R. S. Anderson & Johnston, 1998) found that children with RD did not verbally recode visual stimuli; thus this could be attributed to inefficient inhibitory mechanisms.

Discrepancies have been identified regarding whether children with RD are impaired on all tasks of executive function, or just those that place demands on their language skills. While it is possible to reduce the language demands of tasks, it has been argued that even visual tasks place demands on verbal abilities, although it is possible that children with RD do not engage these strategies. Thus when investigating executive functions in children with RD, it is essential that the demands of tasks are taken into consideration. As many tasks used to investigate executive functions place heavy demands on participant's language skills (Mainela-Arnold & Evans, 2005), it is possible that the ambiguous results regarding executive functioning of children with RD could be a product of the assessment tasks being utilised.

1.3.3 Comorbidity.

In addition to being implicated in RD, executive function deficits have also been identified in other disorders. For example, Autism (Hill, 2004; Rajendran & Mitchell, 2007; Russell, 1997; Russo, et al., 2007), Schizophrenia (Krieger, Lis, Cetin, Gallhofer, & Meyer-Lindenberg, 2005), Developmental Coordination Disorder (Visser, 2003), Tourette's syndrome (Channon, et al., 2009), Down syndrome (Lanfranchi, Jerman, Dal Pont, Alberti, & Vianello, 2010), Williams syndrome (Rhodes, Riby, Park, Fraser, & Campbell, 2010), ADHD (Alderson, Rapport, & Kofler, 2007; Purvis & Tannock, 2000; van Mourik, Oosterlaan, & Sergeant, 2005; Willcutt, Doyle, et al., 2005), and Specific Language Impairment (Marton, 2008). In a review of the literature pertaining to executive function deficits in a range of developmental disorders, Willcutt and colleagues (Willcutt, Sonuga-Barke, Nigg, & Sergeant, 2008) report that impairments are seen across all disorders, however distinct profiles seem to emerge, with some disorders associated with more profound difficulties in some areas than others. They argued however that no single deficit is essential or adequate to cause these developmental disorders. Consistent with this, Nyden and colleagues (Nydén, Gillberg, Hjelmquist, & Heiman, 1999) contrasted the executive function profiles of children with ADHD, Asperger's syndrome and RD. They found that while children with each disorder demonstrated difficulties with executive tasks, a specific "marker" could not be identified, that is, there was no unique pattern of deficit which could explain one disorder. In a review of the literature, Pennington (2006) suggested that developmental disorders may in fact reflect multiple deficits, rather than isolated impairments and that unique endophenotypes associated with any one disorder may not be found. An endophenotype can be defined as "measureable components immediately observable in the behavioural expression of a complex behavioural disorder that are related to distal genotypes" (Berninger, et al., 2008, p. 713). That is, behavioural characteristics of a disorder which are related to genetic characteristics. In addition, Pennington argued that there may be a genetic relationship between disorders, one which increases the likelihood of comorbidity.

Comorbidity is therefore, a further complicating factor in the study of executive functions in children with RD, as RD are known to co-occur with many other developmental disorders, such as ADHD (Tannock, 1998). As such, this means that the identification of areas of difficulty specific to RD is not always straightforward. Executive function difficulties are thought to be one of the main characteristics of ADHD (Hulme & Snowling, 2009). Research by Willcutt and colleagues (Willcutt, et al., 2001; Willcutt, Pennington, et al., 2005) examined the executive function profile of groups of children with ADHD only, RD only, comorbid ADHD and RD and neither disorder. Batteries of tasks assessing inhibition, working memory, shifting, and phonemic awareness were administered in both studies. In both cases, while the RD group and the ADHD group had differing areas of executive function difficulty, both groups showed more symptoms of the other disorder than the control group. That is, while the RD group did not meet clinical cut-offs on assessment of ADHD they did show more symptoms than the control group and vice versa with the ADHD group showing symptoms of RD. This therefore indicates that groups of children with RD may display subclinical presentations of other disorders. As executive function difficulties are thought to occur in both of these disorders it is difficult to attribute executive impairments solely to RD thus complicating further the interpretation of poor executive function task performance. Indeed Savage and colleagues (Savage, et al., 2007) argue that research discriminating the working memory deficits associated with RD from those of comorbid difficulties is certainly warranted and indeed Nigg (2000) advocates the study of comorbid conditions in order to explain executive function deficits in disorders.

1.4 The Present Thesis

The present thesis reports the findings from three studies aimed at exploring the role that executive functions have in RD. While deficits have been identified for a range of areas of executive function, these deficits have not been reported consistently. Given the variety of tasks which have been employed throughout the literature and the issue of task impurity (Morris, 1996), it is unclear whether children with RD may have impairments with all areas of executive functioning, or difficulties restricted to a number of areas; this will be explored in the present thesis. Furthermore, the underlying task demands may have an impact on the pattern of results found, as they may be differentially related to task modality (Nation, et al., 1999), which could have implications for theoretical understanding of executive functions (e.g. Pimperton & Nation, 2010). In addition to this, it is possible that children with RD display executive function deficits due to a delay with their reading/language skills, rather than any specific difficulty in this area, thus the present thesis will examine this issue. As there is a strong relationship between executive functions and IQ (c.f. P. L. Ackerman, et al., 2005), it may be that any difficulties are merely reflective of general cognitive ability, which may have implications for the diagnosis of RD (Restori, et al., 2009). Word reading and reading comprehension are thought to involve different processes (Gough & Tunmer, 1986; Hoover & Gough, 1990) and as such the present thesis will examine whether executive functions may be differentially related depending on which aspect of reading is being assessed. Furthermore, executive functions are thought to be separable but related constructs in adults (Miyake, et al., 2000) and typically developing children (Lehto, et al., 2003), however as yet no study has examined whether this is the case for children with RD; the present thesis aims to address this. If executive functions are important for RD, it is important to question how far these processes predict severity and in addition, whether this relationship is merely reflective of comorbid difficulties (Nigg, 2000; Savage, et al., 2007); exploration of this issue in the present thesis may lead to findings which will have implications for intervention for RD.

1.4.1 Research questions.

The thesis aims to explore the role that executive functions have in children's RD and in particular the impact of task modality, cognitive ability and comorbid conditions. Given the issues identified throughout the literature, the thesis aims to address several research questions:

1) Do children with RD demonstrate equivalent impairments across all tasks and aspects of executive function?
2) Does executive function performance predict reading ability in a heterogeneous group of children, and are there differential affects depending on whether word reading or reading comprehension is being assessed?
3) Is the predictive utility of executive function reflective of cognitive abilities in general?
4) Does task modality influence whether executive function impairments are evident in children with RD?
5) Can any discrepancies which are apparent when children with RD are compared to TD children be attributed to slower developing reading skills of children with RD?
6) Is the "unity and diversity" of executive functions reported for adults and typically developing children also apparent for children with RD?
7) To what extent do executive functions predict reading in a sample of children with RD while controlling for the influence of IQ and are there differences depending on whether word reading or reading comprehension is being predicted?
8) How far do conditions known to be comorbid with RD such as ADHD and LI influence the relationship between executive functions and reading?
9) Does having such a comorbid condition predict the severity of RD?

1.4.2 Organisation of the thesis.

In order to address these research questions a series of three studies will be presented. The first study of the thesis is a meta-analysis of previous research. This was conducted in order to investigate whether executive function impairments are demonstrated for children with RD across all tasks and aspects of executive function or whether some aspects are more impaired than others. The results from this meta-analysis are presented in Chapter Two.

Using tasks identified in this meta-analysis, the second study in the series involved a group of children with reading difficulties, a chronological age matched control group and a reading level matched control group. This study aimed to assess whether the role that executive functions have for reading in a heterogeneous group of children is dependent on whether word reading or reading comprehension is being evaluated and whether the predictive utility is independent of the role of general cognitive ability; these results are presented in Chapter Three. In addition to this, study two also considered whether the executive function impairments demonstrated by children with RD are influenced by the modality of the assessment task being employed and also the slower developing reading skills which children with RD may have; issues which are discussed in Chapter Four.

Chapters Five to Eight report the findings from study three of the programme of research in which a large sample of children with reading difficulties (*N*=213) participated in order to address the remaining four research questions. Chapter Five specifically assesses whether there are commonalities in the factor structure which has been found for executive functions with adults and TDC for children with RD and how far these factors predict reading ability while taking account of the role of IQ. Furthermore, any differences in predictive utility for word reading and reading comprehension for children with RD are also addressed. The contribution of conditions known to be comorbid with RD are also evaluated in study three, specifically ADHD and LI; these results are addressed in Chapters Six and Seven respectively. Furthermore, the impact which having RD and a comorbid condition has on the severity of the difficulty with reading is examined in Chapter Eight.

Finally, Chapter Nine contains a general discussion of the results of the three studies. The ramifications of findings pertaining to each study are addressed in Chapter Nine, as are future directions for research.

Chapter Two

Study 1: Meta-analysis of Previous Research

2.1 Introduction

A growing body of research reports that children with RD are impaired on tasks of executive functions. For example, Everatt et al. (1997) found that children with RD were impaired on the Stroop task compared to typically developing controls. Martinussen and Tannock (2006) also found impaired performance on tasks of verbal and visuospatial working memory for children with RD. Furthermore, Miller-Shaul (2005) administered children with RD a battery of executive function tasks assessing inhibition, working memory, naming and fluency and found statistically lower performance of children with RD across all areas. However, some studies have found that the performance of children with RD is comparable to that of typically developing controls. For example, McGee et al. (McGee, et al., 2004) investigated differences between children with RD (*n*=28) and clinical control children (*n*=42) as part of a larger study looking at the dissociation between ADHD and RD (*N*=113). They found no statistical difference in performance between the RD group and the control group on tasks of working memory and also on the Conners' Continuous Performance Task (Conners, 1995), which gives an overall index which is indicative of attention problems. Furthermore, Swanson et al. (2004) conducted a large scale study (*N*=101) assessing the predictive value of phonological and executive processes on later reading performance. As part of this study children who scored at least one standard deviation below the mean on a task of word reading were compared to those who scored above this cut off score on a battery of tasks of working memory and also random generation tasks which are designed to tap inhibitory skills. No significant difference on task performance was found between these two groups.

A possible source of confound which may underpin the discrepancies between studies which have found significant differences between RD and control groups and studies which have not, is the variety of tasks of executive function which have been employed. This thesis first aims to identify whether children with RD are impaired on all tasks of executive function or whether impairments are restricted to some tasks and aspects, for example, inhibition only. As such a meta-analysis of previous research was conducted.

2.1.1 Candidate moderators.

The primary objective of the present meta-analysis is to evaluate the variety of tasks of executive function which have been identified in the literature regarding children with RD. As such several candidate moderator variables will be explored. Firstly, the impact of IQ-discrepancy criteria in defining RD will be examined as a moderator, followed by the nature of the RD, that is, whether it centres around word reading or reading comprehension. Further, both age and gender will be examined as candidate moderators and finally the modality of the measurement task. Each of these moderators will now be explored in turn.

2.1.1.1 The impact of IQ.

Stuebing et al. (2002) reviewed the applicability of using an IQ/achievement discrepancy definition of reading difficulties in several key areas, including executive function, where RD is defined as a significant discrepancy between IQ and reading attainment. The literature which had directly compared IQ-discrepant readers with IQ-consistent (or non-discrepant) readers was examined and effect sizes relating to behaviour, achievement and cognitive ability measures were calculated. A medium effect size (0.41) was found for measures of executive function in favour of children whose reading problems had been defined using IQ-discrepancy criteria. However the authors suggested that the effect sizes were merely a product of these definitional criteria i.e. the relationship with IQ, and not due to any real differences in executive performance between IQ-discrepant and IQ- consistent readers. They suggested that the use of a discrepancy definition did not add to our understanding of RD and concluded the review by arguing against the use of an IQ-discrepancy definition. Despite this finding, IQ-discrepancy definitions are still employed in research which investigates executive functioning and RD (e.g. Altemeier, et al., 2008). If variability in effect size is due to definitional criteria used, then it is important to examine which definitional criteria is being employed by each study. This will give us a greater understanding of whether effect sizes found are a product of the definitional criteria used or the actual RD.

2.1.1.2 Word reading compared to comprehension.

Research has identified children who have specific problems with reading comprehension despite adequate word reading skills (see Nation, 2005, for a review) and the pattern of reading difficulties seen in poor comprehenders is noted as being different from that seen in children with word reading problems (Hulme & Snowling, 2009). Executive functions, and in particular working memory, have been implicated in both disorders (Swanson, 2006; Vukovic & Siegel, 2006b). A recent study by Sesma et al. (2009) found that executive functions contributed to reading comprehension ability, even after factors such as decoding, reading fluency and vocabulary had been controlled for. Given that word reading difficulties and reading comprehension difficulties manifest as differing disorders, it is possible that there may be differences in executive function performance between children who have word reading difficulties (RD-WR) and those who have poor comprehension ability but good word reading skills (RD-RC). However, a study by Catts et al. (2006) compared children with RD-WR to those with RD-RC and control children; while the RD-RC were found to perform more poorly than controls on distance inference tasks, there was no significant difference between the RD-RC and RD-WR. The authors conceded that the distance inference task could be interpreted as evidence of working memory difficulties. This would imply that there may be a similar pattern of performance on tasks of working memory between these groups. It is therefore important to investigate whether the pattern of performance on tasks of executive function is the same for RD-WR and RD-RC or not and so this will be investigated in the present meta-analysis.

2.1.1.3 Age and gender.

Previous research has shown that performance on tasks of executive function is influenced by both age (Davidson, et al., 2006; McAuley & White, in press) and gender (Lezak, 1995). With regard to the influence of age, Anderson et al. (2008) reviewed the literature concerning the link between the development of executive functions and brain development throughout childhood. The review concluded that it would be expected that performance on tasks of executive function increase in line with brain development and thus be influenced by age. In addition, Giedd et al. (1996) highlighted that there are gender specific differences in brain development and it has been proposed that these differences may be related to hormone production (De Bellis, et al., 2001). It is therefore plausible to suggest that there may be gender differences in performance on tasks of executive function. However, such an influencing role of gender and age on executive function task performance is contrary to some of the findings in the literature (e.g. Jerman & Swanson, 2005; O'Shaughnessy & Swanson, 1998) therefore the possible moderating influence of age and gender will be explored in the current meta-analysis.

2.1.1.4 Response modality.

A review of the literature pertaining to immediate memory in children with learning disabilities in reading was carried out by O'Shaughnessy and Swanson (1998). Forty one studies were included and the overall standardised effect size was moderate (J. Cohen, 1988) in favour of children without reading problems (0.61, *SD* = 0.87), showing that children with RD show deficits in immediate memory. When moderator variables were explored the most prominent finding was that the RD group showed the greatest deficits on memory tasks which involved verbal material as opposed to visuospatial material.

In regard to working memory, which is thought to be an important aspect of executive function (Barkley, 1997; Denckla, 1996b; Diamond, et al., 2007; Pennington, et al., 1996; Roberts & Pennington, 1996), Jerman and Swanson (2005) reviewed 28 studies of working memory in children with RD. These studies yielded an overall large mean effect size of 0.89 (*SE*= 0.08) thus indicating that children with RD are impaired on tasks assessing working memory. Age, IQ, reading level and modality of the measures were not found to predict effect sizes which is in contrast to modality differences found for short-term memory tasks by O'Shaughnessy and Swanson (1998). This therefore suggests that the working memory deficit of RD is not restricted to verbal based tasks.

However, Nation and colleagues (Nation, et al., 1999) investigated the working memory profile of a sample of children with deficits in reading and language comprehension and found that the performance of RD-RC was worse than TDC on tasks that involved verbal material but not on tasks that were non-verbal in nature. Given the discrepancies in the literature regarding working memory it is possible that task modality may influence the magnitude of effect sizes found on tasks assessing all aspects of executive function for children with RD. Task modality will therefore be investigated as a possible moderator variable.

2.1.2 The Present Study: Research Questions.

As the literature reviewed above indicates, executive functions have been shown to be important in reading and to be impaired in children with RD. However there is confusion in the literature arising from the range of measurement tasks used for assessment in the absence of a clear consensus regarding which aspects of executive function are measured by which task. It is therefore necessary to synthesise the literature to give an indication of which tasks of executive function consistently differentiate between RD and control groups and whether this pattern is the same for all measurement tasks.

To my knowledge this is the first review of the performance of children with RD on tasks of executive function in general, rather than specific areas i.e. working memory. Based on the previous literature, the present meta-analysis addresses the following research questions:

1) Which tasks of executive function discriminate best between children with RD and their typically developing peers? Are there differences in effect size depending on the task employed?

2) Is the same pattern evident for children with IQ-discrepant RD and children with non-discrepant RD?
3) Is the magnitude of the effects found for children with RD-WR different from the magnitude of effects for children who are RD-RC?
4) What influence do age and gender of participants have on the magnitude of effect found?
5) Does the response modality of tasks influence the results?

2.2 Method

2.2.1 Locating studies.

A search was conducted of published studies examining executive functioning in school-age children with RD. Web-based search engines (Psych-info, Wilson Web, Web of Knowledge and Pub-med) were used in order to locate papers published in peer-reviewed journals from 1974 until January 2008. Specific terms such as ‘inhibition’, ‘inhibitory skills’, ‘executive function’ and ‘working memory’ were entered in conjunction with terms such as ‘reading’, ‘reading difficulties’, ‘reading disability’, ‘dyslexia’ and ‘children’. Appendix B shows the number of studies located in the varying search engines by key words used (N=2869). Reference citations from published studies were also consulted and authors currently active in the area were contacted.

2.2.2 Eligibility criteria.

Eligibility criteria employed were (i) mean age of participants less than 16 years old; (ii) reading difficulty operationally defined as standard scores below 85 on a norm-referenced measure of reading ability or as a significant discrepancy between chronological age/ability and reading age; and (iii) descriptive or inferential statistics necessary to permit the calculation of effect sizes in regard to a comparison of executive function between children with RD who had no reported comorbidity and their typically developing peers. Appendix C provides details of the 48 studies which fulfilled these criteria and were therefore included in the meta-analysis and method of their retrieval.

2.2.3 Coding.

2.2.3.1 Study coding.

Sample demographics were retrieved from all studies which met the inclusion criteria. Information regarding the sample size, age, gender and non-verbal IQ of participants was recorded from the Method section of studies which gave this information. Studies were also coded according to the criteria that had been used to determine whether participants had difficulties with reading i.e. whether a discrepancy between IQ and reading attainment had been used or not.

The tasks used to measure executive functioning in each study were also recorded. Several studies, which met the eligibility criteria, included tasks in their test battery which assessed abilities other than executive functioning. For example, some studies also included tasks assessing short-term memory. As the present meta-analysis aimed only to investigate executive functions, data relating to these tasks were not included.

In addition, it was found that different names existed for the same task of executive function, for example, the commonly used backward digit span task had been labelled the “numbers reversed” in McGee et al. (2004). In these instances, the task was recorded as being the task under which it is most commonly known in order to allow ease of comparison, but only if the task followed the exact procedure. Where procedure or materials were different, the original name from the study was used.

Tasks were also coded based on whether they specifically required a verbal/language based or a non-verbal response. All coding was performed by the author. Two independent coders were then trained in the coding procedure and, based on the task description given in the study from which the task was retrieved, coded 10% of the total number of tasks. The two independent coders had 100% agreement (Cohen's kappa = 1).

2.2.3.2 Calculation of effect sizes.

Where multiple outcomes were given for the same task, for example reaction time and number of errors made, the most common metric across studies was used to calculate the effect size. For example, if the majority of studies used number of errors as the outcome measure but one study reported both errors and reaction time, then number of errors was used when calculating the mean effect size. For tasks identified only once within the literature but with several outcome scores, the effect size was based upon the score which best discriminated the group of poor readers from the typically developing controls.

Hedge's *g* standardised effect sizes with weight for sample size were calculated[3]. Using this method, a positive effect size indicates better performance by the TDC.

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[3] $g = \frac{\bar{x}_1 - \bar{x}_2}{s^*}$ where $s^* = \sqrt{\frac{s_1^2 (n_1 - 1) + s_2^2 (n_2 - 1)}{n_1 + n_2 - 2}}$

2.2.4 Meta-analysis (procedure).

In total, 48 studies were located which fulfilled the eligibility criteria and from these 84 different tasks assessing executive function were identified which yielded 180 effect sizes (see Table 2.1 for study characteristics, tasks and effect sizes). A meta-analysis of standardised effect sizes weighted for sample size was carried out using Comprehensive Meta Analysis (version 2) software (Borenstein, Hedges, Higgins, & Rothstein, 2005). One of the requirements for meta-analysis stated by Rosenthal (1994) is that it should not contain more than one effect size for each study included. However, the majority of studies identified that met with the criteria for the current meta-analysis contained several outcome measures, thus violating this assumption. While it is possible to perform a correlation of effect sizes and thus reduce the number of effect sizes to one per study, this would be counter to the objectives of the meta-analysis; that is, to investigate the array of tasks commonly employed. Therefore, to deal with this issue, meta-analysis was carried out on the lowest effect sizes from each study to provide the most conservative estimate, the lower bound analysis, and then re-run for the largest, the upper bound analysis (Law, Boyle, Harris, Harkness, & Nye, 1998). Details of tasks included in upper bound and lower bound analyses by modality and definitional criteria can be found in Appendix D. Following recommendations by the National Research Council (1992), instead of reporting the fixed-effects model, the more conservative random effects model is reported throughout.

Regression analyses were carried out to assess whether age, gender and IQ of participants were significant predictors of effect sizes. Moderator variables included in the analysis were whether IQ/achievement discrepancy based criteria had been used to determine whether participants had RD and whether tasks required a verbal or non-verbal response.

Table 2.1. Study characteristics: sample size (number of males), age, non-verbal IQ, selection criteria, task and bias corrected effect size (Hedge's *g*) and standard error (*SE*) of effect size estimate (in parentheses).

Study	Sample characteristics						Task	Hedge's *g* (*SE*)	*z*-value
	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria			
Altemeier et al. (2008)[4]	80 (80)	56 (56)	133	-	-	Dis	Inhibition/switching task	0.56 (0.18)	3.11 **
							Rapid automatic shifting	0.96 (0.18)	5.33 ***
							Stroop	0.74 (0.18)	4.11 ***
Bayliss et al. (2005)	50	50	125	-	-	Non- dis	Verbal working memory task	0.10 (0.20)	0.50
							Visuospatial working memory task	0.23 (0.20)	1.15
Booth & Boyle (2009)	29 (29)	24 (24)	126	-	-	Non-dis	Numerical Stroop (Number detection)	0.52 (0.28)	1.86
							Tower of London	0.42 (0.28)	1.50

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[4] Dyslexic sample mean= 122 but subsample used. Control sample 106 (56 male) in first year of cohort – this data taken from 3rd year cohort in which 7 participants less, however no info given regarding gender of those who left. ES given based on original male sample, but also calculated with 7 less: RAS= 0.94 (0.19), Stroop= 0.74 (0.19), no change for Inhibition/switching task.

Study	Sample characteristics RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria	Task	Hedge's *g* (*SE*)	*z*-value
Brosnan et al. (2002)	30 (30)	30 (30)	167	-	-	Unsure	Group embedded figures test	1.15 (0.28)	4.11 ***
	16 (10)	16	119				Recognition	0.49 (0.36)	1.36
	16 (10)	16	119				Temporal order	0.65 (0.36)	1.81
	16 (10)	16	119				Verbal fluency	0.99 (0.37)	2.68 **
Cain & Oakhill (2006)	23 (8) +	23 (10)	91	9.85	11.15	Non-dis	Digit reading task	0.15 (0.30)	0.50
							Listening span	0.71 (0.30)	2.37 *
Cain (2006)	13 (6) +	13 (4)	116	-	-	Non-dis	Word recall intrusion errors	1.32 (0.43)	3.07 **
Carretti et al. (2005)	109 (59) +	109 (59)	96-132	-	-	Non-dis	Updating task (Delayed intrusions)	1.11 (0.15)	7.40 ***

Study	Sample characteristics						Task	Hedge's *g*	*z*-value
	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria		(*SE*)	
Censabella & Noel (2005)	15 (8)	15 (7)	136	-	-	Unsure	Backward digit span	1.06 (0.39)	2.72 **
							Flanker digits	1.18 (0.40)	2.95 **
							Flanker letters	1.57 (0.42)	3.74 ***
							Numerical Stroop	1.24 (0.40)	3.10 **
							Stroop	0.63 (0.37)	1.70
Condor et al. (1995)	18 (16)	18 (16)	107	112.50	108.70	Unsure	Tower of Hanoi	0.72 (0.34)	2.12 *
De Beni & Palladino (2000)	12 (7) +	12 (7)	101	8.75	9.33	Non-dis	Backward digit span	0.22 (0.41)	0.54
							Listening span-intrusion	0.92 (0.43)	2.14 *
De Jong (1998)	18 (14)	18 (14)	123	-	-	Unsure	Counting span	1.55 (0.38)	4.08 ***
							Computation span	0.45 (0.34)	1.32
							Reading span	1.62 (0.38)	4.26 ***

	Sample characteristics								
Study	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria	Task	Hedge's *g* (*SE*)	*z*-value
							Star counting test	1.39 (0.37)	3.76 ***
Everatt et al. (1997)	20 (20)	20 (20)	128	85.00	85.00	Unsure	Stroop	1.61 (0.36)	4.43 ***
Everatt et al. (2008)	20 (14)	40 (25)	139	29.40	29.35	Unsure	Object interference (Stroop)	-0.09 (0.27)	-0.33
							Spatial memory	-0.32 (0.28)	-1.14
							Stroop	0.60 (0.28)	2.14 *
							Verbal span	0.71 (0.28)	2.54 *
Hall et al. (1997)	17	28	116	94.90	96.50	Non-dis	Continuous performance task	0.54 (0.31)	1.74
Helland & Asbjornsen (2000)	43 [5] (36)	20 (16)	149	-	-	Unsure	Stroop	1.20 (0.30)	4.00 ***
	42	20					Wisconsin Card Sorting	0.41 (0.27)	1.52

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[5] Data missing for 7 participants in RD group for Stroop task so *n*=36

Study	Sample characteristics						Task	Hedge’s *g* (*SE*)	*z*-value
	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria			
Howes et al. (1999)	24 (16)	45 (30)	125	-	-	Unsure	Backward digit span	0.61 (0.26)	2.35 *
							Backward letter span	0.83 (0.26)	3.19 **
							Facial memory	0.24 (0.25)	0.96
							Abstract visual memory	0.45 (0.26)	1.73
Jeffries & Everatt (2004)	21 (18)	40 (35)	131	-	-	Non-dis	Backward digit span	1.48 (0.30)	4.93 ***
							Listening span	0.43 (0.27)	1.59
							Stroop	0.04 (0.27)	0.15
							Verbal numerical Stroop	0.73 (0.28)	2.61 **
Kramer et al. (2000)	57 (44)	114 (88)	113	97.60	-	Dis	California verbal leaning test	0.18 (0.16)	1.13
Kupietz (1990)	11 (9)	11 (8)	116	-	-	Dis	Continuous performance task	1.05 (0.45)	2.33 *

Study	Sample characteristics						Task	Hedge's *g*	*z*-value
	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria		(*SE*)	
Martinussen & Tannock (2006)	14 (9)	25 (17)	110	-	-	Non-dis	Backward digit span	1.44 (0.37)	3.89 ***
	15	30					Reverse finger windows task	1.07 (0.34)	3.15 **
McGee et al. (2004)	28 (25)	42 (34)	106	-	-	Non-dis	Backward digit span	0.29 (0.25)	1.16
							Continuous performance	0.05 (0.24)	0.21
McGee et al. (1989)	13 (13)	62 (62)	156	100.10	107.90	Non-dis	Delayed recall	0.03 (0.31)	0.10
							Verbal fluency	0.31 (0.31)	1.00
							Trail making task	0.35 (0.31)	1.13
							Wisconsin Card Sorting Task	0.06 (0.31)	0.19

Study	Sample characteristics						Task	Hedge's *g*	*z*-value
	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria		(*SE*)	
Miller Shaul (2005)	25	25	~108	-	-	Non-dis	Coding task	6.03 (0.67)	9.00***
							Letter naming	1.52 (0.32)	4.75 ***
							Number naming	1.30 (0.29)	4.48 ***
							Object naming	0.68 (0.29)	2.35 *
							Verbal fluency	1.29 (0.31)	4.16 ***
Närhi & Ahonen (1995)	21 (21)	10 (10)	128	92.30	86.50	Dis	Executive task (combined WCST errors & Trail making task)	0.45 (0.39)	1.15
							Naming	1.05 (0.41)	2.56 *
Nation et al. (1999)	14 +	15	129	101.35	103.69	Non-dis	Listening span	1.38 (0.41)	3.37 **
							Spatial span	0.01 (0.37)	0.03

Study	Sample characteristics						Task	Hedge's *g* (*SE*)	*z*-value
	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria			
Nydén et al. (1999)	10 (10)	10 (10)	121	99.50	-	Dis	Arithmetic task	0.76 (0.46)	1.65
							Coding task	0.81 (0.47)	1.72
							Conflict task	0.87 (0.47)	1.85
							Go/NoGo task	0.73 (0.46)	1.59
							Symbol search	0.80 (0.46)	1.74
							Wisconsin Card Sorting Task	0.17 (0.45)	0.38
Pennington et al. (1993)	15 (15)	23 (23)	107	109.00	108.40	Dis	Continuous performance task	0.42 (0.34)	1.24
							Matching family figures test	-0.03 (0.33)	-0.09
							Tower of Hanoi	0.08 (0.33)	0.24
							Wisconsin Card Sorting Task	0.14 (0.33)	0.42

Study	Sample characteristics						Task	Hedge's *g* (*SE*)	*z*-value
	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria			
Pickering & Gathercole (2004)	29 (21)	636	116. 97m	-	-	Unsure	Backward digit span	0.32 (0.19)	1.68
							Counting span	0.14 (0.19)	0.74
							Listening span	0.07 (0.19)	0.37
Protopapas et al. (2007)	16 (12))	72 (35)	150	33.60	40.00	Unsure	Stroop	0.86 (0.30)	2.87 **
Purvis & Tannock (2000)	17 (8)	17 (11)	113	12.00	12.30	Non-dis	Continuous performance task	-0.31 (0.35)	-0.89
							Stop-signal task	0.41 (0.35)	1.17

Study	Sample characteristics RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria	Task	Hedge's *g* (*SE*)	*z*-value
Reiter et al. (2005)	42 (26)	42 (26)	128	-	-	Dis	Animal test	0.43 (0.23)	1.87
							Backward digit span	0.24 (0.22)	1.09
							Five-point test	0.54 (0.23)	2.35*
							Flexibility task	0.15 (0.22)	0.68
							Go/NoGo task	0.16 (0.22)	0.73
							Stroop	0.31 (0.22)	1.41
							S-word test	0.24 (0.22)	1.09
							Tower of London	-0.13 (0.22)	-0.59
							Trail making task	0.25 (0.22)	1.14
							Wisconsin Card Sorting Task	0.24 (0.22)	1.09
Roodenrys et al. (2001)	16	16	109	-	-	Unsure	Auditory serial addition task	1.41 (0.40)	3.53 ***
							Memory updating (2 updates)	0.94 (0.37)	2.54 *
							Number gen (2sec/item)	0.43 (0.36)	1.19

	Sample characteristics								
Study	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria	Task	Hedge's *g* (*SE*)	*z*-value
Savage & Frederickson (2006)	34 (22)	33 (24)	127	41.51	53.07	Non-dis	Backward digit span	1.00 (0.26)	3.85 ***
							Digit naming	0.80 (0.25)	3.20 **
							Object naming	0.19 (0.24)	0.79
Stothard & Hulme (1992)	14 (7) +	14 (7)	95	-	-	Non-dis	Listening span	0.55 (0.39)	1.41
Swanson (1993)	28 (20)	38 (30)	121	-	-	Non-dis	Auditory digit sequence	0.23 (0.25)	0.92
							Mapping	0.38 (0.25)	1.52
							Matrix	0.62 (0.25)	2.48 *
							Non-verbal sequencing	0.29 (0.25)	1.16
							Phrase sequence	0.22 (0.25)	0.88
							Picture sequence	0.27 (0.25)	1.08
							Rhyming task	0.34 (0.25)	1.36

		Sample characteristics							
Study	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria	Task	Hedge's *g* (*SE*)	*z*-value
							Semantic association	0.85 (0.26)	3.27 **
							Semantic categorisation	0.48 (0.25)	1.92
							Spatial organisation	0.33 (0.25)	1.32
							Story recall	0.67 (0.26)	2.58 *
Swanson (1999a)	18 (17)	18 (9)	137	27.77	41.00	Unsure	Counting span	1.20 (0.36)	3.33 **
							Matrix	1.27 (0.37)	3.43**
							Sentence span	1.46 (0.38)	3.84 ***
Swanson & Alexander (1997)	40 (32)	40 (24)	120	26.97	30.75	Unsure	Concurrent digit colour	0.72 (0.23)	3.13 **
							Concurrent digit semantic	0.72 (0.23)	3.13 **
							Concurrent digit shape	0.63 (0.23)	2.74 **
							Counting span	0.49 (0.23)	2.13 *
							Matrix	0.46 (0.23)	2.00 *
							Sentence span	0.68 (0.23)	2.96 **

Study	Sample characteristics						Task	Hedge's *g* (*SE*)	*z*-value
	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria			
Swanson & Ashbaker (2000)	30 (17)	30 (17)	179	-	-	Unsure	Auditory digit sequence	0.01 (0.26)	0.04
							Mapping	1.25 (0.28)	4.46 ***
							Matrix	0.88 (0.27)	3.26 **
							Sentence span	2.68 (0.36)	7.44 ***
Swanson et al. (1996)	20 (17)	34 (27)	150	-	-	Unsure	Auditory digit sequence	0.84 (0.29)	2.90**
	20 (17)	34 (27)	150				Mapping	0.39 (0.28)	1.39
	20 (17)	34 (27)	150				Matrix	-0.28 (0.28)	-1.00
	30 (22)	30 (27)	174				Sentence span	1.48 (0.29)	5.10 ***
	20 (17)	34 (27)	150				Story recall	0.85 (0.29)	2.93 **
Swanson & Berninger (1995)	22 (12)	33 (18)	160	-	-	Non-dis	Auditory digit sequence	0.76 (0.28)	2.71 **
							Mapping	0.53 (0.28)	1.89
							Matrix	0.22 (0.28)	0.79
							Story recall	1.76 (0.32)	5.50 ***

Study	Sample characteristics						Task	Hedge's *g* (*SE*)	*z*-value
	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria			
Swanson et al. (2006)	19	15	150	105.46	104.43	Unsure	Auditory digit sequence	0.93 (0.36)	2.58 *
							Backward digit span	0.83 (0.36)	2.31 *
							Coding task	0.35 (0.35)	1.00
							Digit naming	1.45 (0.39)	3.72 ***
							Letter generation	0.52 (0.35)	1.49
							Letter naming	1.62 (0.40)	4.05 ***
							Listening sentence span	0.16 (0.35)	0.46
							Number generation	0.57 (0.35)	1.63
							Object naming	1.39 (0.38)	3.66 ***
							Semantic association task	0.81 (0.36)	2.25 *
							Updating task	0.41 (0.35)	1.17

Study	Sample characteristics						Task	Hedge's *g*	*z*-value
	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria		(*SE*)	
Swanson & Jerman (2007)	18	23	130	107.66	107.52	Unsure	Auditory digit sequence	0.75 (0.33)	2.27 *
							Backward digit span	1.19 (0.34)	3.50 ***
							Rhyming task	1.36 (0.35)	3.89 ***
							Updating task	0.64 (0.32)	2.00 *
Swanson et al. (2004)	31	61	75	105.55	103.45	Unsure	Backward digit span	0.17 (0.22)	0.77
							Letter generation	-0.17 (0.22)	-0.77
							Number generation	0.05 (0.22)	0.23
							Rhyming task	0.20 (0.22)	0.91
							Semantic association task	0.00 (0.22)	0.00
van der Schoot et al. (2004)	16 (9)	16 (6)	140	-	-	Unsure	Sentential priming task (% errors)	1.35 (0.39)	3.46 **

Study	Sample characteristics RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria	Task	Hedge's *g* (*SE*)	*z*-value
van der Sluis et al. (2004)	21 (12)	19 (9)	129	-	-	Non-dis	Digit naming	0.34 (0.32)	1.06
							Letter naming	0.79 (0.33)	2.39 *
							Object inhibition task	0.44 (0.32)	1.38
							Object inhibition-shifting task	0.62 (0.32)	1.94
							Object naming	0.52 (0.32)	1.63
							Object shifting task	0.81 (0.33)	2.46 *
							Quantity inhibition task	0.15 (0.32)	0.47
							Quantity naming task	0.17 (0.32)	0.53
							Trail making task	0.08 (0.32)	0.25
van der Sluis et al. (2005)	18 (11)	24 (11)	129	114.65	111.73	Unsure	Backward digit span	0.07 (0.31)	0.23
							Listening span	0.19 (0.31)	0.61

Study	Sample characteristics						Task	Hedge’s *g* (*SE*)	*z*-value
	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria			
Willcutt et al. (2001)	93	121	126	101.90	109.40	Dis	Contingency naming test	0.28 (0.14)	2.00 *
	75	102					Continuous performance task	0.30 (0.15)	2.00 *
	53	84					Counting span	0.36 (0.18)	2.00 *
	53	84					Sentence span	0.36 (0.18)	2.00 *
	75	102					Stop-signal task	0.13 (0.15)	0.87
	53	84					Stroop	0.31 (0.14)	2.21 *
	53	84					Trail making task	0.24 (0.18)	1.33
	93	121					Wisconsin Card Sorting task	0.28 (0.14)	2.00 *
Willcutt et al. (2005)	109 (56)	151 (65)	135	99.00	111.10	Non-dis	Arithmetic task	0.63 (0.17)	3.71***
							Backward digit span	0.53 (0.17)	3.12 **
							Coding task	0.57 (0.17)	3.35**
							Continuous performance task	0.32 (0.13)	2.46 *

Sample characteristics									
Study	RD *n*	Control *n*	Age	RD NV-IQ	C NV-IQ	Criteria	Task	Hedge's *g* (*SE*)	*z*-value
							Counting span	0.46 (0.18)	2.56 *
							Sentence span	0.47 (0.13)	3.62 ***
							Spatial working memory task	0.29 (0.13)	2.23 *
							Stop-signal task	0.33 (0.13)	2.54 *
							Stroop	0.45 (0.13)	3.46 **
							Symbol search	0.67 (0.13)	5.15***
							Trail making task	0.34 (0.13)	2.62 **
							Wisconsin Card Sorting test	0.22 (0.13)	1.69

Note: RD = Reading difficulties group; + = RD-RC; * $p<0.05$; **$p<0.01$; ***$p<0.001$; Criteria – Dis= discrepancy criteria used to determine RD, Non-dis = Non-discrepancy criteria used to define RD, Unsure= no sufficient information provided to determine which criteria used.

2.3 Results

2.3.1 Description of studies included.

The median number of participants per study was 52 (range 20 – 665). The age of participants ranged from 75 to 179 months with a median age of 126 months. The mean number of participants per study in the RD group was 29 (*SD*=24) and in the control group was 49 (*SD*=92). Thirty eight studies reported gender of participants and in the average study 74% of participants in the RD group were male and 70% of the control groups. Twenty three studies provided specific information concerning the non-verbal ability of participants. However, only 15 studies provided information using a comparable metric, that is, figures for Full scale IQ were provided as opposed to raw scores for example, which could not be meaningfully compared. Additionally, this information was only provided for the control groups in 13 of the 15 studies. The mean non-verbal IQ of the RD group was 101.76 (*SD* = 7.78, range = 85-114.65, *n*=15) and for the TDC was 103.41 (*SD* = 8.79, range 85-111.73, *n*= 13).

2.3.2 Publication bias.

Effect sizes were plotted against standard errors to give a funnel plot as illustrated in Figure 2.1, indicating the presence of publication bias which was confirmed by significant results from Egger's test (Egger, Davey Smith, Schneider, & Minder, 1997) and Begg and Mazumdar's (1994) rank correlation (Kendall's tau-b). Rosenthal's (1979) Fail-safe N was 6367, indicating that over 6000 studies would be needed for the cumulative effect to be non-significant. Similarly, Orwin's (1983) Fail-safe N was 171, suggesting that more studies than included in the meta-analysis overall would need to be identified with a effect size of 0.00, before the cumulative effect would be 0.10, that is a small effect. Therefore it can be concluded that the following meta-analysis provides a satisfactory representation of the relationship between executive functions and RD.

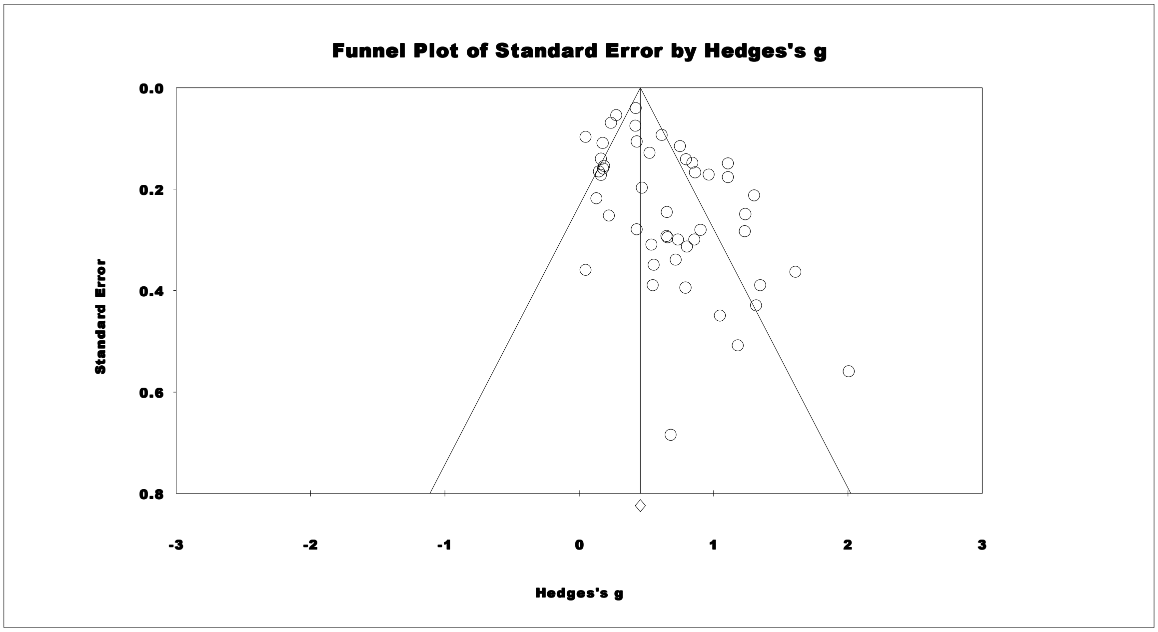

Figure 2.1. Funnel plot of effect size by standard error.

2.3.3 Overall analysis.

Z-scores were calculated as a test of the null-hypothesis and 91 of the 180 effect sizes calculated (50.56%) were significant. Effect sizes ranged from -0.32 (*SE* 0.28) to +1.83 (*SE* 0.84) with the overall mean weighted effect size being +0.57 (*SE* 0.03) in favour of the control groups. There was significant heterogeneity (Q= 528.62, *df* = 179, $p<0.001$) and a moderate-to-large percentage of the variation was due to heterogeneity rather than chance ($I^2 = 66.14$), indicating that exploration of moderator variables was warranted. In order to ensure that the overall effect size was not a product of undue influence of one study, each effect size was removed in turn. With the removal of each study, effect sizes ranged from +0.55 to +0.57 and there continued to be significant heterogeneity. This sensitivity analysis therefore revealed that no single study had an undue influence on the overall effect size. Table 2.2 provides details of the different measurement tasks identified including effect sizes.

Table 2.2. Details of different measurement tasks identified including mean bias corrected effect sizes (Hedge’s g) and standard error of effect size estimate (in parentheses) (84 tasks).

Task (and number of exemplars)	Modality	Mean effect size (standard error)	*z*-value
Abstract visual memory (1)	Non-verbal	0.45 (0.26)	1.73
Animal test (1)	Verbal	0.43 (0.23)	1.87
Arithmetic task(2)	Verbal	0.65 (0.16)	4.05 ***
Auditory digit sequence (6)	Verbal	0.55 (0.16)	3.46 **
Auditory serial addition task (1)	Verbal	1.41 (0.40)	3.53 ***
Backward digit span (14)	Verbal	0.63 (0.12)	5.34 ***
Backward letter span (1)	Verbal	0.83 (0.26)	3.19 **
California verbal learning test (1)	Verbal	0.18 (0.16)	1.13
Coding task (4)	Non-verbal	1.83 (0.84)	2.18 *
Computation span (1)	Verbal	0.45 (0.34)	1.32
Concurrent digit colour (1)	Non-verbal	0.72 (0.23)	3.13 **
Concurrent digit semantic (1)	Verbal	0.72 (0.23)	3.13 **
Concurrent digit shape (1)	Verbal	0.63 (0.23)	2.74 **
Conflict task (1)	Non-verbal	0.87 (0.47)	1.85
Contingency naming test (1)	Verbal	0.28 (0.14)	2.00 *
Continuous performance task (7)	Non-verbal	0.29 (0.10)	2.95 **
Counting span (6)	Verbal	0.59 (0.17)	3.52 ***
Delayed recall (1)	Verbal	0.03 (0.31)	0.10
Digit naming (3)	Verbal	0.83 (0.28)	2.91 **
Digit reading task (1)	Verbal	0.15 (0.30)	0.50
Executive task (1)	Non-verbal	0.45 (0.39)	1.15
Facial memory (1)	Non-verbal	0.24 (0.25)	0.96
Five-point test (1)	Non-verbal	0.54 (0.23)	2.35 *
Flanker digits (1)	Non-verbal	1.18 (0.40)	2.95 **
Flanker letters (1)	Non-verbal	1.57 (0.42)	3.74 ***
Flexibility task (1)	Non-verbal	0.15 (0.22)	0.68

Task (and number of exemplars)	Modality	Mean effect size (standard error)	*z*-value
Group embedded figures test (1)	Non-verbal	1.15 (0.28)	4.11 ***
Inhibition/switching test (1)	Verbal	0.56 (0.18)	3.11 **
Letter generation (2)	Verbal	0.12 (0.34)	0.36
Letter naming (3)	Verbal	1.29 (0.27)	4.86 ***
Listening span – intrusions (1)	Verbal	0.92 (0.43)	2.14 *
Listening span (7)	Verbal	0.43 (0.15)	2.81 **
Mapping (4)	Non-verbal	0.63 (0.20)	3.09 **
Matching family figures test (1)	Non-verbal	-0.03 (0.33)	-0.09
Matrix (6)	Non-verbal	0.51 (0.20)	2.57 *
Memory updating (2 updates) (1)	Verbal	0.94 (0.37)	2.54 *
Naming (1)	Verbal	1.05 (0.41)	2.56 *
Non-verbal sequencing (1)	Non-verbal	0.29 (0.25)	1.16
Number generation (3)	Verbal	0.25 (0.17)	1.49
Number naming (1)	Verbal	1.30 (0.29)	4.48 ***
Numerical Stroop (1)	Non-verbal	0.52 (0.28)	1.86
Numerical Stroop (1)	Verbal	1.24 (0.4)	3.10 **
Object- inhibition-shifting task (1)	Verbal	0.62 (0.32)	1.94
Object interference (Stroop) (1)	Verbal	-0.09 (0.27)	-0.33
Object naming (4)	Verbal	0.64 (0.24)	2.71 **
Object shifting (1)	Verbal	0.81 (0.33)	2.46 *
Object-inhibition task (1)	Verbal	0.44 (0.32)	1.38
Phrase sequence (1)	Verbal	0.22 (0.25)	0.88
Picture sequence (1)	Non-verbal	0.27 (0.25)	1.08
Quantity inhibition task (1)	Verbal	0.15 (0.32)	0.47
Quantity naming task (1)	Verbal	0.17 (0.32)	0.53
Rapid automatic shifting (1)	Verbal	0.96 (0.18)	5.33 ***
Reading span (1)	Verbal	1.62 (0.38)	4.26 ***
Recognition task (1)	Non-verbal	0.49 (0.36)	1.36
Reverse finger windows task (1)	Non-verbal	1.07 (0.34)	3.15 **

Task (and number of exemplars)	Modality	Mean effect size (standard error)	*z*-value
Rhyming task (3)	Verbal	0.58 (0.31)	1.85
Semantic association task (3)	Verbal	0.52 (0.31)	1.70
Semantic categorisation (1)	Verbal	0.48 (0.25)	1.92
Sentence span (6)	Verbal	1.13 (0.29)	3.86 ***
Sentential priming task (1)	Verbal	1.35 (0.39)	3.46 **
Spatial memory (1)	Non-verbal	-0.32 (0.28)	-1.14
Spatial organisation (1)	Non-verbal	0.33 (0.25)	1.32
Spatial span (1)	Non-verbal	0.01 (0.37)	0.03
Spatial working memory task (1)	Non-verbal	0.29 (0.13)	2.23 *
Star counting test (1)	Verbal	1.39 (0.37)	3.76 ***
Stop-signal (3)	Non-verbal	0.26 (0.10)	2.71 **
Story recall (3)	Verbal	1.07 (0.32)	3.32 **
Stroop (10)	Verbal	0.61 (0.12)	5.19 ***
S-word test (1)	Verbal	0.24 (0.22)	1.09
Symbol search (2)	Non-verbal	0.68 (0.13)	5.43***
Temporal order (1)	Non-verbal	0.65 (0.36)	1.81
Tower of Hanoi (2)	Non-verbal	0.40 (0.32)	1.23
Tower of London (2)	Non-verbal	0.12 (0.27)	0.43
Trail making task (5)	Non-verbal	0.28 (0.09)	3.24 **
Updating task (2)	Verbal	0.54 (0.24)	2.27 *
Updating task (Delayed intrusion) (1)	Verbal	1.11 (0.15)	7.40 ***
Verbal fluency (3)	Verbal	0.86 (0.31)	2.80 **
Verbal numerical Stroop (1)	Verbal	0.73 (0.28)	2.61 **
Verbal span (1)	Verbal	0.71 (0.28)	2.54 *
Verbal working memory task (1)	Verbal	0.10 (0.20)	0.50
Visuospatial working memory task (1)	Non-verbal	0.23 (0.20)	1.15
Wisconsin Card Sorting task (7)	Non-verbal	0.24 (0.08)	3.13 **
Word recall intrusion errors (1)	Verbal	1.32 (0.43)	3.07 **

Note: * $p<0.05$; ** $p<0.01$; *** $p<0.001$

Inspection of Table 2.2 reveals that the coding subtest from the WISC IV (Wechsler, 2004)was found to be the best at discriminating RD from their typically developing peers. This task was identified four times in the included papers and was associated with a mean effect size of +1.83 (*SE* 0.84) (although see discussion section for fuller interpretation). This task involves transcribing a digit-symbol code as quickly as possible and while it constitutes part of the processing speed factor derived in factor analytic studies of the WISC (see manual; Cockshott, et al., 2006) it involves a variety of skills including attention and impulsivity (Flanagan & Kaufman, 2004; Nydén, et al., 1999).

The least efficient task at discriminating RD from TDC was Nation et al.'s (1999) spatial span task which was only identified once in the review of literature, and was associated with an effect size of only 0.01 (*SE* 0.37). Descriptions of each task identified can be found in Appendix E.

2.3.4 Overall Lower bound analysis.

The overall mean weighted effect size for the lower bound analysis was +0.35 (*SE* 0.06). There was significant heterogeneity (Q = 115.02, $df = 47$, $p<0.001$) and a moderate percentage of the variation in effect sizes was due to heterogeneity rather than chance ($I^2 = 59.14$). This suggested that the effects of moderator variables should be examined.

2.3.5 Overall Upper bound analysis.

The mean weighted effect size for the upper bound analysis was +0.97 (*SE* 0.09). Significant heterogeneity was found (Q = 211.47, $df= 47$, $p<0.001$) and a moderate to large percentage of the variation of effect sizes was due to heterogeneity rather than chance ($I^2 = 77.77$). Thus, moderator variables were also examined for the upper bound analysis.

2.3.6 Moderator analysis.

2.3.6.1 IQ/achievement discrepancy.

2.3.6.1.1 Lower bound.

A smaller mean effect size was found when a discrepancy based criteria was employed (+0.24, *SE* 0.11) as opposed to a non-discrepancy criteria (+0.35, *SE* 0.10), however this difference failed to achieve statistical significance ($p>0.05$).

2.3.6.1.2 Upper bound.

When participants were selected based on a discrepancy between IQ and achievement a smaller mean effect size was found (+0.60, *SE* 0.13) than when a non-discrepancy criteria (+1.00, *SE* 0.16) was utilised. This difference was found to be statistically significant (Q= 3.90, $df = 1$, $p<0.05$, $I^2=79.76$).

2.3.6.2 Is the magnitude of the effects found for children with word reading difficulties (RD-WR) the same as for children who are poor comprehenders (RD-RC)?

Participants in six of the studies included were defined as being RD-RC namely studies by Cain and Oakhill (2006), Cain (2006), Carretti et al. (2005), De Beni and Palladino (2000), Nation et al. (1999), and Stothard and Hulme (1992). That is, participants had average word reading skills but their reading comprehension was significantly poorer. The remaining 42 studies employed participants with RD-WR whose main operational definition centered on word reading. Using a random effects analysis, the mean effect size for the RD-RC was +0.82 (*SE* 0.16) and for the participants with RD-WR was +0.59 (*SE* 0.05). This difference was not found to be statistically significant (Q=1.95, $df = 1$, $p>0.05$), which justifies treating the RD as one group for the purpose of this analysis.

2.3.6.3 Meta-regression analyses.

Meta-regression analyses were carried out to assess whether the magnitude of effect found varied as a function of the sample characteristics. The mean effect size from each study was used as the criterion variable and the age of participants, percentage of males in the RD group and non-verbal IQ of the RD group and of the control group were all employed as predictor variables. As not all studies reported the necessary information, regression analyses were performed on a sub-sample of studies which did provide the relevant information. None of these variables were found to significantly predict effect size (all p values > 0.05).

2.3.6.4 Response modality.

2.3.6.4.1 Lower bound.

For the lower bound analysis, tasks which required a verbal response had a higher effect size (+0.45, *SE* 0.09) than tasks which required a non-verbal response (+0.22, *SE* 0.07). This difference was found to be statistically significant ($Q = 3.97$, $df = 1$, $p<0.05$) and a moderate percentage of the variation of effect sizes was due to heterogeneity rather than chance ($I^2 = 59.14$).

2.3.6.4.2 Upper bound analysis.

The mean effect size for the tasks which required a verbal response in the upper bound analysis was +1.02 (*SE* 0.10) and for tasks which a required a non-verbal response was +0.89 (*SE* 0.18). This difference was not found to be statistically significant, however ($p>0.05$).

The findings of the upper and lower bound analysis are summarised in Table 3.

Table 2.3. Summary of upper and lower bound results with mean effect size (*SE*).

		IQ discrepancy		Modality	
	Overall	Discrepant	Non-discrepant	Verbal	Non-verbal
Lower bound	+0.35 (0.06)	+0.24 (0.11)	+0.35 (0.10)	+0.45 (0.09)	+0.22 (0.07)*
Upper bound	+0.97 (0.09)	+0.60 (0.13)	+1.00 (0.16)*	+1.02 (0.10)	+0.89 (0.18)
Overall	+0.57 (0.03)				

Note: * $p<0.05$

2.3.7 Classification by executive function.

Tasks were classified according to which executive function they are purported to predominately measure in the literature and then further separated by response modality. Two independent coders rated 10% of the task classification with a resulting good level of agreement (Cohen's kappa= .73). Details of the different executive functions identified and the tasks used to measure these executive functions, including effect sizes, are shown in Table 2.4. Descriptions of each task identified can be found in Appendix E.

57.14% of the tasks identified found significant differences between children with RD and chronological age matched controls. Eight different executive functions were identified and for five of these, tasks which required both verbal and non-verbal responses were included. Updating and naming were only measured using tasks which require a verbal response and planning was only investigated using tasks which were non-verbal in nature. The mean effect size and associated standard error for each executive function identified is illustrated in Figure 2.2.

As is evident from Figure 2.2, the magnitude of effect found was greatest for tasks purporting to assess shifting skills, using tasks which required verbal responses. It is important to note however, that the effects found for verbal shifting skills are based upon the single administration of two different tasks. For non-verbal shifting, a small effect size was found, and while this was also based on two different tasks, 12 effect sizes were produced. Therefore while it may seem that children with reading difficulties are most likely to show impairments on tasks assessing shifting skills, caution must be taken not to over interpret results which have not yet been adequately replicated.

Table 2.4 Executive functions measured and tasks used in measurement including mean effect sizes (84 tasks).

Executive function	Modality	Task (and number of exemplars)	Hedges *g* (*SE*)	*z*-value
Fluency	Non-verbal	Five-point test (1)	0.54 (0.23)	2.35 *
	Verbal	Animal test (1)	0.43 (0.23)	1.87
		S-word test (1)	0.24 (0.22)	1.09
		Verbal fluency (3)	0.86 (0.31)	2.80 **
		Mean effect size (5)	*0.61 (0.20)*	*3.08 ** *
Inhibition/ Attention/Vigilance	Non-verbal	Coding task (4)	1.83 (0.47)	2.18 *
		Conflict task (1)	0.87 (0.47)	1.85
		Continuous performance task (7)	0.30 (0.10)	2.87 **
		Executive task (1)	0.45 (0.39)	1.15
		Flanker digits (1)	1.18 (0.40)	2.95 **
		Flanker letters (1)	1.57 (0.42)	3.74 ***
		Flexibility task (1)	0.15 (0.22)	0.68
		Go/NoGo (2)	0.30 (0.25)	1.23
		Group embedded figures test (1)	1.15 (0.28)	4.11 ***
		Matching family figures test (1)	-0.03 (0.33)	-0.09

Executive function	Modality	Task (and number of exemplars)	Hedges *g* (*SE*)	*z*-value
		Numerical Stroop (1)	0.52 (0.28)	1.86
		Stop-signal (3)	0.26 (0.10)	2.71 **
		Symbol search (2)	0.68 (0.13)	5.43***
		Temporal order (1)	0.65 (0.36)	1.81
		Mean effect size (27)	*0.58 (0.10)*	*5.58 ****
	Verbal	Auditory serial addition task (1)	1.41 (0.40)	3.53 ***
		California verbal learning test (1)	0.18 (0.16)	1.13
		Contingency naming test (1)	0.28 (0.14)	2.00 *
		Inhibition/switching test (1)	0.56 (0.14)	4.00 ***
		Letter generation (2)	0.12 (0.34)	0.36
		Listening span – intrusions (1)	0.92 (0.43)	2.14 *
		Number generation (3)	0.25 (0.17)	1.49
		Numerical Stroop (1)	1.24 (0.4)	3.10 **
		Object interference (Stroop) (1)	-0.09 (0.27)	-0.33
		Object-inhibition task (1)	0.44 (0.32)	1.38
		Object- inhibition-shifting task (1)	0.62 (0.32)	1.94
		Quantity inhibition task (1)	0.15 (0.32)	0.47
		Sentential priming task (1)	1.35 (0.39)	3.46 **

Executive function	Modality	Task (and number of exemplars)	Hedges *g* (*SE*)	*z*-value
		Star counting test (1)	1.39 (0.37)	3.76 ***
		Stroop (10)	0.61 (0.12)	5.31 ***
		Updating task (Delayed intrusions) (1)	1.11 (0.15)	7.40 ***
		Verbal numerical Stroop (1)	0.73 (0.28)	2.61 **
		Word recall intrusion errors (1)	1.32 (0.43)	3.07 **
		Mean effect size (30)	*0.60 (0.08)*	*7.34* ***
Naming	Verbal	Digit naming (3)	0.83 (0.28)	3.2.91 **
		Letter naming (3)	1.29 (0.27)	4.86 ***
		Naming (1)	1.05 (0.41)	2.56 *
		Number naming (1)	1.30 (0.29)	4.48 ***
		Object naming (4)	0.64 (0.24)	2.71 **
		Quantity naming task (1)	0.17 (0.32)	0.53
		Mean effect size (13)	*0.87 (0.14)*	*6.12* ***
Planning	Non-verbal	Tower of Hanoi (2)	0.40 (0.32)	1.23
		Tower of London (2)	0.12 (0.27)	0.43
		Mean effect size (4)	*0.23 (0.19)*	*1.20*

Executive function	Modality	Task (and number of exemplars)	Hedges *g* (*SE*)	*z*-value
Shifting	Non-verbal	Trail making task (5)	0.28 (0.09)	3.24 **
		Wisconsin Card Sorting task (7)	0.24 (0.08)	3.13 **
		Mean effect size (12)	*0.26 (0.06)*	*4.49* ***
	Verbal	Object shifting (1)	0.81 (0.33)	2.46 *
		Rapid automatic shifting (1)	1.00 (0.14)	7.14 ***
		Mean effect size (2)	*0.97 (0.13)*	*7.53* ***
Updating	Verbal	Memory updating (2 updates) (1)	0.94 (0.37)	2.54 *
		Updating task (2)	0.54 (0.24)	2.27 *
		Mean effect size (3)	*0.65 (0.20)*	*3.27* **
Verbal working memory	Non-verbal	Recognition task (1)	0.49 (0.36)	1.36
	Verbal	Arithmetic task(2)	0.65 (0.16)	4.05 ***
		Auditory digit sequence (6)	0.55 (0.16)	3.46 **
		Backward digit span (14)	0.63 (0.12)	5.34 ***
		Backward letter span (1)	0.83 (0.26)	3.19 **
		Computation span (1)	0.45 (0.34)	1.32

Executive function	Modality	Task (and number of exemplars)	Hedges *g* (*SE*)	*z*-value
		Concurrent digit semantic (1)	0.72 (0.23)	3.13 **
		Counting span (6)	0.59 (0.17)	3.52 ***
		Digit reading task (1)	0.15 (0.30)	0.50
		Listening span (7)	0.43 (0.15)	2.81 **
		Phrase sequence (1)	0.22 (0.25)	0.88
		Reading span (1)	1.62 (0.38)	4.26 ***
		Rhyming task (3)	0.58 (0.31)	1.85
		Semantic association task (3)	0.52 (0.31)	1.70
		Semantic categorisation (1)	0.48 (0.25)	1.92
		Sentence span (6)	1.13 (0.29)	3.86 ***
		Story recall (3)	1.07 (0.32)	3.32 **
		Verbal span (1)	0.71 (0.28)	2.54 *
		Verbal working memory task (1)	0.10 (0.20)	0.50
		Mean effect size (59)	*0.65 (0.06)*	*10.79* ***
Visuospatial working memory	Non-verbal	Abstract visual memory (1)	0.45 (0.26)	1.73
		Concurrent digit colour (1)	0.72 (0.23)	3.13 **
		Facial memory (1)	0.24 (0.25)	0.96
		Mapping (4)	0.63 (0.20)	3.09 **

Executive function	Modality	Task (and number of exemplars)	Hedges *g* (*SE*)	*z*-value
		Matrix (6)	0.51 (0.20)	2.57 *
		Non-verbal sequencing (1)	0.29 (0.25)	1.16
		Picture sequence (1)	0.27 (0.25)	1.08
		Reverse finger windows task (1)	1.07 (0.34)	3.15 **
		Spatial memory (1)	-0.32 (0.28)	-1.14
		Spatial organisation (1)	0.33 (0.25)	1.32
		Spatial span (1)	0.01 (0.37)	0.03
		Spatial working memory task (1)	0.29 (0.13)	2.23 *
		Visuospatial working memory task (1)	0.23 (0.20)	1.15
		Mean effect size (21)	*0.42 (0.08)*	*5.32 ****
	Verbal	Concurrent digit shape (1)	0.63 (0.23)	2.74 **
		Delayed recall (1)	0.03 (0.31)	0.10
		Mean effect size (2)	*0.37 (0.30)*	*1.23*

Note: * $p<0.05$; **$p<0.01$; ***$p<0.001$

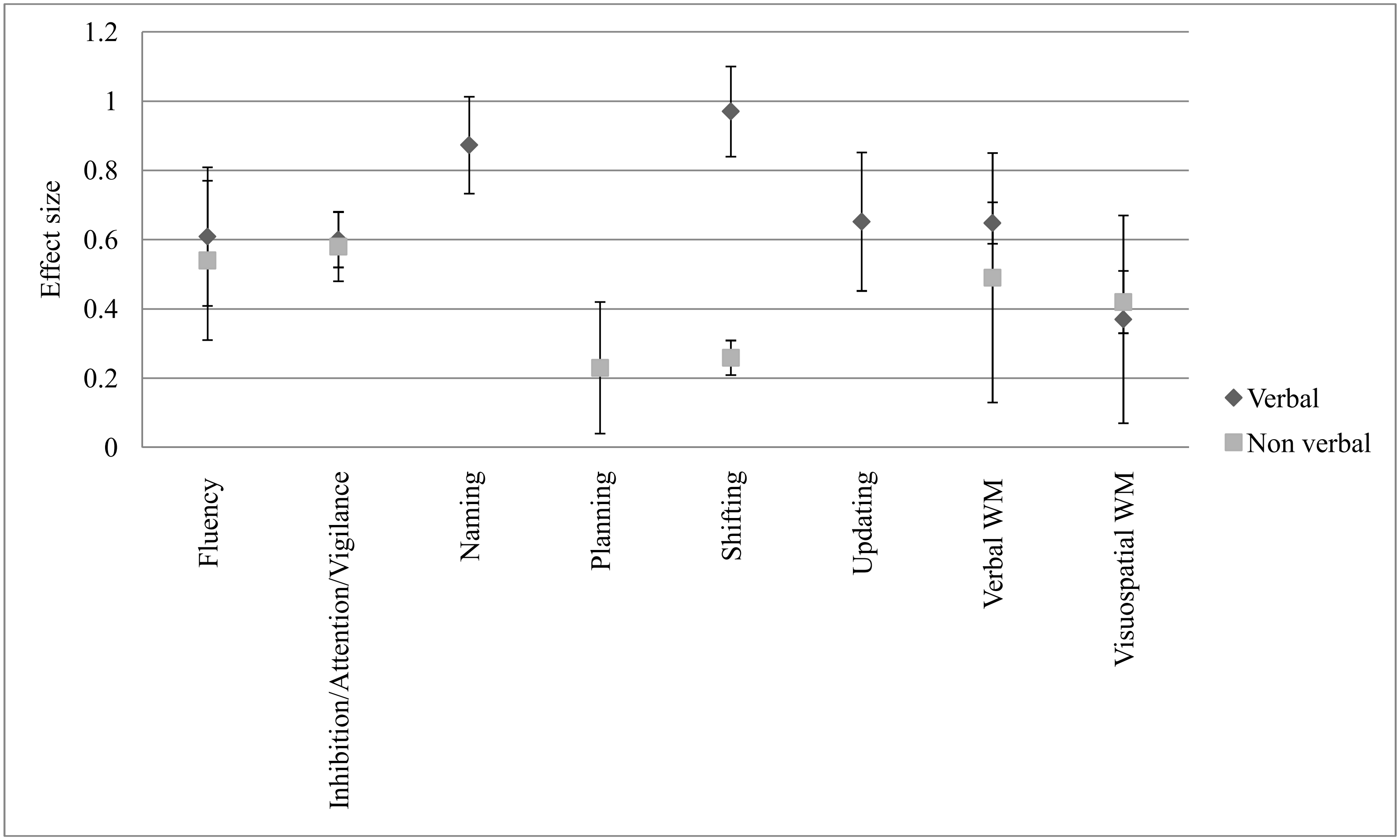

Figure 2.2 Mean effect size and associated standard error for each executive function identified[6].

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[6] Note that one Verbal WM task employed a non-verbal response and that one Visuospatial WM task employed a verbal response (c.f. Appendix E).

2.4 Discussion

The results of the present meta-analysis found that children with RD are generally impaired in executive functioning when compared with TDC, with a medium-sized effect (J. Cohen, 1988) being found overall in favour of TDC. However, the findings highlight that there is wide variation in the magnitude of effects found which relate to the assessment tasks utilised. Moderators such as task modality and the criteria used to define RD were found to moderate the magnitude of these effects. The findings therefore suggest that children with RD may have more pronounced difficulties in some areas of executive function compared to other areas.

2.4.1 Task discrimination.

The task found to discriminate best between RD and TDC was the coding subtest from the WISC IV (Wechsler, 2004). This task is seen to involve a variety of skills including attention and impulsivity (Flanagan & Kaufman, 2004; Nydén, et al., 1999) however it also constitutes part of the processing speed factor derived in factor analytic studies of the WISC (see manual; Cockshott, et al., 2006). The different interpretations about which underlying constructs are measured by this task is a problem inherent in research on executive function. Poor performance on this task could be taken as evidence that children with RD have attentional difficulties but there may be other interpretations.

While this task was found to have the largest effect size, caution must be taken not to over-interpret these results. Four different effect sizes were generated by this task, however one study in particular (Miller-Shaul, 2005) contributed an extremely large effect size (+6.03) thus increasing the overall effect size somewhat. The participants in the Miller-Shaul study seem to be particularly impaired on the processes that the coding subtest is assessing, however, as this task was not a language based task the results cannot be attributed to any language based differences between the participants in this sample and those in the other samples which also used this task. It must be noted however, that the participants in the Miller-Shaul study were Hebrew speakers (see the limitations section for a fuller discussion).

When the effect size from the Miller-Shaul study was removed, the reading span task employed by de Jong (1998) became the task with the greatest effect size, however, this task was only identified once within the included studies, indicating that further research using this task is required before it can be concluded that it discriminates well between RD and controls.

2.4.2 Moderator analysis.

2.4.2.1 Does IQ/achievement discrepancy have any utility?

The criteria used to select RD was evaluated as a moderator variable. In some studies a discrepancy between IQ and attainment was used to define RD, while in others, no such discrepancy was utilised and RD were defined on low reading level alone. Differences in the magnitude of effect were identified but only in the upper bound analysis, with non-discrepancy criteria being associated with a higher mean effect size. As no significant differences were found in the lower bound analysis it could be that there are no fundamental differences in executive function profile between discrepant RD and non-discrepant RD and that actually the observed differences are a product of the assessment task utilised, as different tasks were identified in the upper and lower bound analyses with only a third of the tasks in the upper bound analysis also found in the lower bound.

This finding is supportive of the meta-analysis carried out by Stuebing et al. (2002), and is consistent with the position of Stanovich (2005) who continues to argue against the use of IQ-discrepancy definitions of RD and suggests that IQ-discrepant readers do not differ from IQ-consistent readers on any of the propositions which would support such a distinction. The findings from the present meta-analysis indicate that statistically significant differences can be found depending on which definition is used, but only as a function of assessment task. This could be taken as evidence that tasks of executive function vary in how much they implicate fluid intelligence, and in fact that different executive functions vary in the strength of relationship with intelligence. However, Swanson (2006) discusses the literature which assesses the relationship between working memory and intelligence in children with RD. He concluded that children with RD are impaired on tasks of working memory even when intelligence is taken into account. This supports the premise that executive function impairments seen in children with RD are not simply a consequence of whether they have IQ-discrepant RD or not.

However, as differences were only found in the upper bound analysis in the present study- with possible implications for the utility of non-verbal IQ in defining RD- this conclusion cannot be unequivocally accepted. As the findings in the present meta-analysis were not consistent and instead varied as a function of task clear conclusions cannot yet be drawn and further research is needed to investigate whether the findings of Swanson (2006) are the case for all aspects of executive function or restricted to working memory. Until this complex underlying relationship is more fully understood, care is required when selecting tasks of executive function and indeed, measures of more general cognitive functioning, which may also have implications for definitional criteria.

2.4.2.2 Word reading and reading comprehension.

Six of the studies included in the present meta-analysis involved children whose RD were based on comprehension difficulties rather than word reading difficulties. Analyses found that the magnitude of effect found did not differ as a function of these group differences. This suggests that the executive function profile of children with RD-WR is no different from those with RD-RC. This is contrary to research by Cutting, Materek, Cole, Levine and Mahone (2009) who found prominent difficulties on tasks of executive function for those with comprehension difficulties but not those with word reading difficulties. However, it must be acknowledged that the results of the present meta-analysis could be related to the unequal sample sizes as only six studies employed children with reading comprehension difficulties, and so further research is needed in order to discern whether these groups truly do have the same pattern of results in terms of executive function task performance.

2.4.2.3 Age and gender.

Regression analyses found that neither age nor gender of participants influenced the magnitude of effect sizes found. This finding is consistent with the findings of previous meta-analyses which have looked at working memory and RD (Jerman & Swanson, 2005; O'Shaughnessy & Swanson, 1998), however, the suggestion that age has no bearing on executive function performance does not sit comfortably within the developmental literature. One possible explanation could be that as the majority of studies in this meta-analysis involved participants aged between 114 months and 138 months, this age range is not wide enough to be sensitive to any age related differences in performance. A further possible explanation is that different executive functions have different developmental trajectories (Davidson, et al., 2006) and thus the array of executive functions involved in this meta-analysis concealed any developmental differences. Longitudinal research is thus required to fully understand the pattern of developmental changes.

2.4.2.4 Modality.

Modality differences were found in general in the more conservative lower bound analysis, with verbal tasks producing a significantly larger effect than non-verbal tasks. While the extent of the difference in effect sizes between verbal and non-verbal tasks for the upper bound analysis was not found to be statistically significant, a large effect size was obtained for the tasks which required a non-verbal response as well as tasks which required a verbal response.

Mixed findings regarding the role of task modality have been reported in previous studies. O'Shaughnessy and Swanson (1998) found a domain general deficit on working memory tasks for children with RD-WR whereas Nation et al. (1999) reported a domain specific deficit for RD-RC. Our findings suggest that children with RD have deficient performance in general on tasks of executive function but that this depression increases as a function of increased language demands of the tasks. Given an approximate 50% overlap between RD and SLI (McArthur, Hogben, Edwards, Heath, & Mengler, 2000) it is of no surprise that the language demands of the tasks influence the performance of children with RD. However, research by Archibald and Gathercole (2006a) found that children with SLI had impairments with tasks of working memory even when language age was used to calculate standard scores. Thus their deficient performance on tasks of working memory was above and beyond their difficulties with language. It therefore seems unlikely that the performance of children with RD is completely a function of any difficulties with language they may have. Furthermore, the large effect sizes found for non-verbal tasks imply that RD have general impairments with executive function tasks, which become more pronounced when the language demands of the tasks increase.

This has many implications for the assessment of executive function in children with RD as it highlights that in order to gain a full understanding of the nature of the executive function impairment, non-verbal tasks should be emphasised (Booth & Boyle, 2009). The contradictory results found for children with comprehension difficulties could reflect underlying differences between the causes of these impairments; however, as suggested previously, further research is needed to understand these potential group differences.

2.4.3 Classification of area of executive function.

The classification of tasks into which executive function they are purported to measure revealed that the pattern of deficit is not uniform across all executive functions. Based on this classification, planning and shifting abilities (using tasks which are non-verbal in nature) appear to be less impaired than other areas of executive functioning with inhibition and fluency skills appearing to be more impaired, regardless of task modality. This finding is consistent with the meta-analysis reported by Willcutt and colleagues (Willcutt, et al., 2008) which identified small effects sizes for children with RD on shifting and planning but more substantial effect sizes for working memory[7]. However given the issues of task impurity, clear conclusions cannot be drawn; although the present analysis does emphasis the disparity in effect between different executive functions and gives some indication regarding areas where there may be more severe impairments.

2.4.4 The relation to theoretical accounts.

Theoretical accounts of reading imply the involvement of higher order cognitive processes such as activation and inhibition (Lupker, 2005) and research into RD suggests that executive function impairments may be integral (Swanson, 2006). While there continues to be discussion in the executive function literature regarding which executive function may be more dominant in general, several theories highlight the importance of both inhibition and working memory (Barkley, 1997; Denckla, 1996b; Diamond, et al., 2007; Pennington, et al., 1996; Roberts & Pennington, 1996). The results of the present meta-analysis indicate that the executive function impairment of children with RD is not uniform across all tasks, thus suggesting that some areas of executive function may be more impaired than others. However, until further research allows the exact nature of the executive function impairment to be isolated, it is not possible to say whether the impairment is specific to areas such as inhibition and working memory, or involves more areas, but perhaps just to differing degrees.

2.4.5 Limitations of the present study.

One limitation of the present study concerns the lack of unpublished studies. While authors currently active in the area were contacted, only one unpublished study was

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[7] Details of effect size estimates are not supplied in this paper.

identified. However, the analysis concerning publication bias revealed that the present study is an adequate representation of this area. A further limiting factor is that not all studies gave information concerning the non-verbal IQ of participants. In order to investigate the impact of non-verbal IQ, regression analysis were therefore carried out on the sub-sample of studies which did provide this information.

Furthermore, while studies included in the meta-analysis were confined to those whose participants had RD with no reported comorbidity, it is important to acknowledge that some of the participants in these studies may have had undiagnosed difficulties. These difficulties could influence their performance on tasks of executive function which would therefore be reflected in the results of this review.

In addition it must be noted that some studies included in the present meta-analysis included participants who were not English speakers (i.e. the study by Miller-Shaul (2005) included Hebrew speakers). The considerable disagreement in the literature regarding the underlying causes of RD in different languages must be acknowledged. In a review of the literature Caravolas (2005) states that findings are mixed; some researchers posit that differing writing systems influence the nature of the deficits seen in RD, whereas others argue that phonological skills play a role in RD despite differences in orthographic transparency. There seems to be no consensus at present, however it is also perhaps worth mentioning that both English and Hebrew can be considered deep orthographies (Frost, 2005). Never the less, the differing languages of participants could be considered a limitation of the present study.

One further limitation is that there are several outcome measures for studies in many cases. Combined with the issues of task impurity and in the absence of complete data sets, this resulted in the use of the upper and lower bound analyses. While the use of separate upper and lower bound analyses allowed for comparison of several effect sizes per study, it has the limitation of not allowing a mapping between tasks and the putative executive function which they measure, something which is further complicated by task impurity.

The fact that many executive tasks implicate several areas of functioning limits the conclusions which can be drawn from the present meta-analysis. This issue of task impurity means that it is not possible to argue that children with RD have definite impairments with some aspects of executive function but not with others as we can never be entirely sure that we are not just assessing several aspects of executive function to differing degrees. This is coupled with the fact that there are differing opinions about the underlying constructs measured by each task. The results of the present meta-analysis do highlight that children with RD do not have a uniform impairment with executive functioning though.

2.4.6 Implications.

Burgess et al. (1998, p 556) argued that " If different executive tasks measure different aspects of the dysexecutive syndrome, it makes sense to administer, standardly, a variety of tests rather than relying on just one or two". The results of the present meta-analysis support this conclusion. While the mean effect size found for performance on tasks of executive function of RD compared to typically developing controls could be described as "medium", it ranged considerably, depending on the task and the underlying demands. This highlights the fact that results found can vary considerably depending on the assessment task utilised.

To take a practical example in regards to working memory, the Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001) is a widely used test battery within the UK which uses tasks which were identified in the present meta-analysis. The three tasks used to assess central executive function within this battery are the backward digit recall task, the counting recall task and the listening recall task; all of which are included in the present meta-analysis. Mean effect sizes found for these individual tasks ranged from +0.43 to + 0.63, and the mean effect size for this battery was found to be +0.57 (*SE* 0.08); that is, a medium effect. Furthermore, the mean effect size identified for participants who had been defined as RD using a non-discrepancy definition was higher (+0.72, *SE* 0.13) than the mean effect size found using discrepancy criteria (+0.31, *SE* 0.14), a difference which was found to be statistically significant ($Q = 4.97$, $df = 1$, $p < 0.05$). Therefore the WMTB-C can be seen to be sensitive to differences between RD and TDC, especially if non-discrepancy criteria are employed. While other working memory batteries may be equally sensitive to between group differences, without being able to locate the tasks they use within those identified in this review, conclusions about their sensitivity cannot be drawn. This example serves to highlight the practical implications of assessing working memory in children with RD and the significance of using discrepancy criteria for the assessment of reading difficulties.

Ultimately, the tasks which are employed will depend upon the researcher's theoretical orientation regarding the underlying constructs that each task measures and also the research questions being addressed. However, the findings of the present meta-analysis may assist researchers in identifying appropriate tasks of executive function to maximise sensitivity of between group comparisons, for example, between discrepant and non-discrepant reading difficulties.

2.4.7 Conclusions.

Discrepancies have been identified in the literature regarding whether children with RD show impairments on tasks of executive functioning, even when the same test is used, for example, the Stroop test (e.g. Helland & Asbjornsen, 2000). The findings from the present meta-analysis indicate that children with RD do have impairments with executive function and that the discrepancies found in the literature could be a product of the wide variety of assessment tasks being used and also that differences between the criteria used to select RD may account for further variation. Thus it seems that both researchers and practitioners alike need to give their task selection considerable thought, not only towards which tasks help answer the research hypotheses but also including consideration of the underlying task demands and participant characteristics.

Chapter Three

Study 2.1: Differential Effects for Word Reading and Reading Comprehension

Following the results of the meta-analysis presented in Chapter Two which revealed that children with RD have a general impairment on tasks of executive function which is related to the demands of the assessment tasks employed, the second study of the thesis has four main aims. Firstly, study two aims to assess how far executive functions predict reading ability in a heterogeneous group of children and whether the predictive utility is independent of the role of general cognitive ability. Secondly, the study will determine whether the role of executive functions is dependent on whether word reading or reading comprehension is being evaluated; these results are presented in the current chapter. In addition to this, study two also considers whether the executive function impairments demonstrated by children with RD are influenced by the modality of the assessment task being employed and also the slower developing reading skills which children with RD may have; issues which are discussed in Chapter Four.

3.1 Introduction

A number of theoretical accounts of executive functioning have postulated the importance of inhibition and working memory processes (Denckla, 1996b; Pennington, et al., 1996; Roberts & Pennington, 1996). Further to this, the results presented in Chapter Two demonstrate that when tasks are classified according to which executive function they are predominately used to assess, tasks of inhibition and working memory were consistently found to discriminate between children with RD and TDC. These results therefore suggest a primary role for both inhibition and working memory. However, given the strength of the relationship between executive functions and IQ (c.f.

Chapter One page 40) it is conceivable that the extent to which executive functions are predictive of reading ability is not entirely independent of general cognitive ability.

3.1.1 The contribution of general cognitive ability.

Given the strong correlations reported between working memory and reasoning ability (e.g. Kyllonen & Christal, 1990) it is unsurprising that there have been suggestions that IQ may account for reported differences in working memory skill between children with RD and TDC (Stothard & Hulme, 1992). Swanson (2006) however argued that children with RD have difficulties in working memory even when intelligence is taken into account. Further, structural analytic studies highlight the dissociation between working memory and non-verbal IQ (e.g. Alloway, et al., 2004). In addition, recent research by Alloway (2009) examined how far working memory and IQ predicted reading and maths ability in a sample of children with learning difficulties. Sixty four children were tested on verbal STM, verbal working memory and also visuospatial STM as well as IQ, reading and maths ability. Two years later, 37 of these participants were re-tested on measures of reading and maths. Regression analyses found that verbal working memory predicted reading ability at time two but that IQ did not. These findings serve to highlight the fact that working memory skills are important for reading ability even when IQ has been controlled for, at least in a sample of children with learning difficulties.

Alloway and Alloway (2010) conducted an additional study employing a sample of 98 typically developing participants. Participants completed tasks assessing verbal working memory and IQ at time one when they were aged approximately 5 years old. Six years later they were tested again on tasks of verbal working memory, IQ and attainment in both literacy and maths and the predictive utility of working memory and IQ at both time points was evaluated. The results found that verbal working memory, which had been assessed at time one, and verbal IQ, which was assessed at time two, were the only significant predictors of literacy (based on a composite of word reading, reading comprehension and spelling). However, performance on both aspects made unique contributions to literacy scores, suggesting that the two processes are dissociable.

The results reported by Alloway and colleagues (Alloway, 2009; Alloway & Alloway, 2010) therefore suggest that working memory and IQ are dissociable processes which make unique contributions to literacy performance in both TDC and children with learning difficulties. It is important to note however, that it was only verbal working memory that was used in both studies and that measures of visuospatial working memory were not included. Given that deficits in visuospatial working memory have also been reported in children with RD (Jerman & Swanson, 2005) the present study aims to evaluate whether similar results ensue if visuospatial working memory skills are included. Furthermore, given the theoretical importance of inhibition, the present study will also assess the pattern of results when inhibitory ability is taken into account as well, using a sample of children with heterogeneous reading ability (although see Chapter Four for the predictive utility of IQ in a sample of children with RD). In addition, Alloway's (2009; 2010) results were reported using a composite score of word reading and reading comprehension. However, as word reading and reading comprehension are separable processes, as illustrated in the Simple View of reading (Gough & Tunmer, 1986; Hoover & Gough, 1990), it is conceivable that a differential pattern of results may ensue depending on which component of reading ability is being evaluated.

3.1.2 Word reading and reading comprehension.

Word reading and reading comprehension can be conceived as separable distinct processes for which differing cognitive functions may be important (see Chapter One, page 4). Further to this, distinctions are made between children with RD-WR and RD-RC, suggesting that different aspects of executive function may be implicated in these disorders. Research by Catts, Adlof and Weismer (2006) evaluated the relative importance of language and cognitive processes to children with RD-WR, RD-RC and TDC. Results found that the two groups of children with RD had differing patterns of deficits in regard to language abilities, supportive of the Simple View of reading. In regard to cognitive processes however, while the RD-RC were found to perform more poorly than the TDC group on distance inference tasks, there was no significant difference between the RD-RC and RD-WR. The authors suggested that the distance inference task could be interpreted as evidence of working memory difficulties thus implying that there may be a similar pattern of performance on tasks of working memory between these groups. Consistent with this finding, the results of the meta-analysis reported in Chapter Two revealed that there was no difference in observed effect sizes for RD-WR and RD-RC (although see page 106 for further discussion of this issue). These results therefore suggest that while RD-WR and RD-RC are distinct developmental disorders, the underlying pattern of executive deficit may be comparable.

However, a recent study by Cutting and colleagues (Cutting, et al., 2009) indicates a less consistent pattern of results. A group of children with RD-RC were recruited, along with a group of RD-WR and a group of TDC and tasks assessing oral language, fluency, working memory and planning ability were administered. Those with

RD-RC were found to be more impaired than those with RD-WR on the Tower of London task, however no such group differences emerged for a task of working memory, consistent with the findings of Catts and colleagues (Catts, et al., 2006). Furthermore, no group differences were found in the mazes tasks, which the authors suggested assessed planning and organisation abilities. Therefore, it is possible that the nature of the reading difficulty has an impact on executive function performance for some aspects of executive function and some tasks, but not others. Indeed, Cutting and colleagues argued that their results demonstrate that executive functions are important for reading comprehension. However, they make no such claim regarding word reading. It is therefore possible that the predictive utility of executive functions for reading ability is dependent on whether word reading or reading comprehension is being assessed.

Consistent with this proposition, Savage and colleagues (Savage, et al., 2007) recommended that distinctions between word reading and reading comprehension should be taken into account when evaluating the role of working memory in RD. Indeed, a recent study by Sesma and colleagues (Sesma, et al., 2009) evaluated distinctions between the importance of executive functions for word reading and reading comprehension. The sample comprised a heterogeneous group of children recruited based on a number of areas of difficulty, including RD-WR, RD-RC, ADHD and also some who were TDC; thus while the mean reading score was approximately 100, the range of reading ability was considerable. Separate regression analyses were conducted with word reading employed as the criterion variable in one model and reading comprehension in the other. The results revealed that planning and working memory scores were significant predictors of increases in reading comprehension performance in this sample of mixed reading ability, however neither of these aspects of executive function predicted word reading. The authors therefore argued that while executive functions were important for comprehension they were not required for word reading. Given the extant literature demonstrating the importance of executive functions for reading, it is thus important that this finding be evaluated, especially in light of dissociations between separable aspects of executive function and indeed, the proposed importance of inhibition.

3.1.3 The present study.

The present study evaluates the role that working memory and inhibition have in predicting word reading in light of the impact of IQ in a heterogeneous sample of children, including whether there are dissociations between performance on tasks of working memory and inhibition. Given that theoretical accounts of word reading and reading comprehension emphasise differing higher order processes (c.f. Chapter One), it is conceivable that different aspects of executive function may be more or less important depending on which aspect of reading is being assessed. The present analysis therefore examines whether the same pattern of results is evident when predicting reading comprehension.

3.2 Method

3.2.1 Participants.

A total of 63 participants attending mainstream schools took part in study two. Participants were recruited in order to fulfil the requirements for all aspects of study two; therefore a group of children with RD were recruited as well as two matched control groups. However, as the purpose of the present analysis was to evaluate the predictive utility of working memory and inhibition in a heterogeneous group of children, the groups were collapsed to provide one heterogeneous group of participants (see Chapter Four for analysis regarding group performance), although recruitment was based on group.

Recommendations for sample size for multinomial logistic regression specify a ration of ten participants for every independent variable (Ottenbacher, Ottenbacher, Tooth, & Ostir, 2004). Furthermore, Miles and Shevlin (Miles & Shevlin, 2001) recommend that effect sizes obtained in previous research should be used to calculate necessary sample size. Tasks included in the present study were all selected from the meta-analysis presented in Chapter Two. The overall effect size for the four tasks selected was 0.79 (95% confidence intervals 0.67-0.91), and the lower bound confidence interval effect size estimate was used in calculations employing G-Power. The recommended sample size for regression analysis with an expected effect size of 0.67 was 56 participants.

Twenty-one participants constituted the reading difficulties group (RD). The eligibility criterion for this group was a score beneath the 15th percentile on an age-corrected standardised test of word reading (WIAT- II ^{UK}; Wechsler, 2005). While reading scores beneath the 25th percentile are employed within the research literature, it has been suggested that this may lead to the inclusion of participants whose difficulties with reading may be related to environmental factors (Bishop, 2001; Bishop & Snowling, 2004); therefore a more stringent criterion of a reading score at least one standard deviation beneath the mean was employed. Participants in the RD group were individually matched for chronological age (within three months) and gender to a participant who attended the same school. In addition, participants in the RD group were individually matched to a younger participant of the same gender whose reading level was within 10 raw score points on the word reading subtest of the WIAT- II ^{UK}. The groups were collapsed to provide one heterogeneous group of participants for the present analysis; therefore the sample employed comprised 63 participants, 42 male and 21 female, with a mean age of 115.13 months (*SD* 18.09) (for group level information see Table 4.1 pg 142).

3.2.2 Instrumentation.

All tests were administered following their standardised instructions. The word reading subtest (split-half reliability .97) and the reading comprehension subtest (split-half reliability .95) of the WIAT- II ^{UK} (Wechsler, 2005) were administered to all participants. In the word reading task participants read single unrelated words from a card, and in the reading comprehension task participants read passages of text and answered questions concerning each passage requiring drawing of inferences and locating details. The short form of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) comprising the vocabulary and the matrix reasoning subtests, where participants provide word definitions and use deductive reasoning to complete a pictorial pattern respectively, was completed by each participant. Scores on each of these subtests were used to compute a pro-rated verbal IQ and performance IQ score for each participant (split half reliability.93).

The Expressive Attention subtest from the Cognitive Assessment System (CAS; Naglieri & Das, 1997) is based on the Stroop task (Stroop, 1935) and was used as a measure of participants' inhibitory skills (test-retest reliability .80). Separate versions of the tasks are given for children aged 5-7 and children aged 8-16. For children aged 8-16, in the first trial of this task participants are presented with a page with rows of colour names printed on it in black and white and are required to name the colour word. In the second trial participants are presented with a page with rows of blocks of colours printed on it in either red, blue, yellow or green and are required to name the colour of each block. The final trial consists of a page of rows of colour names printed in different colours. Participants' are required to name the colour of the ink in which a colour name is printed e.g. for the word "yellow" writen in red ink, participants should respond with "red". For children aged 5-7, the colour words are replaced with pictures of animals which are drawn either congruous or incongruous in size e.g. a picture of an elephant can be drawn either as big in scale or small and participants are required to name the size of the animal, not the size of the scaled picture. The number of errors made and time taken to complete each item was recorded using a stop-watch, and if participants did not complete each item within a designated time limit they were instructed to stop. Standardised scoring procedure and age-corrected standardised scores are available, with higher scores indicating that participants are better at ignoring interference i.e. better at inhibiting.

In order to assess participant's inhibitory skills using a task which does not require a specific verbal response, the Number Detection subtest from the CAS (Naglieri & Das, 1997) was administered (test-retest reliability .77). The Number Detection task involves two items in which participants are presented with a page of numbers, 15 rows with 12 numbers in each row, and asked to underline specific numbers that are presented at the top of each page using a red pencil. For 8-16 year olds, in the first item participants are required to underline the numbers 1, 2 and 3 when they are printed in outlined type and ignore all other numbers and in the second item participants are instructed to switch response and underline the numbers 1, 2 and 3 when they are printed in regular font and the numbers 4, 5 and 6 when they are printed in outlined typeface, again ignoring distractors. For 5-7 year olds, participants are required to underline the numbers 1, 2 and 3 in the first trial and 4, 5 and 6 in the second trial. As with the Expressive Attention subtest, the number of errors made and time taken to complete each item was recorded using a stop-watch. Standardised scoring procedure and age-corrected standardised scores are available, with higher scores also indicating that participants are better at ignoring interference i.e. better at inhibiting.

The Backward digit span subtest from the Wechsler Intelligence Sale for Children (WISC-IV ^{UK}; Wechsler, 2004) was administered as a measure of verbal working memory skills. The task involves the experimenter reading lists of digits of increasing length to the participant. Participants' are required to repeat each list of digits back to the experimenter in reverse order. Age-corrected standardised scores are based on the number of correctly recalled lists and average split-half reliability is reported as .80.

As a measure of visuospatial working memory, the Mapping and Directions subtest from the Swanson-Cognitive Processing Test (S-CPT; Swanson, 1996) was used (coefficient alpha .72). Participants are presented with a picture of a "map", involving squares which represent buildings, dots as traffic lights, and lines and arrows as directions. Participants are given five seconds to look at the picture, before it is taken away and they are required to answer a processing question concerning whether or not any traffic lights appeared in the first column, and point to a picture which shows the strategy they will use to remember the map. Participants are then asked to reproduce the map on a blank map which has only the squares printed on it. Maps of increasing complexity are administered until participants' make an error in their reproduction of the map. Raw scores are based on the number of maps correctly produced and age – corrected standardised scores are available.

In addition, the teacher's version of the Conners 3AI (Conners, 2008) was issued to the class teachers of all participants' in the RD group. This is a ten item check list which consists of the items best at differentiating children most at risk of a definition of ADHD from those in the general population (Cronbach's alpha .94).

3.2.3 Procedure.

Eight primary schools in North Lanarkshire agreed to participate in the present study, and informed consent[8] was gained from all participants and their parents following the Code of Ethics and Conduct (BPS, 2009). All participants were tested individually in either a quiet room or quiet area of their school. Before testing commenced all participants were reminded of the rights of participation and also gave their verbal consent.

Testing took place in two sessions of approximately 45 minutes each. In the first session, participants were administered the word reading subtest and reading comprehension subtest from the Wechsler Individual Achievement Test (WIAT- II ^{UK}; Wechsler, 2005) and the short-form of the WASI. Order of administration was held

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[8] See Appendices F-I for examples of information sheets and consent forms for schools, parents and participants.

constant in the first session. All other instruments were administered in the second session and order of presentation was randomised. At the end of testing, any questions that participants had were answered.

3.3 Results

3.3.1 Descriptive statistics.

Raw scores were converted to age corrected standardised scores using test manuals. Table 3.1 illustrates the mean raw scores and standardised scores for the word reading and reading comprehension tasks. Full scale IQ was calculated using the two subtest short form of the WASI and pro-rata verbal IQ and performance IQ was also calculated. Mean and standard deviations for full scale, verbal and performance IQ are also shown in Table 3.1.

Table 3.1. Mean, standard deviation (*SD*), minimum and maximum raw scores and standardised scores for the word reading and reading comprehension subtests and verbal, performance and Full-scale IQ.

		Mean	*SD*	Min	Max
Raw scores	Word reading	95.27	12.59	74.00	122.00
	Reading comprehension	122.29	16.34	78.00	146.00
Standard scores	Word reading	93.98	14.96	63.00	123.00
	Reading comprehension	98.67	10.61	73.00	118.00
	Verbal IQ	91.83	11.19	71.00	132.00
	Performance IQ	99.71	15.55	64.00	131.00
	Full-scale IQ	95.49	11.67	71.00	124.00

Note: Standard scores for all tasks give a mean score of 100 and a *SD* of 15.

Inspection of Table 3.1 reveals that the mean scores for all tasks were within the normal range to be expected for the standardisation of the instruments. The mean and standard deviation for all executive function task scores are reported in Table 3.2.

Table 3.2. Mean and *SD*, minimum and maximum scores for all executive function tasks.

	Mean	*SD*	Min	Max
Expressive attention (I V)	10.41	3.04	2.00	17.00
Number detection (I NV)	9.33	2.23	5.00	14.00
Backward digit span (WM V)	8.35	3.76	1.00	16.00
Mapping (WM NV)	7.21	2.11	5.00	12.00
Inhibition composite	9.87	2.37	3.50	15.00
Working memory composite	7.78	2.27	3.00	13.00

Note: Standard scores for all tasks give a mean score of 10 and a *SD* of 3.

Standard scores for all executive function tasks provide a mean score of 10 with a respective standard deviation of 3. As such, Table 3.2 illustrates that the mean score of all tasks was within the normal range, although the mean score for the mapping task was almost one standard deviation below the mean expected based on the standardisation.

In order to detect univariate outliers, scores on all measures within each group were converted to z-scores. Following guidelines which suggest that standardised scores greater than 3.29 are potential outliers (Tabachnick & Fidell, 2001), no univariate outliers were detected. Inspection of residuals (standardised and Cook's) identified four multivariate outliers which were removed (Tabachnick & Fidell, 2001).

Normality was assessed by inspection of probability plots (Field, 2005). Following guidelines set out in Tabachnick and Fidell (2001) the distribution of residuals was deemed normal. Furthermore, linearity was investigated by inspection of residual plots and homoscedasticity was assessed by way of scatterplot examination; no issues were identified. In order to assess multicollinearity, tolerance statistics and the variance inflation factor (VIF) were inspected. Field (2005) states that VIF values above 10 are cause for concern as are tolerance statistics below .2 ; as values were within acceptable levels, there was no cause for concern (Field, 2005).

Correlations between all tasks administered can be seen in Table 3.3, which reveals that the majority of tasks administered were significantly correlated to some degree.

Table 3.3. Correlations between reading, IQ and executive function tasks scores.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1.Word reading	-									
2. Reading comprehension	.75**	-								
3. Verbal IQ	.67**	.70**	-							
4. Performance IQ	.45**	.43**	.44**	-						
5. Full scale IQ	.64**	.64**	.80**	.89**	-					
6. Expressive attention (I V)	.53**	.46**	.50**	.43**	.54**	-				
7. Number detection (I NV)	.46**	.34**	.35**	.38**	.43**	.61**	-			
8. Backward digit span (WM V)	.30*	.33**	.25	.30*	.31*	.30*	.32**	-		
9. Mapping (WM NV)	.31*	.34**	.40**	.27*	.39**	.38**	.03	.13	-	
10. Inhibition composite	.55**	.46**	.49**	.45**	.54**	.93**	.86**	.35**	.26*	-
11. Working memory composite	.39**	.44**	.39**	.37**	.44**	.43**	.28*	.89**	.57**	.41**

Note: *p<0.05; **p<0.01; ***p<0.001

3.3.2 Hierarchical linear regression.

3.3.2.1 Predicting word reading.

Hierarchical linear regressions were carried out in order to determine whether participants' performance on tasks of executive function accounted for unique variance in word reading scores above the impact of IQ. Composite scores of inhibition and working memory were created using the standardised scores for each of the subtests measuring these constructs. Two separate hierarchical linear regressions were performed; one with full scale IQ (FSIQ) entered at step one and then both executive function composite scores entered at step two, and another with the executive function composites entered first in order to assess the unique contribution of the variables. Inspection of mahalanobis and leverage statistics, standardised residuals and Cook's distance statistics revealed no multivariate outliers or influential cases.

For the first regression analysis a significant model emerged at step one with FSIQ entered as the predictor variable and word reading score as the criterion variable: F (1, 61) = 43.15, p<0.001. This model explained some 40% of the variance (Adjusted R^2= .41). When the executive function tasks scores were added at step two a significant model also emerged (F (3, 59) = 17.98, p<0.001) which accounted for an additional 4% of the variance, meaning that the final model accounted for 45% of the overall variance (Adjusted R^2= .45), a large effect size (f^2 > 0.35; J. Cohen, 1988). Table 3.4 provides details of the predictor variables entered at each step of the model.

Table 3.4 Standardised and unstandardised regression coefficients for variables entered predicting word reading scores.

	B	*SE* B	β	R^2	Adjusted R^2	f^2
Model 1:						
Step 1				.41	.41	0.71
Constant	15.18	12.09				
FSIQ	0.83	0.13	.64***			
Step 2				.48	.45	0.92
Constant	16.50	11.62				
FSIQ	0.59	0.15	.46***			
Inhibition	1.71	0.73	.27*			
Working memory	0.50	0.71	.08			
Model 2:						
Step 1				.34	.32	0.51
Constant	54.40	7.36				
Inhibition	3.00	0.73	.47***			
Working memory	1.29	0.76	.20			
Step 2				.48	.45	0.92
Constant	16.50	11.62				
FSIQ	0.59	0.15	.46***			
Inhibition	1.71	0.73	.27*			
Working memory	0.50	0.71	.08			

Note: * $p<0.05$; ** $p<0.01$; *** $p<0.001$

The Standardised Beta coefficients (β) shown in Table 3.4 reveal that for a change of 1 *SD* of FSIQ, word reading scores are predicted to increase by 0.64 *SD*. When the executive function tasks were added at step 2 this fell to 0.46 *SD* and a change of 1 *SD* on the inhibition composite meant that word reading scores were predicted to increase 0.27 *SD*. The working memory composite was not found to be a significant predictor of word reading skills.

For the second model, when the executive function composites were entered in step one a significant model emerged (*F* (2, 60) = 15.35, $p<0.001$) which accounted for 31% of the variance in word reading scores (Adjusted $R^2 = .32$). In step two, FSIQ was also entered which accounted for an additional 14% of the variance above the impact of the executive function scores. Details of the predictor variables entered at each step can be found in Table 3.4.

The Standardised Beta coefficients (β) in Table 3.4 show that when the executive function scores were entered into the model at step one, for a change of 1 *SD* on the inhibition task, word reading scores are predicted to increase by 0.47 *SD*. When FSIQ was added at step two this fell to 0.27 *SD*. The working memory composite was again not found to be significant predictor.

The results of these regression analyses show that the composite score of inhibition and FSIQ were both unique predictors of word reading scores. Scores on the working memory composite did not account for any unique variance in word reading though.

3.3.2.2 Predicting reading comprehension.

In order to assess whether the same pattern of results were evident for the case of reading comprehension, two further hierarchical regression analyses were conducted, this time with reading comprehension scores as the criterion variable. In the first model, when FSIQ was entered in isolation a significant model emerged (*F* (1, 61) =43.27, $p<0.001$) accounting for 41% of the variance in reading comprehension scores (Adjusted

$R^2 = .41$). When the executive function composites were entered in step two, while the overall model was still significant (F (3, 59) = 16.22, $p<0.001$), the addition to the model was not significant. Neither inhibition nor working memory were significant predictors of reading comprehension when FSIQ was entered into the model first (see Table 3.5 for standardised regression coefficients).

However, in the second model, when composite scores of inhibition and working memory were entered into the model first, the overall model was significant (F (2, 60) = 11.75, $p<0.001$) accounting for almost 26% of the variance in reading comprehension scores with both inhibition and working memory emerging as significant predictors. When FSIQ was entered at step two, neither of the executive functions remained significant predictors. Therefore while both inhibition and working memory significantly predict reading comprehension, this is not in addition to the impact of FSIQ.

Table 3.5. Standardised and unstandardised regression coefficients for variables entered predicting reading comprehension scores.

	B	*SE* B	β	R^2	Adjusted R^2	f^2
Model 1:						
Step 1				.42	.41	0.71
Constant	42.75	8.56				
FSIQ	0.59	0.09	.64***			
Step 2				.45	.42	0.82
Constant	43.32	8.44				
FSIQ	0.47	0.11	.51***			
Inhibition	0.48	0.53	.11			
Working memory	0.79	0.51	.17			
Model 2:						
Step 1				.28	.26	0.39
Constant	73.08	5.44				
Inhibition	1.49	0.54	.33**			
Working memory	1.40	0.56	.30*			
Step 2				.45	.42	0.82
Constant	43.32	8.44				
FSIQ	0.47	0.11	.51***			
Inhibition	0.48	0.53	.11			
Working memory	0.79	0.51	.17			

Note: * $p<0.05$; ** $p<0.01$; *** $p<0.001$

3.4 Discussion

Results revealed that while inhibition and FSIQ were independent predictors of children’s word reading skills, working memory was not a significant predictor. In contrast, inhibition and working memory were both significant predictors of comprehension ability but not when FSIQ was taken into account, demonstrating differential affects depending on which aspect of reading is being assessed.

3.4.1 Does IQ have a role to play?

The results demonstrated that the predictive utility of executive function task performance may not be completely independent of FSIQ, depending on which aspects of reading are utilised as outcome measures. Alloway (2009; 2010) found that working memory was more predictive of reading than FSIQ; a composite measure of reading was used, which included measures of both word reading and reading comprehension and verbal tasks only of working memory. When tasks of both inhibition and working memory were included in the present study, inhibition was found to be more predictive of reading than working memory task performance. Although when FSIQ was included in the model predicting reading comprehension, tasks of inhibition and working memory were no longer predictive. While the present study involved a heterogeneous group of children, one third of whom were recruited on the basis of word reading difficulties, it may be that the inclusion of children with adequate reading skills (as in the sample of Sesma et al., 2009) masked the predictive utility of working memory task performance. However given that Alloway and Alloway (2010) found that working memory was more predictive of IQ in a sample of TDC, this is unlikely to be the only explanation.

This finding is consistent with recent research which suggests that the relationship between learning difficulties and working memory is not related to IQ (Maehler & Schuchardt, 2009) as well as research which has reported that IQ scores are not related to cognitive differences between children with RD and their typically developing peers (Jiménez, et al., 2009). Furthermore, these findings add to the growing body of research which suggests that IQ should not be as central to the assessment of RD as other cognitive processes (Restori, et al., 2009; Stanovich, 2005; Stuebing, et al., 2002; Swanson, 2006).

3.4.2 Word reading and reading comprehension.

The findings are consistent with previous research findings from Sesma et al. (2009) who highlighted the fact that differential aspects of executive function contributed to word reading and reading comprehension ability. Specifically, they found that working memory and planning skills predicted scores on tasks of reading comprehension but that they did not significantly predict word reading though tasks assessing IQ were not included in their test battery. The results of the present study found that executive functions only predicted reading comprehension ability when IQ was not controlled. It is important to acknowledge however, that different aspects of executive function were assessed in the present study, although previous research has found that inhibition is more predictive of reading comprehension than planning ability, albeit in a heterogeneous group of children with a relatively high proportion of below average readers (Booth & Boyle, 2009). In addition, the present study found that performance on tasks of inhibition accounted for unique variance in word reading even when IQ was included in the model. These findings indicate that differential processes contribute to word reading and reading comprehension skill, but that inhibitory mechanisms are important for all aspects of reading.

These findings are supportive of theoretical accounts which have postulated the importance of inhibitory mechanisms for successful word reading (Gernsbacher, 1993; Lupker, 2007; Perfetti, 1984), and indeed research which has suggested that inhibition is important for phonological recoding (Palmer, 2000b). Furthermore, working memory ability is believed to be integral to reading comprehension (Perfetti, Landi, & Oakhill, 2007; Vukovic & Siegel, 2006b) however inhibitory skills have also been implicated in research studies (e.g. Palladino, et al., 2001).

3.4.3 Limitations.

The results of the present chapter are limited in the extent to which they can be generalised. While a heterogeneous sample of children was employed, it must be noted that one third of the sample were recruited based on low word reading scores. Thus while the results indicate the extent to which inhibition and working memory are predictive for a heterogeneous sample, caution must be taken when generalising the findings of hierarchical regression to participants who all have appropriate word reading abilities.

Furthermore, while the present study involved children with word reading difficulties, it did not include any children with specific reading comprehension difficulties. The study by Sesma et al. (2009) involved a heterogeneous sample of children, however this included a small number of children with specific reading comprehension difficulties. A recent study by Cutting et al. (2009) found that there were differences between children with general reading difficulties (defined as low scores on measures of word recognition and non-word decoding) and those with specific reading comprehension difficulties on tasks assessing planning, but not on tasks assessing working memory skills. As the predictive utility of tasks of executive function varied depending on whether word reading or reading comprehension was being assessed in the present study, future research involving children with specific reading comprehension difficulties as well as those with word reading difficulties could go some way towards a fuller explanation of the underlying functions involved in these processes.

3.4.4 Conclusion.

The present study found that inhibition and working memory predict reading ability in a heterogeneous group of children. When tasks of IQ were also included, only inhibitory skills significantly predicted word reading. When reading comprehension was employed as the criterion variable, both working memory and inhibition were important predictors, but not in light of the impact of IQ. The results therefore suggest that executive functions are distinct from IQ, although the pattern of results requires further consideration and will be discussed in Chapter Five. Furthermore, as there are differences in underlying factors important for word reading and reading comprehension it is important to treat these as separable factors and not synonymous with each other; an issue also examined further in Chapter Five.

Chapter Four

Study 2.2: Can Executive Function Task Performance Predict Reading Group Membership?

4.1 Introduction

Results of Study 2.1 presented in Chapter Three demonstrated that inhibition and IQ are independent predictors of word reading in a heterogeneous sample of children. Furthermore, while inhibition and working memory both predicted reading comprehension ability, they did not contribute unique variance once IQ was included in the model. The present chapter employs the sample previously described in Chapter Three but grouped by reading ability and aims to assess whether performance on tasks of inhibition and working memory can discriminate between children who have RD and matched control groups, including children of the same reading level. Given the modality differences identified in Chapter Two, the present analysis will explore whether task modality influences the results.

4.1.1 Reading difficulties, working memory and inhibition.

There is a growing body of research evidence which demonstrates the relationship between working memory skills and RD (De Jong, 1998; Martinussen & Tannock, 2006; Nation, et al., 1999; Swanson, 1999a; Swanson & Alexander, 1997; Swanson & Jerman, 2007). For example, research by Swanson, Howard and Sáez (2006) found that children with RD demonstrate impaired performance on tasks assessing working memory when compared to skilled readers. In addition, Gathercole, Alloway, Willis and Adams (2006) found that working memory skills significantly predicted reading and maths ability in children with RD. Furthermore, Gathercole et al. (2008) found that the majority of a group of children recruited on the basis of low working memory skills had impaired scores on standardised measures of reading ability. In addition to this, half of the group had elevated scores on the inhibition aspect of a behavioural rating questionnaire. The relationship between working memory and reading difficulties is further supported by the recent findings of Alloway, Gathercole, Kirkwood and Elliott (2009) who screened over 3000 children in order to assess the prevalence of working memory impairments. They found that approximately 10 % of children screened had very low working memory ability and this sample were also found to have impaired reading performance and high levels of executive function difficulties as assessed by a behavioural questionnaire.

In terms of the relationship between RD and inhibition, research studies have found that children with RD are impaired on a variety of tasks assessing inhibitory skills. These include the Stroop task (e.g. Altemeier, et al., 2008; Everatt, et al., 1997; Everatt, et al., 2008; Helland & Asbjornsen, 2000) and also the Stop-signal task (e.g. Willcutt, et al., 2001; Willcutt, Pennington, et al., 2005). Protopapas, Archonti and Skaloumbakas (2007) report results from two studies concerning the relationship between RD and Stroop interference. In the first study, 16 children with RD were compared to a TDC group and in the second study 156 children were recruited from across the full range of reading ability. Findings were consistent across both studies; poorer reading ability was associated with poorer performance on the Stroop task suggesting a strong relationship between RD and inhibitory impairment.

However, there are inconsistencies in the literature. Several studies have failed to find working memory impairments in children with difficulties with reading (e.g.

Pickering & Gathercole, 2004; Stothard & Hulme, 1992; Van der Sluis, et al., 2005) and in a review of the literature Savage, Lavers and Pillay (2007) concluded that claims of a clear and unambiguous concurrent association between RD and working memory can still currently be questioned. Furthermore, similar results have been found for tasks assessing inhibitory skills (e.g. Hall, et al., 1997; McGee, et al., 2004; Pennington, et al., 1993) where the performance of groups of children with RD has been equivalent to TDC.

4.1.2 Modality.

In addition to discrepancies regarding deficits in inhibition and working memory, one further factor for consideration concerns the role of task modality. Discrepant findings have been noted in the literature, with some studies reporting that children with RD have domain general deficits in working memory (e.g. Jerman & Swanson, 2005) whereas others report difficulties which are specific to tasks of working memory involving verbal material (Everatt, et al., 2008). Further to this, Pimperton and Nation (2010) found impaired performance on tasks of working memory and inhibition for children with reading comprehension difficulties only when tasks were verbal in nature, despite unimpaired performance on verbal short-term memory tasks; findings which they argued add support to those who advocate a model suggesting a fractionated central executive (e.g. Shah & Miyake, 1996). As children with RD-WR have impairments with the phonological system, impairments with verbal tasks of executive function might be expected when compared to age-matched control children but it is unclear whether the same pattern will be found when compared to children matched for reading-level. In Chapter Two, the meta-analysis reported found significantly greater effect sizes for tasks involving verbal material, however this finding was not completely consistent. One possibility is that there are modality differences for some aspects of executive function but not for others, which would be suggestive of a less pervasive deficit. The present study will go some way to reconcile these discrepancies.

4.1.3 Aims.

Given the theoretical prominence of inhibition and working memory and the inconsistencies reported in the literature it is important to gain a clearer understanding of the relationship that these processes have with children's reading difficulties. The present study therefore aims to extend the current literature by applying a rigorously controlled methodology to investigate inhibition and working memory in children with difficulties with reading, a chronological age matched control group and a reading-level matched control group. While participants were recruited for the RD group based on low word reading only, it may be that there is differential performance for those who fulfil IQ/achievement discrepancy criteria and those who do not (c.f. Chapter One page 17) as the results presented in Chapter Two were inconclusive. As such this will also be explored in the present study.

In light of the modality differences identified previously, this study further aims to assess whether scores on tasks of inhibition and working memory predict whether children had difficulties with reading or not above the impact of IQ and whether task modality influences the pattern of results. Furthermore, the possibility that any performance deficiencies identified for children with RD are attributable to slower developing reading skills will also be evaluated through inclusion of the reading level matched control group.

4.2 Method

4.2.1 Participants.

The same participants described in Chapter Three took part in the present analysis. Twenty-one participants constituted the reading difficulties group (RD). The eligibility criterion for this group was a score below the 15th percentile on an age-corrected standardised test of word reading (WIAT- II ^{UK}; Wechsler, 2005). Participants in the RD group were individually matched for chronological age (within three months) and gender to a participant who attended the same school (the CA group). In addition, participants in the RD group were individually matched to a younger participant of the same gender whose reading level was within 10 raw score points on the word reading subtest of the WIAT- II ^{UK} (the RL group). Age and gender of participants in each group can be seen in Table 4.1.

Table 4.1. Gender and age of participants' in each group.

	Reading difficulties (RD) (*n* = 21)	Chronological age matched (CA) (*n*= 21)	Reading level matched (RL) (*n*=21)
Male/female	14/7	14/7	14/7
Age (in months)	127.86 (*SD* 5.08)	127.10 (*SD* 3.87)	90.43 (*SD* 3.60)

4.2.2 Instrumentation and procedure.

All instrumentation employed and procedures adopted are described in Chapter Three (page 121).

4.3 Results

4.3.1 Descriptive statistics.

Raw scores were converted to age corrected standardised scores using test manuals. Table 4.2 shows the mean raw scores, standardised scores and reading age equivalents for the word reading subtest and the reading comprehension subtest for all three groups.

Table 4.2. Mean, standard deviation (*SD*), minimum and maximum raw scores, standardised scores and reading age equivalents for the word reading subtest and the reading comprehension subtest for all three groups.

		Reading difficulties (RD) (*n*=21)				Chronological age matched (CA) (*n*=21)				Reading level match (RL) (*n*=21)			
		Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max
RS	WR	86.62	5.79	75.00	96.00	110.71	5.66	103.00	122.00	88.48	6.93	74.00	97.00
	RC	110.52	8.23	96.00	127.00	128.05	10.44	106.00	146.00	98.29	13.46	78.00	117.00
SS	WR	75.76	5.98	63.00	84.00	104.48	8.81	90.00	123.00	101.71	7.31	86.00	115.00
	RC	88.00	7.29	73.00	101.00	104.52	8.53	89.00	118.00	103.48	6.63	92.00	128.00
R AE	WR	7;04	5.55	6;08	8;04	12;03	25.74	10;00	16;00	7;06	7.47	6;06	8;06
	RC	9;00	11.97	7;00	10;08	10;08	13.48	8;04	12;08	7;06	16.19	6;00	9;06

Note: WR= word reading; RC= reading comprehension; RS = Raw score; SS = Standard score; RAE = Reading age equivalent

Inspection of Table 4.2 reveals that there was only a difference of two raw score points in the mean word reading scores of the RD and RL groups. Independent t-tests confirmed that there was no significant difference between the RD group and the RL group on word reading raw scores and in addition, that the RL group did not differ statistically from the CA group on either word reading or reading comprehension standard scores (all *p* values >0.10).

Full scale IQ was calculated using the two subtest short form of the WASI and pro-rata verbal IQ and performance IQ was also calculated. Mean and standard deviations for full scale, verbal and performance IQ, number detection subtest, expressive attention subtest, backward digit span and mapping tasks for all groups are shown in Table 4.3.

Inspection of Table 4.3 reveals that the RD group have lower mean IQ scores than both of the other groups. A one-way ANOVA and follow-up pairwise comparisons revealed no statistically significant difference between performance IQ scores of the RD group and the CA group and the CA group and the RL group. Similarly, the verbal IQ scores of the CA group and the RL group did not differ statistically.

Further inspection of Table 4.3 reveals that the RD group had lower mean scores on all of the tasks of executive function with the exception of the Mapping task. Performance of the RD group was lower than the CA group but similar to the RL group, indicating that there may have been a floor effect for this task.

In order to detect univariate outliers, scores on all measures within each group were converted to z-scores. Following guidelines which suggest that standardised scores greater than 3.29 are potential outliers (Tabachnick & Fidell, 2001), no univariate outliers were detected.

Table 4.3. Mean and standard deviations (*SD*) for verbal and performance IQ, number detection subtest, expressive attention subtest, backward digit span and mapping tasks for all groups.

	Reading difficulties (RD) (*n*=21)		Chronological age matched (CA) (*n*=21)		Reading level age match (RL) (*n*=21)	
Task	Mean	*SD*	Mean	*SD*	Mean	*SD*
Full Sale IQ	86.81	8.29	100.24	10.49	95.49	11.67
Verbal IQ	83.52	7.00	99.24	10.43	92.71	9.98
Performance IQ	91.10	13.88	101.19	15.01	106.86	14.05
Number detection (I NV)	7.52	1.47	9.33	1.59	11.14	1.96
Expressive attention (I V)	8.29	2.28	11.48	2.71	11.48	2.99
Backward digit span (WM V)	5.95	3.11	9.76	3.55	9.33	3.53
Mapping (WM NV)	6.57	2.06	8.67	2.18	6.38	1.20

4.3.2 IQ/achievement discrepancy.

IQ/achievement discrepancy criteria require that participants should have a 12-15 point discrepancy between their ability (which should fall within the normal range) and their reading ability score (Stuebing, et al., 2002). While this selection criterion was not employed in the current study, as a measure of non-verbal ability was included in the test battery, it was possible to investigate the performance on tasks of executive function of participants who fulfilled this criterion compared to participants who did not.

Fourteen participants in the RD group who had a non-verbal ability score above 85 (within average range), and a word reading standard score at least 15 points lower, were classed as fulfilling IQ/achievement discrepancy criteria. The seven remaining participants in the RD group did not fulfil this criterion and were classed as non-discrepancy RD. The mean scores and standard deviations for the executive function tasks for these two subgroups can be seen in Table 4.4.

As illustrated in Table 4.4, the subgroup which fulfilled traditional IQ/achievement discrepancy criteria had higher mean scores on all of the executive function tasks. As the sample size for these two groups was relatively small, a Mann-Whitney test was used to compare group performance. No significant differences emerged (all p values > 0.05), indicating that the performance of these groups on tasks of executive function was no different. Therefore scores across these groups were collapsed for subsequent analyses.

Table 4.4. Mean scores and Standard deviations (*SD*) for executive function tasks for discrepancy criteria subgroup and non-discrepancy subgroup.

	Discrepancy group (*n*=14)		Non-discrepancy group (*n*=7)	
Task	Mean	*SD*	Mean	*SD*
Expressive attention	8.64	1.60	7.57	3.31
Number detection	7.79	0.97	7.00	2.16
Backward digit span	6.71	3.20	4.43	2.44
Mapping	6.79	2.15	6.14	1.95

4.3.3 ADHD characteristics.

In order to identify participants who had significantly high levels of ADHD symptoms and were thus at risk of receiving a diagnosis of ADHD, the Conners teachers rating scale was administered (Conners, 2008). Scores above 70 indicate a high level of risk of receiving a diagnosis. Three teachers did not complete the rating scale and so this information was available for 18 of the participants in the reading difficulties group, nine of whom had significant levels of ADHD symptoms and nine of whom did not. Mann-Whitney tests revealed no significant differences between scores on the measures of executive function of those who had significant ADHD symptoms and those who did not. Scores were therefore collapsed across this category for all subsequent analyses.

4.3.4 Moderator analysis.

Correlations between each of the executive function task scores and word reading score were compared to partial-correlations with non-verbal IQ controlled for using Fisher's *r* to *z* transformations. No significant differences between z-scores were found (all *p* values >0.05) indicating that non-verbal IQ did not significantly influence the relationship between the executive function task scores and word reading.

4.3.5 Multinomial logistic regression.

Multinomial logistic regression was carried out in order to investigate whether tasks of working memory and inhibition predict reading group membership. Two separate regressions were performed, the first using tasks which were verbal in nature as predictor variables (expressive attention and backward digit span tasks) and the second using tasks which placed fewer demands on participants' language skills (number detection and mapping tasks). As estimates of verbal IQ and FSIQ may be influenced by participants' potential difficulties with language, performance IQ was also entered into each model (RD mean = 91.10, *SD* = 13.88; CA mean = 101.19, SD = 15.01; RL mean = 106.86, *SD* = 14.05). Furthermore, the two competing models were compared. Inspection of residuals (standardised and Cook's) identified four multivariate outliers (three from the verbal model and one in the non-verbal model) which were removed (Tabachnick & Fidell, 2001). Results of the multinomial logistic regressions excluding outliers are shown in Table 4.5.

Table 4.5. Multinomial logistic regression

	CA v's RD				RL v's RD			
	B *(SE)*	Exp (B)	95% Conf Interval for Exp (B)		B *(SE)*	Exp (B)	95% Conf Interval for Exp (B)	
Verbal model								
P IQ	.07 (0.04)	1.07	.98-1.16		.10* (0.05)[9]	1.11	1.02-1.21	
Expressive attention	.70** (0.23)	2.02	1.30-3.14		.69** (0.23)	1.99	1.26-3.13	
Backward digit span	.41** (0.15)	1.51	1.12-2.04		.40* (0.16)	1.49	1.10-2.03	
Model	- 2 log likelihood		χ^2Goodness -of-fit index	*df*	Cox & Snell R^2	Nagelkerke	AIC	% Classification accuracy
	87.57		44.16***	6	.52	.59	103.57	66.7
Non-verbal model								
P IQ	.02 (0.03)	1.02	.96-1.09		.09 (0.05)[10]	1.09	1.00-1.19	
Number detection	.74**(0.28)	2.10	1.21-3.66		1.86 *** (0.50)	6.41	2.40-17.09	
Mapping	.36 (0.19)	1.44	.99-2.09		-.57 (0.36)	0.57	0.28-1.15	
Model	- 2 log likelihood		χ^2Goodness -of-fit index	*df*	Cox & Snell R^2	Nagelkerke	AIC	% Classification accuracy
	71.28		64.92***	6	.65	.73	87.28	77.4

Note: AIC= Akaike's information criterion; *$p<0.05$; **$p<0.01$; ***$p<0.001$

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[9] This relationship is non-significant when outliers are included

[10] This relationship is significant when outliers are included

4.3.5.1 Verbal model.

The -2log likelihood and chi-squared statistics show that the predictor variables provided a significant fit to the verbal model. Both the expressive attention task and the backward digit span task significantly distinguished between the RD and CA groups and between the RD and RL groups. A one unit increase in the expressive attention task increased the odds of being in the CA group rather than the RD group by 102% and increased the odds of being in the RL group rather than the RD group by 99% (ExpB column). An increase in the backward digit span task increased the odds of being in the CA group by 51% and in the RL group by 49% compared to the RD group. Performance IQ was only significant at differentiating the RL group from the RD group, and it increased the odds of this by 11%.

4.3.5.2 Non-verbal model.

The -2log likelihood and chi-squared statistics demonstrate that the predictor variables also provided a significant fit to the non-verbal model. The number detection task significantly distinguished both the CA and RD groups and the RL and RD groups. An increase in number detection increased the odds of being in the CA group by 110% and increased the odds of being in the RL group by 541% when compared to the RD group. While there was a statistically significant relationship between the mapping task and reading group (χ^2 (2) = 14.67, *p*<0.01) it did not significantly distinguish the RL group or the CA group from the RD group, although the latter did approach conventional levels of significance (*p*=0.058). Performance IQ did not have a statistically significant relationship with reading group in the non-verbal model.

4.3.5.3 Model comparison.

In order to discern which model provided a better fit, the pseudo R^2 statistics (Cox & Snell R^2 and Nagelkerke) were examined, together with Akaike's Information Criterion (AIC) and the percentage classification accuracy. As can be seen in Table 4.5, the non-verbal model correctly classified almost 11% more cases than did the verbal model, with the AIC lower by some 16 points. Table 4.6 reveals that while the verbal model correctly classified 86% of the RD group this was at the expense of poor classification of the control groups (50% correctly classified for CA and 63% for RL match) meaning that while the sensitivity of this model was good the specificity was poorer. In the verbal model 76% of the RD group were correctly classified, however, specificity of this model was improved with 67% of the CA group correctly classified and 90% of the RL group. The non-verbal model was therefore deemed to be a more sensitive model in terms of predicting reading group membership.

Table 4.6. Percentage of sample correctly classified in multinomial regression analyses

Correctly classified	RD %	RD *n*	CA %	CA *n*	RL %	RL *n*	Overall %	Overall *n*
Verbal model	86	18	50	10	63	12	66.7	40
Non-verbal model	76	16	67	14	90	18	77.4	48

4.4 Discussion

Results revealed that when verbal tasks were examined in isolation, scores on tasks of both inhibition and working memory significantly discriminated the group of children with difficulties with reading from both the chronological-age matched and also the reading-level matched control groups. However, when tasks which placed fewer demands on participants' language skills were examined, only performance on tasks of inhibition significantly differentiated the groups. Furthermore, when the two competing models were compared, the model which employed the non-verbal tasks was found to be more sensitive in predicting reading group membership. The results are therefore suggestive of a more pervasive deficit in inhibitory skills than working memory skills in children with difficulties with reading. This relationship was found to be one that is influenced by the modality of the assessment task used; however as task performance discriminated the RD group from the RL group, the relationship cannot be attributed to slower developing reading skills of the children in the RD group.

In addition, it was found that both inhibition and working memory predicted reading group and were stronger predictors than non-verbal IQ, but only when verbal tasks of executive function were included. When analyses focussed on non-verbal tasks, only inhibition successfully discriminated between the groups, not non-verbal IQ. As well as suggesting a more pervasive deficit in inhibition than working memory, these results indicate that executive function task performance may be more predictive of reading difficulties than IQ. This finding is accordant with those presented in Chapter Three, however it is worth noting that this finding is also consistent with recent research which suggests that the relationship between learning difficulties and working memory is not related to IQ (Maehler & Schuchardt, 2009) as well as research which has reported that IQ scores are not related to cognitive differences between children with RD and their typically developing peers (Jiménez, et al., 2009). Furthermore, as no differences were found in executive function task performance between those participants who had a discrepancy between their IQ and reading level and those who did not, these findings add to the growing body of research which suggests that IQ should not be as central to the assessment of RD as other cognitive processes (Restori, et al., 2009; Stanovich, 2005; Stuebing, et al., 2002; Swanson, 2006).

4.4.1 Task modality.

The predictive utility of tasks of executive function varied as a result of task modality in the present study. When verbal tasks were employed both inhibition and working memory predicted whether children had difficulties with reading or not. However, when non-verbal tasks were employed, only inhibition was a significant predictor. These findings indicate domain specific deficits in tasks of working memory for children with RD, but domain general deficits in inhibition. This is consistent with previous conclusions of a more profound impairment with verbal aspects of working memory in RD than visuospatial aspects (Nation, et al., 1999; Swanson, 2006). Interestingly, the results also indicate that children with RD have deficits on tasks of inhibition, regardless of modality. This suggests that inhibitory difficulties may be more pervasive in children with RD, lending support to theoretical accounts which highlight the predominance of inhibitory processes (e.g. Barkley, 1997).

In accordance with the findings from the present study, domain specific deficits on tasks of working memory were also found by Pimperton and Nation (2010) with a sample of children with specific reading comprehension difficulties. The authors noted that their results conflicted with the Baddeley and Hitch (1974) working memory model and suggested that alternative conceptualisations of working memory (e.g. Shah & Miyake, 1996) may be more accurate. The findings of the present study would seem to support this conclusion, although as the contribution of the phonological loop was not controlled for, it is suggested that further research is required if support is to be gleaned for one model of working memory over another.

Furthermore, Pimperton and Nation (2010) found domain specific inhibitory deficits which do not concur with the present findings. As the present sample of children with RD were recruited based on difficulties with word reading alone, it may be that these conflicting results could be indicative of a differing profile of executive impairment for those with word reading difficulties and those with specific reading comprehension difficulties. This raises the possibility of explaining differing presentations of reading impairments in terms of such profiles. However, Nigg (2000) suggested that there are eight kinds of inhibition (c.f. section 1.2.1.1, page 31) and so an alternative explanation could be that a different inhibitory aspect was assessed in the study of Pimperton and Nation (2010). Further research using a range of inhibitory tasks would therefore assist in the conclusions which can be drawn.

The results of the meta-analysis presented in Chapter Two found modality differences on tasks of executive function in children with RD, but it was concluded that this may not be consistent across all aspects of executive function; the findings from the present study chime with this conclusion (although see comments on the limitations of the study below for an alternative explanation). As the model which employed the non-verbal tasks was found to classify correctly a larger proportion of the participants into the correct reading group, support is found for suggestions that non-verbal tasks may allow for a more complete explanation of executive function impairment in this sample (Booth & Boyle, 2009). Furthermore, as results were found to differ depending on which aspect of executive function was being assessed, these findings also support studies which suggest that executive functioning is not a unitary process (Lehto, et al., 2003; Miyake, et al., 2000; St Clair-Thompson & Gathercole, 2006; Willcutt, et al., 2001; Willcutt, Pennington, et al., 2005).

4.4.2 Reading level matching.

The present study also aimed to evaluate whether impairments found on tasks of executive function for children with RD are merely reflective of potentially slower developing reading skills. By employing a reading level matched control group the present study determined that performance on tasks of executive function discriminated the RD group from the CA group to the same extent as it discriminated the children with RD from those who were reading at the same level. Therefore suggestions that the executive function performance is attributable to reading level alone can be discredited. In addition this contributes to the conclusion that while impairments in executive function are certainly influenced by task requirements, children with RD demonstrate executive deficiencies which go beyond difficulties related to their primary diagnosis.

4.4.3 Limitations and future directions.

One potential limitation of the study regards the fact that different stimuli are used in the verbal inhibition task (the Expressive Attention subtest from the CAS) for those aged less than and more than 8 years of age. The task is from a standardised test battery which employs rigorous test development, and evaluation of the tasks indicates that while the stimuli may differ, the underlying task requirements are the same (Naglieri & Das, 1997). However, it may be that slight variations in task requirement could have affected the results, although it seems unlikely that the results would have varied considerably given that the expressive attention task also discriminated between RD group and the CA group to a similar extent.

In addition, it must be noted that while the Number detection subtest does not require a verbal response, participants may employ some element of inner speech when completing the task (although see section1.3.2 pg 46 for fuller discussion of this issue). Furthermore, the task involves scanning rows of numbers from left to right and from top to bottom and therefore bears some similarities with the visual procedure involved in reading in English.

A further limitation of the present study is that, while multiple tasks of each aspect of executive functioning were included in the test battery, when task modality was assessed only one task of inhibition and one task of working memory per modality were involved. As such, it is possible that the interpretation of a domain specific deficit in working memory could be a product of the assessment task utilised. The Mapping subtest from the S-CPT was employed as a measure of non-verbal working memory. This test is part of a working memory assessment battery and correlates highly with widely used tests of working memory such as the sentence span task (*r*=.66) devised by Daneman and Carpenter (1980). However, while participants are required to answer a processing question before recalling the information, it should be noted that the task does not involve simultaneous manipulation and recall of information. Inspection of the group means on the non-verbal working memory task (the mapping subtest from the S-CPT) are suggestive of potential floor effects, with the RD group and the RL group scoring very similarly. As this task did not discriminate between the CA group and RD group either though, it seems unlikely that floor effects are the only explanation for the pattern of results and instead it is more likely to be representative of domain specific deficits. However, it is possible that different effects would be found if alternative assessment tasks were employed and as such it is suggested that the inclusion of multiple tasks of each aspect of executive function per modality would preclude such ambiguity in future studies. Furthermore, the inclusion of multiple tasks assessing each aspect of executive function and the employment of latent variable analysis would allow for a more conclusive explanation regarding the underlying processes of executive function without the influence of task modality.

4.4.4 Implications and conclusions.

When tasks were used to discriminate children with RD from both chronological-age matched and reading-level matched control groups, inhibitory skill was found to be the most discriminatory. However, modality differences were identified for tasks of working memory. These findings suggest that children with RD have a pervasive deficit in inhibition, but a more domain specific deficit in working memory skills; one that cannot be attributed to slower developing reading skills. As the non-verbal tasks were found to be most predictive of group differences, it could be that non-verbal tasks are more reflective of underlying impairments and thus may have the highest utility for researchers and practitioners alike.

Chapter Five

Study 3.1: Measurement Model and Predicting Severity of Reading Difficulty

The results of Study two indicate that children with RD have pervasive deficits with inhibition tasks but difficulties with working memory which are modality dependent. However as issues surrounding task impurity have been identified, the use of latent variable analysis is advocated; study three aims to extend results from previous chapters by employing latent variable analysis in order to examine the contribution of executive functions to RD.

The third study of the thesis, therefore, had two main aims. The first aim of the study was to evaluate the underlying factor structure of executive functions and assess how far they predict reading ability in a sample of children with RD while controlling for the influence of IQ. In addition, the possibility of there being differential prediction depending on whether word reading or reading comprehension is being assessed and indeed depending on gender will also be examined; this will be discussed in the present chapter. The predictive utility of executive functions was therefore assessed in a sample of children with reading difficulties. Given the task impurity recognised in the literature, latent variable analysis is recommended as a means of reducing the influence of task specific requirements and modelling the underlying executive function processes specifically (Fletcher, et al., 1996; McAuley & White, in press).

The second aim of study three was to take account of the comorbidity between RD and other disorders, specifically ADHD and SLI. As RD has high rates of comorbidity with a number of other developmental disorders which are also reported to have executive function difficulties, identifying executive function difficulties specific to RD is problematic. Chapters six and seven will discuss these respective comorbid relationships.

5.1 Introduction

The results of the meta-analysis presented in Chapter Two indicate that while children with RD have a general impairment with tasks of executive function, the magnitude of effect size varied greatly depending on the assessment task employed. As tasks are commonly believed to involve a number of executive functions (as noted in the discussion of task impurity in Chapter One, p.36), interpretation of task performance and the underlying functions assessed is problematic. In order to reduce the influence of this task impurity, latent variable analysis has been employed in the literature as a means of assessing the underlying processes common amongst tasks and reducing the influence of task requirements, however inconsistencies have emerged.

5.1.1 Factor analytic studies.

Research by Miyake et al. (2000) investigated three key executive functions: shifting, updating and inhibition. A battery of tasks designed to assess each of these aspects of executive functioning was administered to a sample of adults and a series of factor analytic models evaluated. Results found that a three factor model with tasks loading on latent variables of shifting, updating and inhibition provided a better fit to the data than both a one factor solution and alternative two factor solutions. These latent variables were found to be significantly inter-correlated (*r*-values ranging from .42-.63) and also contributed differentially to performance on commonly used tasks of executive function; the shifting latent variable predicted performance on the WCST, inhibition predicted TOH performance, both updating and inhibition contributed to performance on a random generation task and updating was predictive of operation span task performance. The authors suggested that their results evidenced the “unity and diversity” of executive functions, however they also postulated that underlying inhibitory processes may be involved in each of the executive functions assessed.

While further research has confirmed the separable nature of executive functions of shifting, updating and inhibition (e.g. Friedman, et al., 2007; Friedman, et al., 2008), not all studies identify the same relationships amongst underlying executive functions. Specifically, research by Hull, Martin, Beier, Lane and Hamilton (2008) confirmed latent variables of shifting and updating but found that inclusion of an inhibition latent variable did not significantly improve the model. The authors suggest that their results are indicative of the differential nature of the inhibition tasks used and also potentially related to their sample characteristics as their sample comprised adults with a mean age of 60 years. Further to this, in a sample of adults aged 18-90, McCabe, Roediger, McDaniel, Balota and Hambrick (2010) found that a model with a single executive function latent variable provided a better fit to the data than a two factor solution comprising a working memory latent variable and an “executive function” latent variable with performance on the WCST, a verbal fluency task, a mental control task and a mental arithmetic task loaded onto it. The correlation between these two factors was found to be .96, thus the two factors were combined to provide what the authors labeled an “executive attention” latent variable. Together with the findings of Hull et al. (2008), these findings are indicative of potential differences in the underlying executive functions identified being related to characteristics of the sample involved.

In terms of the underlying factor structure of executive functions in children, findings have also been mixed. Lehto, Juujärvi, Kooistra and Pulkkinen (2003) confirmed that a three factor solution with tasks loading on latent variables of shifting, updating and inhibition provided the best fit to the data in a sample of TDC children aged 8 to 13. However, van der Sluis, de Jong and van der Leij (2007) failed to find evidence for a distinct inhibition factor in a sample of TDC children aged 9 to12, with latent variables of shifting and updating providing the most appropriate fit to the data. In addition to this, St Clair-Thompson and Gathercole (2006) administered tasks of executive function purporting to measure shifting, updating and inhibition to a sample of 11 year old children attending mainstream secondary school. A two factor solution with latent variables of inhibition and updating emerged, with the measures employed to assess shifting ability failing to load onto a distinct factor. When tasks of working memory were also included in a principle components analysis, they distinctly loaded onto the updating factor with the inhibition factor remaining separate. The authors labeled these resulting factors as inhibition and working memory. More recently, McAuley and White (in press) assessed the separability of the structure of executive functions in a sample of participants aged 6-24. One hundred and forty seven participants categorised into four ages groups were administered tasks assessing executive functioning, processing speed and IQ. Results found that the executive function tasks loaded onto two factors labeled inhibition and working memory, with a further factor of processing speed emerging. This model provided the best fit to the data for all age groups assessed thus indicating the separability and indeed stability of the structure of executive functions.

While different underlying factors have been found in previous research with TDC children, there has been more consensus in studies which have included children with developmental disorders. In a study which compared a group of children with RD to a group with ADHD, a group with comorbid disorders and also a group with neither disorder, Willcutt et al. (2001) administered a range of executive function tasks designed to give a complete picture of common and differential deficits. Participants completed eight different executive function tasks and in order to evaluate the aspect of executive function predominately measured by each task, a principle components analysis was performed using the sample as a whole (*N*=314). Tasks were found to load onto factors similar to that found for adults and TDC children: those of working memory, shifting and inhibition. However, the Stroop task, which is commonly employed as a measure of inhibition, was not found to load uniquely onto any of the emerging factors, suggesting that it did not share common variance with the other measures of inhibition. Thus while the three commonly reported executive function latent variables emerged, the findings were not completely unambiguous.

Further to this, Willcutt, Pennington, Olson, Chhabildas and Hulslander (2005) aimed to investigate the etiology of comorbidity between RD and ADHD. One hundred and thirteen children with ADHD, 109 with RD, 64 with comorbid RD and ADHD and a control group of 151 children with neither RD nor ADHD were recruited for participation; it is worth noting that these children were distinct from the sample described in Willcutt et al. (2001). Included in the task battery were 10 tasks assessing executive functions. Exploratory factor analysis (EFA) was conducted and factors representing verbal working memory, shifting and inhibition were extracted.

Interestingly, the interference-control score from the Stroop task failed to load onto any of the factors above .30 and was thus not included in the factor structure, although other scores derived from the Stroop were included. In conjunction with the previous findings from Willcutt et al. (2001) these results serve to confirm that executive functions can be identified as separable processes in children with developmental disorders, with the same factor structure emerging. However, given that the same three factors have not consistently been identified in previous research with TD children the conclusions which can be drawn are limited, as the samples used by Willcutt and colleagues included TDC children as well as those with different developmental disorders.

While separable executive function factors have commonly been reported in the literature, the same factor structure has not always been identified. Table 5.1 provides a summary of the factor structures found in studies reviewed. As sample characteristics may have an influence on the emerging structure, it is important to assess whether there are commonalities in factor structure in a sample solely comprising children with RD. In the meta-analysis reported in Chapter Two, tasks of executive function were classed according to which executive function they were most commonly reported as measuring in the literature (c.f. Chapter Two, p. 94). Tasks classified as measuring inhibition, working memory and fluency were most consistently found to differentiate between TDC children and those with RD, regardless of task modality. Therefore tasks assessing each of these aspects of executive function were included in the present study. As the effect found for tasks assessing shifting ability varied considerably depending on the task modality, this suggests that children with RD have a more modality specific difficulty with shifting. Therefore, although shifting has been reported as a unique latent variable in studies which have evaluated the factor structure of executive function, shifting tasks were not included in the present study. Thus the present study aimed to assess whether distinct factors of inhibition, working memory and fluency would emerge in a sample of children with RD.

Table 5.1. Summary of executive function latent variables extracted and goodness-of-fit.

	Authors	Tasks	Participants	Latent variables identified
Adults	Miyake et al. (2000)	Plus-minus; Number-letter; Local-global; Keep track; Tone monitoring; Letter memory; Antisaccade; Stop-signal; Stroop.	137 undergraduate students	Shifting, Updating, Inhibition (SRMR=0.047)
	Friedman et al. (2007)	Antisaccade; Stop-signal; Stroop; Keep-track; Letter-memory; Spatial 2-back; Number-letter; Colour-shape; Category switch.	866 adolescents mean age 17.4 (*SD* 0.6, range 16.1-20.1)	Shifting, Updating, Inhibition (RMSEA=0.043)
	Friedman et al. (2008)	Antisaccade; Stop-signal; Stroop; Keep-track; Letter-memory; Spatial 2-back; Number-letter; Colour-shape; Category switch.	582 adolescents mean age 17.3 (*SD* 0.6, range 16.1 to 20.1)	Shifting, Updating, Inhibition (RMSEA=0.039)
	Hull et al. (2008)	Local-global; Plus-minus; N-back; Keep track; Stroop.	100 adults mean age 60.24 years (*SD* 5.58, range 51-74)	Shifting, Updating (RMSEA=0.05)
	McCabe et al. (2010)	Computation span, reading span, match span, letter rotation span, mental arithmetic, mental control, verbal fluency, WCST.	206 adults age range 18-90	General Executive factor (RMSEA=0.099)
TDC	Lehto et al. (2003)	Trail-making; Auditory attention and response set; word fluency; matching-familiar figures test; mazes; spatial working memory, Tower of London.	108 children mean age 10.5 years (*SD* 1.3, range 8-13)	Shifting, Updating, Inhibition (SRMR=0.04)
	van der Sluis (2007)	Quantity inhibition; Object inhibition, Stroop, Numerical size inhibition, object shifting, symbol shifting, place shifting, making trails; keep track; letter memory;	172 children mean age 128.08 months (*SD* 8.65)	Shifting, Updating (RMSEA=0.05)

		digit memory.		
	St Clair-Thompson & Gathercole (2006)	Plus-minus; Local-global; letter memory; keep track; Stop-signal; Stroop; Listening recall; Backward digit; Odd-one-out, Spatial –span.	51 children mean age 11.9 (*SD* 3, range 11:4 – 12:3)	Inhibition, Updating/working memory*
	McAuley &White (*In press*)	Go/NoGo, Stimulus-response compatibility, Two-back, Recognition span, digit span	153 participants. Age range 6-24 years	Inhibition, working memory (RMSEA =0.07)
Developmental disorders	Willcutt et al. (2001)	WCST; CNT; CPT; Stopping task; Sentence span; Counting span; Trail making; Stroop	93 RD, 52 ADHD, 48 RD+ADHD, 121 TDC. Mean age 10 years	Working memory, Shifting, Inhibition*
	Willcutt et al. (2005)	Stop-signal; CPT; WCST; Trail making; Sentence span; Counting span; Arithmetic; Backward digit span; Spatial working memory; Stroop; Coding; Symbol search	109 RD, 113 ADHD, 64 RD+ADHD, 151 TDC. Mean age 11 years	Verbal working memory, Shifting, Inhibition*

Note: WCST = Wisconsin Card Sorting Task; CNT= Contingency Naming Task; CPT= Continuous Performance Task;
* indicates no Goodness-of-fit information provided.

5.1.2 Predicting reading.

Results of study two (presented in Chapters Three and Four) demonstrate that different executive functions are important for reading depending on which aspect of reading was being assessed, at least in a heterogeneous sample of children. When hierarchical linear regression was used to predict word reading in the sample as a whole, it was found that inhibition and IQ were independent predictors of word reading ability. When reading comprehension was used as the criterion variable, inhibition and working memory were both significant predictors, but not when FSIQ was entered into the model. As research by Alloway et al. (2009) found that working memory predicted a measure of reading comprising both word reading and reading comprehension with IQ controlled for in a sample of children with learning difficulties, the present analysis aims to extend the findings of study two by focusing on a sample of children all with RD. While the results presented in Chapter Three highlight that the ability to differentiate between a group of children with RD and both age and reading level matched control groups was influenced by the modality of working memory tasks, the use of latent variable analysis will allow for an understanding of the role of the underlying processes irrespective of additional task requirements. As inhibition was found to discriminate between the groups regardless of task modality, it would be expected to contribute to reading ability in a sample of children with RD. However, while it predicted word reading in the heterogeneous group, it did not contribute to reading comprehension when IQ was also included in the model. It is unclear therefore whether inhibition will be a significant predictor of reading comprehension in a sample comprising only children with RD.

5.1.3 Gender.

Lezak (1995) suggested that performance on tasks of executive function may be related to gender. Indeed, Giedd et al. (1996) highlighted that there are gender specific differences in brain development in terms of rate of myelination and synaptic pruning and indeed it has been proposed that these differences may be related to hormone production (De Bellis, et al., 2001). As such then, it is conceivable that males and females differ in developmental trajectories of executive processes; therefore it is important to assess whether the extent to which executive functions predict reading is equivalent for males and females. While gender was not found to moderate the magnitude of effect found in the meta-analysis reported in Chapter Two, this may have been due to the fact that for the studies which reported gender, 74% of the participants in the RD groups were male. Thus the extremely unequal number of male and female participants may have made it difficult to detect any gender differences. Therefore the present chapter aims to address the following research questions:

1) Are there commonalities between the factor structure of executive functions observed in adults and typically developing children and those with RD?
2) To what extent do executive functions predict reading in a sample of children with RD while controlling for the influence of IQ and are there differences depending on whether word reading or reading comprehension is being predicted?
3) Is the same pattern of results evident for males and females?

5.2 Method

5.2.1 Participants.

Two hundred and thirteen participants attending mainstream schools across the UK took part in study three[11]. The sample comprised 124 males and 89 females with a mean age of 124.40 months (*SD* = 9.16, range, 109-142). The eligibility criteria for inclusion in the study were a) that participants should have difficulties with reading operationally defined as a word reading score beneath the 15th percentile (i.e. < -1*SD*) on the word reading subtest from the Wechsler Individual Achievement Test (WIAT- II ^{UK}; Wechsler, 2005) and b) that participants should be free from reported neurological disorder.

5.2.2 Instrumentation.

5.2.2.1 Reading.

The word reading and reading comprehension subtests from the WIAT- II ^{UK} (Wechsler, 2005) were administered to all participants (split-half reliability .97 and .95 respectively for the relevant age range; c.f. Chapter Three, section 3.2.2 page 121for test procedure).

5.2.2.2 Oral language.

In order to assess participants' oral language skills the Word classes subtest from the Clinical Evaluation of Language Fundamentals, fourth UK edition (CELF – 4 ^{uk}; Semel, Wiig, & Secord, 2006) was administered. This sub-test comprises an expressive and receptive language component which yields a short-form total oral language score and has the highest correlation with core language score from those available in the CELF – 4 ^{uk}. Test-retest reliability for the total oral language score ranges from .85 to .92 for 9 to 11 year olds, from .86 to .91 for the receptive component and from .83 to .90 for the

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[11] Kline (2005) recommends sample size > 200 for SEM

expressive language component. Participants are presented with series of blocks of four words and identify which words are related to give the receptive language component score. They are then asked to provide justification for their answer in order to give the expressive language component score. The test is discontinued after five incorrect responses on the receptive part of the task. Scores are totalled and the UK norms provide age-corrected standardised scores.

5.2.2.3 Non-verbal ability.

The block design and matrix reasoning subtests from the Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 1999) were administered to all participants. The matrix reasoning subtest (split-half reliability .89-.93 for children aged 9-11 years old) requires participants to use deductive reasoning to complete pictorial patterns and the block design subtest (split-half reliability .90-.92 for children aged 9-11 years old) requires participants to configure differing patterns using a set of blocks which have sides of different colours in order to match an image. Age-corrected T- scores are available for each subtest.

5.2.2.4 Behavioural rating scale.

The Conners' 3AI, teachers' version (Conners, 2008) was administered to assess participants' ADHD-related behaviour. This is a ten-item checklist comprising the items which best differentiate children most at risk of a definition of ADHD from those in the general population (Cronbach's alpha .94). This rating scale was completed by the class teachers for all but four of the participants.

5.2.2.5 Executive function measures.

5.2.2.5.1 Inhibition.

The Expressive Attention and the Number Detection subtests from the Cognitive Assessment System (CAS; 1997) were administered in order to assess verbal and non-verbal inhibitory skills respectively. Task administration in all cases followed the relevant standardised test procedure as described in Chapter Three. Information regarding test reliability may be found in section 3.2.2, page 121.

5.2.2.5.2 Fluency.

The Word Associations subtest from the CELF – 4 ^{uk} (Semel, et al., 2006) was administered in order to assess participants' verbal fluency ability. In this task participants are required to name as many unique exemplars of a semantic category as possible in one minute. Three different categories are presented; food, animals and occupations. The total number of unique responses are calculated and compared to a criterion reference score provided in the test manual (decision consistency reliability .96 for ages 8:0 to 12:11).

The Five-point test described by Regard, Strauss and Knapp (1982) was employed as a measure of non-verbal fluency. While normative data for the children is provided by Regard et al. (1982) reliability coefficients are not reported. However, Fernandez, Moroni, Carranza, Fabbro and Lebowitz (2009) report test-retest reliability coefficients of .78 for a sample of adults and split-half reliability of .80. Participants are presented with an A4 sheet of paper with 40 printed rectangles on it (eight lines with five rectangles in each line). Each rectangle contains five dots as seen in Figure 5.1.

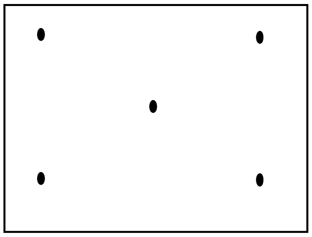

Figure 5.1. Example stimuli from Five-point test.

Participants are instructed to produce as many unique figures as possible by connecting the dots in each rectangle with straight lines. They are advised that not all dots have to be used in each figure and that they should not repeat figures or draw lines which do not connect dots. Participants are given five minutes to draw as many figures as possible and the total number of unique figures was calculated.

5.2.2.5.3 Working memory.

Two tasks from the Automated Working Memory Assessment (AMWA; Alloway, 2007) were administered in order to assess participants' working memory abilities. All tasks from this battery were presented on a laptop PC and age-corrected standardised scores are provided. The listening recall task was employed as a verbal working memory task (test-retest reliability .88). This task requires participants to listen to a series of sentences and to judge the veracity of each sentence, for example, "sheep have hair". Following this, the final word from each sentence is recalled in serial order. The number of sentences presented in each block increases until three errors are made within a block.

The spatial recall test was presented to participants to assess visuospatial working memory (test-retest reliability .79). In this task participants are presented with a series of diagrams showing two shapes which are either facing the same or opposite direction, some of which are rotated. Participants have to report whether the shapes are pointing in the same or opposite direction. One of the shapes in each pairing has a red dot and participants are asked to recall the serial position of these dots after presentation of an increasing numbers of shape pairs. As with the listening recall task, the number of shape pairings increases in each block until three errors are made in a block.

Tasks used to assess each aspect of executive functioning by response modality are shown in Table 5.2.

Table 5.2 Tasks of executive function administered, by modality.

Executive function	Verbal	Non-verbal
Inhibition	Expressive attention	Number detection
Fluency	Word associations	Five-point test
Working memory	Listening recall	Spatial recall

5.2.3 Procedure.

Following ethical permission from the Department of Psychology ethics committee, 26 Local Education Authorities (LEAs) across Scotland and England were approached requesting permission to undertake research in schools in their area. 16 LEAs agreed to participate, 14 in Scotland and two in England. 365 schools within these LEAs were contacted regarding the possibility of pupil recruitment and from these, 41 schools (38 in Scotland and three in England) agreed to participate (approximately 11%). Following the Code of Ethics and Conduct (BPS, 2009), information sheets providing details of the study and consent forms (Appendices J-L) were issued to parents and pupils whom class teachers had identified as being in the lowest reading groups.

All participants were tested individually in a room or quiet area of their school during normal school hours. Before testing began all participants were reminded of the rights to withdraw from participation at any time and also gave their verbal consent. Testing was carried out in two sessions each lasting approximately 45 minutes. In the first session the word reading, reading comprehension, oral language and non-verbal ability measures were administered with all the executive function measures administered in the second session in varied sequence to minimise possible order effects. All testing followed standardised test procedures as set out in the administration manuals, except for the Five-point test where testing procedure followed that described by Regard et al. (1982). At the end of each testing session, any questions that participants had were answered.

5.2.3.1 Data preparation and analyses.

5.2.3.1.1 Recalibrated age-adjusted fluency measures.

With the exception of the fluency measures, all tasks used were converted to age-corrected standardised scores as per the relevant test manual instructions. For ease of comparison, regression-predicted age norms were calculated for the fluency measures using a procedure described by Iverson, Woodward and Iverson (2002)[12]. The total number of unique responses for both the word associations task and the five-point test were regressed on age in months and the unstandardised residuals were saved[13].

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[12] Iverson et al(2002) calculated normative data using a sample of 248 children

[13] Age was a significant predictor of both verbal and non-verbal fluency ($p<0.01$ in both cases)

Following this, predicted scores were calculated for each age group separately using the unstandardised beta-coefficient for age. The residual and the predicted score were then summed to give the distribution of scores and subsequently percentile ranks were computed for each age range. Finally, psychometric conversion tables were used to convert the percentile ranks to standard scores with a mean of 100 and a standard deviation of 15 for each age group separately. Each age band was then combined to create a new variable of standard scores for the whole sample.

Research studies employing both of the fluency measures with a sample of children with reading difficulties had been identified in Chapter Two. When performance was compared to typically developing participants it was found to be approximately one standard deviation below the mean in all studies identified. Therefore the standard scores of the fluency measures were recalibrated to reflect this (Cronbach, 1984, p. 115). All standard scores were thus re-scaled by one standard deviation (i.e. 15 standard score points) thus providing a mean score for the word associations tasks of 85.29 (*SD*=16.28) and for the five-point test of 85.77 (*SD*=15.34).

5.2.3.1.2 Data screening.

Following recommendations by Tabachnick and Fidell (2001, p. 67), a z-score greater than 3.29 was identified as an extreme outlier. Seven such extreme univariate outliers were identified and as they can cause collinearity and non-normality were removed (T. A. Brown, 2006). Multivariate outliers were identified by checking Mahalanobis distance, Cooks and Leverage statistics. The minimum Mahalanobis distance to detect a multivariate outlier is set at a chi-square value with degrees of freedom the same as the number of variables where $p<0.001$ (Tabachnick & Fidell, 2001, p. 68). Cook's statistic should be no greater than one and Leverage statistics with values greater than three times the average ((k+1)/n) are thought to have undue influence (Field, 2005). Using these criteria, two multivariate outliers were detected and subsequently removed (Tabachnick & Fidell, 2001).

As values for skewness and kurtosis are influenced by large sample sizes (Field, 2005), normality was assessed by inspection of probability plots. Following guidelines set out in Tabachnick and Fidell (2001) the distribution of residuals was deemed normal. Furthermore, linearity was investigated by inspection of residual plots and homoscedasticity was assessed by way of scatterplot examination; no issues were identified.

In order to assess multicollinearity, tolerance statistics and the variance inflation factor (VIF) were inspected. Field (2005) states that VIF values above 10 are cause for concern as are tolerance statistics below .2 . Tolerance statistics ranged from 0.65-0.88 and VIF ranged from 1.14-1.54, thus giving no cause for concern (Field, 2005). In order to reduce nonessential multicollinearity, all variables were centered by subtracting the variable mean from each score (Kline, 2005) giving each variable a mean of zero but retaining the variability. Centered scores were therefore used for all structural equation modelling (SEM).

5.2.3.1.3 Statistical analyses.

All analyses were conducted using PASW version 17.0.2 (2009) and Mplus version 5.21 (2009). Missing data was treated using Maximum likelihood (ML) estimation which was employed for all analysis conducted using Mplus with the exception of parts of section 5.3.3.1 which employed robust maximum likelihood (MLR) estimation. ML and MLR are both approaches which use all available data, that is, cases with missing data are included in the estimation. For analyses conducted using PASW, listwise deletion was employed as pairwise deletion is known to lead to biased standard error estimates due to the variation in sample size specified (T. A. Brown, 2006).

For all SEM, factors were allowed to correlate and no correlated errors were included (Hanna, Shevlin, & Dempster, 2008). For a model to be identified each latent variable must have a scale. In order to assign a scale to a factor, the first indicator of each latent variable was set to be 1.00 (Kline, 2005). For mediational analysis, bootstrap confidence intervals were constructed and reported instead of standard error estimates following recommendations by Preacher and Hayes (2008). The goodness of model fit was assessed using a range of statistics following guidelines in Kline (2005) and McDonald and Ho (2002). A non-significant chi-square and comparative fit index (CFI) and Tucker-Lewis index (TLI) above .9 are generally considered acceptable. Lower values of Akaike information criterion (AIC) represent a better fitting model and values of the root mean square error of approximation (RMSEA) below .08 represent an acceptable level of model fit with values less than .05 being a good fit. Accompanying 90% confidence intervals are reported for all RMSEA following Curran and colleagues (Curran, Bollen, Chen, Paxton, & Kirby, 2003) who argued that values for 80%, 90% and 95% confidence intervals are the same when sample sizes in excess of 200 are employed. Additionally, Curran et al. (2003) suggested that the 90% confidence interval be reported for the RMSEA. Furthermore, the standardised root mean square residual (SRMR) should be below .10 to indicate adequate model fit. Following convention, SEM are illustrated with ovals representing latent variables and rectangles representing manifest variables. Curved arrows indicate correlations between variables with straight lines coming from latent variables indicating regression paths and factor loadings. Furthermore, lines entering manifest variables designate the measurement error term.

5.3 Results

5.3.1 Descriptive statistics.

Age-corrected standardised scores for the word reading and reading comprehension subtests, for the oral language measures and the non-verbal ability tasks are shown in Table 5.3.

As Table 5.3 illustrates, the mean performance of participants was approximately one standard deviation below the mean expected across all tasks. Independent t-tests confirmed that there was no significant difference in either word reading or reading comprehension performance between males and females and as all *p* values were greater than 0.50, the groups can be considered matched on reading ability (see Mervis & Klein-Tasman, 2004).

Table 5.4 shows the mean and standard deviations for all executive function measures.

Table 5.3. Mean standard scores and standard deviations for reading, oral language and non-verbal ability measures.[14][15]

	Word reading	Reading comprehension	Receptive language	Expressive language	Block design	Matrix reasoning
Males						
Mean	72.29	76.39	6.00	5.67	43.71	39.97
SD	9.64	14.56	2.25	2.44	7.09	9.93
Females						
Mean	72.78	76.03	6.09	5.69	43.22	40.94
SD	8.88	12.64	1.95	2.15	7.20	9.95
Total						
Mean	72.49	76.24	6.04	5.68	43.51	40.38
SD	9.31	13.75	2.12	2.32	7.12	9.93

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[14] Word reading & reading comp: M=100, *SD* = 15; Oral language, M=10, *SD* = 3; NVIQ, M=50, *SD*=10 Working memory and fluency measures, M =100, SD=*15*; Inhibition measures, M=10, *SD* = 3

[15] Means given are excluding outliers as are all analyses reported here

Table 5.4. Mean standard score and standard deviations for all executive function tasks.

	Verbal working memory	Visuospatial working memory	Verbal inhibition	Non-verbal inhibition	Verbal fluency	Figural fluency
Males						
Mean	81.64	90.67	7.56	7.41	86.39	85.51
SD	12.35	16.14	2.31	1.91	15.47	15.11
Females						
Mean	80.66	89.59	8.35	7.98	84.32	86.17
SD	11.70	15.18	2.43	1.97	16.35	15.83
Total						
Mean	81.23	90.22	7.89	7.65	85.52	85.79
SD	12.07	15.72	2.39	1.95	15.84	15.38

As illustrated by Table 5.4, the performance of the sample was approximately one standard deviation below the expected mean for all tasks except the visuospatial working memory task. However, the mean score of 90.22 (*SD*=15.72) on the visuospatial working memory task is equivalent to the 25th percentile on a standardised measure implying that the group performance was still below the average expected performance. The correlations between reading, non-verbal IQ and all executive function tasks are shown in Table 5.5.

Table 5.5. Correlations between reading, non-verbal cognitive ability and executive function tasks.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1.Word reading									
2. Reading comprehension	.55**								
3.Block design	.10	.32**							
4. Matrix	.18*	.42**	.46**						
5. Verbal working memory	.20**	.32**	.17*	.19**					
6. Visuospatial working memory	.10	.40**	.43*	.38**	.26**				
7. Verbal inhibition	.24**	.26**	.10	.10	.13	.130			
8. Non-verbal inhibition	.21**	.30**	.19*	.26**	.22**	.19**	.26**		
9. Verbal fluency	.22**	.35**	.17*	.26**	.37**	.25**	.26**	.36**	
10. Figural fluency	.12	.31**	.30**	.26**	.15*	.35**	.29**	.45**	.34**

Note:*$p<0.05$; **$p<0.01$; ***$p<0.001$

5.3.2 Measurement model.

In order to specify the underlying factor structure of the tasks of executive function, a series of measurement models were examined. Initially, a four factor structure was fitted to the data, with the tasks of each aspect of executive functioning measured and non-verbal ability loaded onto separate latent variables. That is, a working memory latent variable, an inhibition latent variable, a fluency latent variable and a non-verbal ability latent variable with each latent variable having two indicator variables. This model failed to converge due to a Heywood case (i.e. a correlation greater than 1 between the inhibition factor and the fluency factor) (Kline, 2005). As inhibition and fluency are held to be separate executive functions (Baron, 2004), two alternative models were evaluated; one model with latent variables of non-verbal ability, working memory and inhibition (model B) and an alternative model with a fluency latent variable replacing the inhibition latent variable (model C). Table 5.6 shows the fit indices for each model as well as a one factor model where all indicators were loaded onto a common latent variable (model A).

Table 5.6. Fit indices for measurement models evaluated.

Model	χ^2	*df*	*p*	CFI	TLI	AIC	RMSEA	90% CI	SRMR
A	70.61	20	0.000	0.82	0.75	10964.16	0.112	0.084, 0.141	0.067
B	6.82	6	0.34	0.99	0.99	7700.47	0.026	0.000, 0.098	0.03
C	21.79	6	0.00	0.92	0.81	9283.81	0.11	0.065, 0.168	0.046
D	30.24	17	0.03	0.95	0.92	10929.79	0.062	0.022, 0.097	0.044

Chi-square difference tests ($\Delta\chi^2$) showed that both models B and C were a significantly better fit to the data than model A, the one factor model ($\Delta\chi^2$= 63.79, *df* =14, p<0.0001 and $\Delta\chi^2$=48.82, *df*=14, p<0.0001 respectively). Inspection of fit indices presented in Table 5.6 reveals that model B provides the best fit to the data.

In addition, due to the strong nature of the relationship between the tasks of inhibition and fluency indicated by the evaluation of a four factor model, a three factor model with a working memory factor, a non-verbal ability factor and the tasks purported to assess inhibition and fluency loaded onto one factor was tested (model D). When compared to a one factor solution, this three factor solution also provided a significantly better fit to the data ($\Delta\chi^2$= 40.37, *df* =3, p<0.0001; see Table 5.6), however fit indices illustrate that model B continued to provide the best fit and indeed delta chi-square revealed that it was a significantly better fit than model D ($\Delta\chi^2$=23.42, *df*=11, p<0.05). Thus model B emerged as the best fitting model and is illustrated in Figure 5.2.

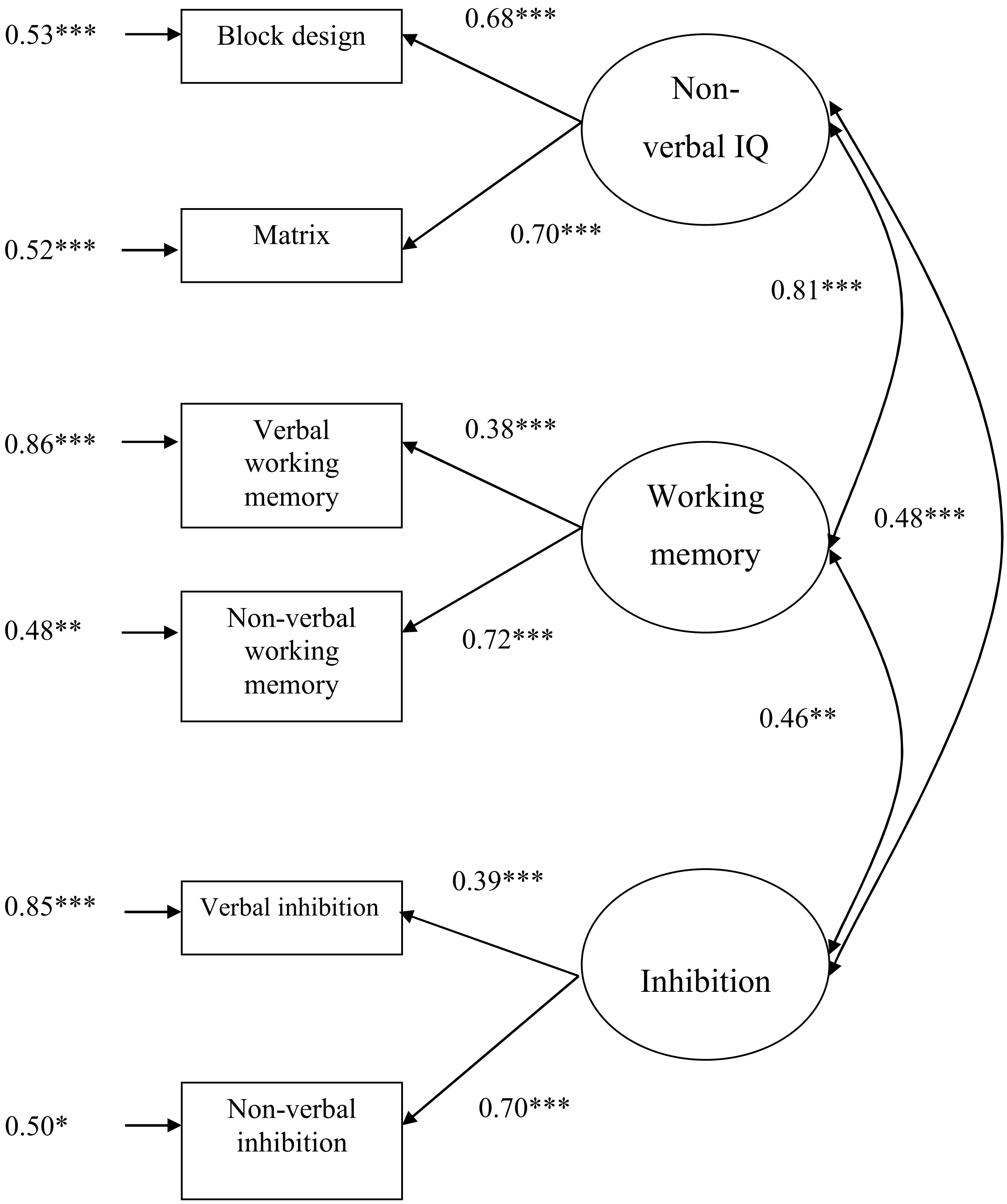

Figure 5.2. Standardised solution for the three factor model

5.3.2.1 Modality.

While the inclusion of verbal and non-verbal tasks and indeed the use of SEM will reduce the influence of tasks demands, it is possible that the assessment tasks included may represent a general executive function which is more appropriately differentiated by modality. As such, a model comprising two latent variables was evaluated; one latent variable with the tasks requiring a verbal response loaded onto it and another latent variable for the non-verbal tasks. This model provided an adequate fit to the data (χ^2=17.60, *df*=8, *p*=0.025, CFI=0.94, TLI=0.88, AIC=7707.24, RMSEA=0.08, 90% CI=0.03-0.13, SRMR=0.048) and while this was a significant improvement compared to a one factor solution ($\Delta\chi^2$=53.01, *df*=12, *p*<0.001) it was not a better fit than the three factor solution represented by model B, as indicated by the goodness of fit statistics and a significant delta chi-square ($\Delta\chi^2$=10.78, *df*=2, *p*<0.01). Thus a model with latent variables representing differing aspects of executive function (model B) was a better fit than a model representing modality specific executive functions.

5.3.2.2 Relationship between non-verbal IQ and working memory latent variables.

Given the magnitude of the correlation between the latent variables of non-verbal IQ and working memory, further evaluation of the relationship between these constructs is warranted. Model B was thus compared to a two factor model with tasks of non-verbal ability and tasks of working memory loaded onto one factor. While fit indices showed that the resulting model provided an acceptable level of fit (χ^2=9.25, *df*=8, *p*=0.32, CFI=0.99, TLI=0.98, AIC=7698.89, RMSEA=0.028, 90% CI=0.00-0.09, SRMR=0.034), chi-square difference tests revealed that this model was not a significant improvement on model B. Inspection of the resulting factor loadings illustrated that the loadings of the non-verbal IQ tasks were comparable to the non-verbal working memory task (all factor loadings ranging from 0.62-0.68, all *SE*'s 0.06) but dissimilar to the verbal working memory task (0.34, *SE* 0.08). It is therefore possible that the high correlation between the latent variables of working memory and non-verbal IQ observed in model B is a function of the task demands, that is, it can be attributed to the strong demands that the particular non-verbal IQ tasks are placing on non-verbal working memory. As such it can be hypothesised that alternative non-verbal IQ tasks would have resulted in a different strength of correlation. As research suggests that working memory and IQ are separable constructs (e.g. P. L. Ackerman, et al., 2005), separate latent variables of working memory and non-verbal IQ were employed for all subsequent analyses.

5.3.3 Full structural model predicting reading.

In order to assess the predictive utility of the executive function latent variables for severity of reading difficulty, word reading and reading comprehension were included in model B as latent variables with single indicators (T. A. Brown, 2006; Kline, 2005). In this way the measurement error is explicitly modelled using the reliability of the instrument provided by the test manual and the variance[16]. While the model fit was almost identical to that when word reading and reading comprehension were included as manifest variables, taking account of the measurement error is to be preferred (T. A. Brown, 2006).

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[16] $\delta = VAR(X)(1-\rho)$ where VAR is the sample variance (i.e. SD^2) and ρ is the reliability estimate of the indicator.

In addition to assessing how far the executive function latent variables predict reading ability in this sample, given the prominence of non-verbal IQ in definitional criteria of RD (Jiménez, et al., 2009; Restori, et al., 2009; Stuebing, et al., 2002) the potential role of non-verbal IQ as a moderator and a mediator of the relationship between executive functions and reading was evaluated.

5.3.3.1 Non-verbal IQ as a moderator.

Two separate models were evaluated to investigate whether the relationship between the executive function latent variables and reading was moderated by non-verbal IQ. That is, whether there was a significant interaction between non-verbal IQ and inhibition and also an interaction with working memory. A latent moderated structural equation approach (Klein & Moosbrugger, 2000) was adopted where a random slope representing the interaction was used as a predictor of word reading and reading comprehension separately. The interaction between inhibition and non-verbal IQ did not significantly predict word reading (β=-0.26, *SE*=0.29) or reading comprehension (β=-0.16, *SE*=0.16). It was not possible to achieve convergence using this approach for the interaction between non-verbal IQ and working memory and so instead an unconstrained approach was employed where the product of the indicator variables are used as the indicators of an interaction term (Marsh, Wen, & Hau, 2004). This interaction term was then used to predict word reading and reading comprehension separately. The interaction between working memory and non-verbal IQ was not a significant predictor of word reading (β=0.042, *SE*=0.34) or reading comprehension (β=0.02, *SE*=0.03). Therefore, non-verbal IQ was not deemed to moderate the relationship between executive functions and reading.

5.3.3.2 Non-verbal IQ as a mediator.

While non-verbal IQ was not deemed to be moderating the relationship between executive functions and reading, its potential role as a mediator variable was examined. In order to infer mediation, the strength of relationship between two variables (path c in Figure 5.3) is compared to a model which includes a potential mediating variable (Figure 5.4). Path c in Figure 5.3 denotes the total effect that X has on Y and path c’ in Figure 5.4 denotes the direct effect, that is, the effect of X on Y while controlling for M. The indirect effect that X has on Y via M (i.e. ab) is calculated as c - c’. Complete mediation is deemed when path c’ is zero, that is, that X no longer effects Y when M is controlled for. When partial mediation is apparent, the amount of mediation is indicated by the indirect effect.

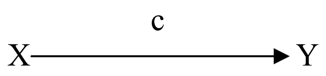

Figure 5.3. Illustration of an unmediated model

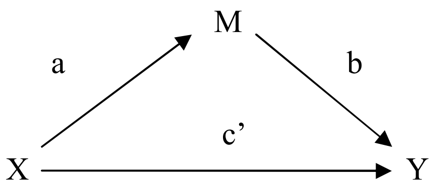

Figure 5.4. Illustration of a mediated model

Non-verbal IQ was evaluated as a potential mediator of the relationship between inhibition and both word reading and reading comprehension (see Figure 5.5, diagram a) and separate mediated models were evaluated assessing the mediation between working memory and both aspects of reading (see Figure 5.5, diagram b). For ease of interpretation, indicator variables and errors are not included in the diagrams and unstandardised and standardised path estimates are detailed in Table 5.7.

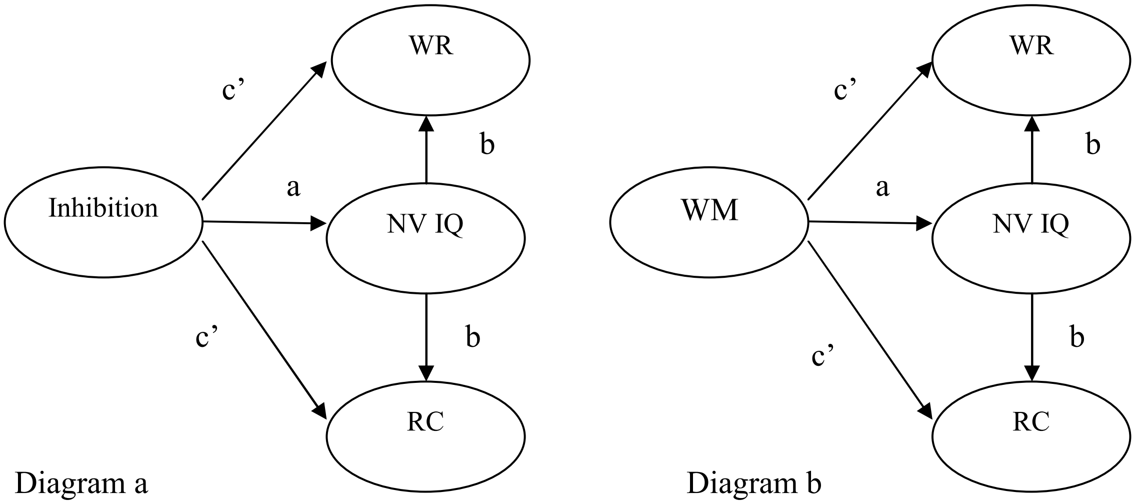

Diagram a

Diagram b

Figure 5.5. Mediation of the relationship between executive functions and reading.[17]

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[17] WM=working memory, WR= word reading, RC=reading comprehension, NV IQ= non- verbal IQ.

Table 5.7. Unstandardised and standardised estimates with bootstrap 95% [18]confidence intervals in parentheses for mediated models.

Path estimated	Effect	Unstandardised	Standardised
Inhibition Word reading	Total effect	5.04 (0.41-9.67)**	0.39 (0.16-0.62)**
	Indirect effect	-4.12 (-36.13-27.89)	-0.32 (-2.23-1.59)
	Direct effect	9.16 (-24.94-43.25)	0.71 (-1.26-2.67)
Reading comprehension	Total effect	14.47 (-0.19-29.13)**	0.77 (0.59-0.94)***
	Indirect effect	-5.47 (-72.46-61.52)	-0.29 (-2.74-2.16)
	Direct effect	19.94 (-54.15-94.04)	1.05 (-1.45-3.56)
Working memory Word reading	Total effect	0.69 (0.11-1.27)**	0.36 (0.12-0.59)**
	Indirect effect	-0.49 (-4.37-3.39)	-0.25 (-1.92-1.42)
	Direct effect	1.18 (-2.99-5.35)	0.61 (-1.15-2.37)
Reading comprehension	Total effect	2.14 (0.94-3.33)***	0.75 (0.58-0.92)***
	Indirect effect	-0.84 (-8.94-7.26)	-0.30 (-2.54-1.95)
	Direct effect	2.97 (-5.77-11.72)	1.05 (-1.26-3.53)

Note: *$p<0.05$; **$p<0.01$; ***$p<0.001$

Table 5.7 reveals that, in all instances, the relationship between executive functions and reading is not mediated by non-verbal IQ, as indicated by non-significant indirect effects[19]. Direct causal paths from non-verbal IQ to word reading and reading comprehension were thus excluded from the model. Furthermore, the non-verbal IQ latent variable was not found to be significantly correlated with either word reading

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[18] 95% Confidence intervals are reported for bootstrapped mediation following recommendations by Zhao, Lynch and Chen (2010)

[19] Personal communication from Preacher (2010) advised that the fact that the CI's surrounding the indirect and direct effects were larger than that for the total effect was not a cause for concern.

(r=.015, p>0.8) or reading comprehension (r=.016, p>0.9). As such, this analysis suggests that non-verbal IQ does not significantly influence the relationship between executive functions and reading and indeed does not have a significant relationship with reading above the role of executive functions. However, non-verbal IQ was found to be significantly correlated with both inhibition (r=.53, p<0.001) and working memory (r=.82, p<0.001) and indeed removal of this altogether led to non-convergence; non-verbal IQ was therefore retained in the model to correlate with the executive function latent variables.

5.3.3.3 Prediction of reading ability.

With the inclusion of the non-verbal IQ latent variable as a correlate of the executive function latent variables only, direct paths were included from working memory and inhibition to both word reading and reading comprehension to assess how far these executive functions predicted reading in this sample of children with RD. The resulting model, termed model Bi, provided a good fit to the data (χ^2=13.77, df=14, p=0.467, CFI=1.00, TLI=1.00, AIC=10661.88, RMSEA=0.00, 90% CI=0.00-0.067, SRMR= 0.035) and is illustrated in Figure 5.6. For diagrammatical clarity, factor loadings and error estimates for indicators variables are not shown in Figure 5.6 however, unstandardised and standardised estimates for all parameters in model Bi are detailed in Table 5.8.

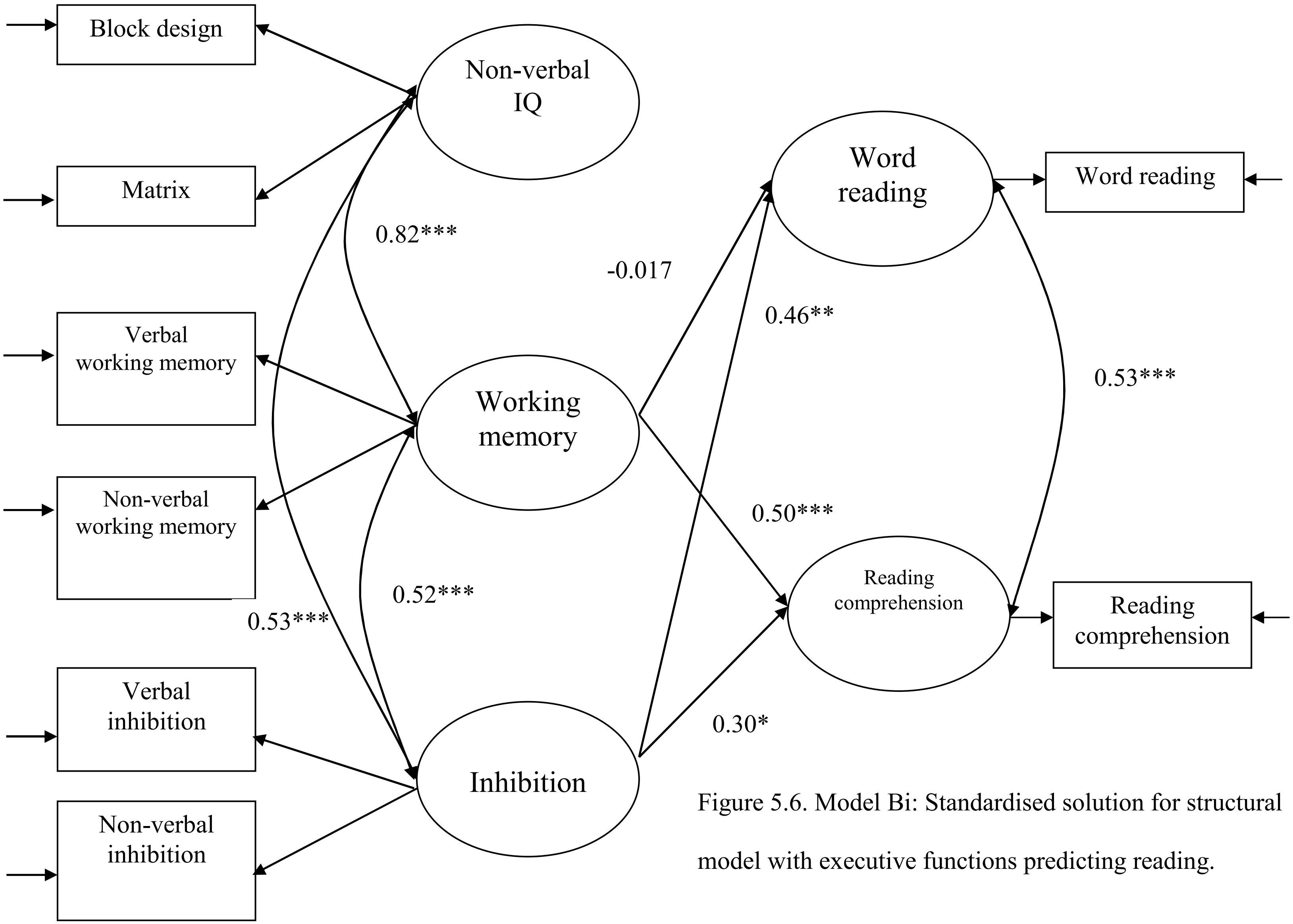

Figure 5.6. Model Bi: Standardised solution for structural model with executive functions predicting reading.

Table 5.8. Unstandardised and standardised parameter estimates for model Bi with standard errors in parentheses.

Parameter estimates	Unstandardised	Standardised
Measurement model estimates		
Non-verbal IQ→ Block design (X1)	1.00	0.65 (0.06)***
Non-verbal IQ→ Matrix (X2)	1.61 (0.25)***	0.74(0.06)***
Working memory → Verbal working memory (X3)	1.00	0.40 (0.07)***
Working memory → Non-verbal working memory (X4)	2.25 (0.53)***	0.69 (0.07)***
Inhibition → Verbal inhibition (X5)	1.00	0.46 (0.09)***
Inhibition → Non-verbal inhibition (X6)	1.02 (0.28)***	0.60 (0.10)***
Word reading → Word reading (X7)	1.00	0.99(0.001)***
Reading comprehension → Reading comprehension (X8)	1.00	0.98(0.002)***
Error in X1	28.33(4.02)***	0.58(0.08)***
Error in X2	44.63 (8.59)***	0.46(0.09)***
Error in X3	122.90 (13.28)***	0.84(0.06)***
Error in X4	129.85 (23.26)***	0.53(0.09)***
Error in X5	4.39 (0.55)***	0.79(0.08)***
Error in X6	2.22 (0.41)***	0.65(0.12)***
Error in X7	1.73 (0.00)	0.02(0.002)***
Error in X8	7.56 (0.00)	0.04(0.004)***
Covariance Working memory & Inhibition	2.72 (1.10)*	0.52(0.15)***
Covariance Working memory & non-verbal IQ	17.73 (4.60)***	0.82(0.08)***
Covariance Inhibition & non-verbal IQ	2.60 (0.79)**	0.53(0.12)***
Covariance word reading & reading comprehension	41.95 (9.59)***	0.53(0.08)***
Structural model		
Working memory → word reading	-0.03 (0.29)	-0.017(0.15)
Working memory → reading comprehension	1.40 (0.43)**	0.50(0.12)***
Inhibition → word reading	3.95 (1.62)*	0.46(0.16)**
Inhibition → reading comprehension	3.77 (2.01)	0.30(0.15)*

Inspection of parameter estimates detailed in Table 5.8, reveal that working memory significantly predicted reading comprehension ability and accordingly, as working memory performance improved, so did reading comprehension. Furthermore, as inhibitory performance improved so did word reading: thus a one *SD* increase in inhibition predicted a 0.46 *SD* increase in word reading. In addition, the standardised estimates show that inhibition also predicted reading comprehension, with a one unit increase predicting an increase in reading comprehension of 0.30 *SD*. Thus inhibition was an important predictor of both word reading and reading comprehension with working memory contributing to reading comprehension but not word reading.

In order to determine whether hypotheses regarding possible causation were justified, a further model was evaluated in which the reading latent variables were included as predictors of executive function ability. This model failed to achieve an acceptable level of satisfactory model fit (χ^2=36.11, *df*=14, *p*=0.001 CFI=0.93, TLI=0.86, AIC=10684.22, RMSEA=0.09, 90% CI=0.05-0.12, SRMR= 0.06) suggesting that it was more appropriate to model reading as being predicted by executive function.

As a final check, models C and D were also evaluated with the addition of the executive function latent variables predicting both word reading and reading comprehension (termed models Ci and Di). Table 5.9 shows the respective model fit statistics.

Table 5.9. Fit indices for structural models.

Model	χ^2	*df*	*p*	CFI	TLI	AIC	RMSEA	90% CI	SRMR
Bi	13.77	14	0.467	1.00	1.00	10661.88	0.000	0.000, 0.067	0.035
Ci	29.82	14	0.008	0.96	0.91	12253.52	0.075	0.037, 0.112	0.043
Di	42.49	29	0.051	0.97	0.95	13892.79	0.048	0.000, 0.077	0.044

The fit statistics in Table 5.9 suggest that model Bi provides the best fit to the data. In addition, a non-significant delta chi-square showed that model Ci was no better fit to the data than model Di ($\Delta\chi^2=12.67$, $df=15$, $p>0.05$), however, model Bi was a significantly better fit to the data than model Di ($\Delta\chi^2=28.72$, $df=15$, $p<0.05$). Therefore, this justifies the conclusion that model Bi provides the best fit to the data and was therefore employed for all subsequent analyses.

5.3.4 Multi-sample SEM.

When comparing groups using structural equation modelling there are several criteria which must be assessed. Firstly, the measurement model must be tested and show an acceptable level of fit across groups i.e. the model is tested separately for each group and fit assessed. Measurement invariance demonstrates whether the same constructs are measured by the same manifest variables across groups (Kline, 2005). To indicate measurement invariance, configural, metric and scalar invariance must all be obtained (T. A. Brown, 2006; Kline, 2005). Configural invariance assesses the variance of the factor structure by initially testing an unrestricted baseline model. Following this, the factor loadings are constrained to be equal and the model fit is compared to the model found for configural invariance. If the model fit is no different, it can be concluded that the assumptions for metric invariance have been met, that is, the factor structure is the same between groups. Metric invariance is a prerequisite for comparing measurement and structural models. Subsequently the intercepts are constrained to be equal and the resulting chi-square is compared to that found when testing for metric invariance. If delta chi-square is not significant then the intercepts are the same across groups thus the assumptions for scalar invariance have been met and the latent means can be compared. In order to evaluate the latent means, one group is used as a baseline group and the latent means of that group are set to zero. The relative difference of the other group is compared to this baseline in order to determine whether the latent means are significantly different between groups. Furthermore, in order to assess whether the structural paths are comparable across groups, a model where the factor loadings and intercepts are constrained to be equal (as is the default in MPlus) but all of the structural paths are freely estimated is compared to a model with a specific path of interest constrained to be equal across the groups (Muthén, 2010).[20] If the chi-square difference test is non-significant, it can be concluded that the structural path is equivalent across groups.

5.3.4.1 Gender.

In order to assess whether model Bi was comparable for males and females, a multi-sample SEM was performed. A baseline model was initially established for each group separately with a three factor model as shown in Figure 5.2 (model B) compared to a one

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[20] Personal communication from Bengt O. Muthén advised that this was appropriate

factor model (model D). The three factor model provided an acceptable level of model fit for both males (χ^2=16.75, *df*=12, *p*=0.16, CFI=0.97, TLI=0.94, AIC=6517.58, RMSEA=0.057, 90% CI=0.00-0.12, SRMR=0.047) and females (χ^2=7.12, *df*=12, *p*= 0.85, CFI=1.00, TLI=1.09, AIC=4667.85, RMSEA=0.00, 90% CI=0.00-0.061, SRMR=0.041) and in both cases the model fit was preferable to a one factor model.

Following this, configural, metric and scalar invariance were each assessed using the procedure described above. The resulting chi-square statistics are shown in Table 5.10. As the chi-square difference tests were non-significant, it can be concluded that both metric and scalar invariance were established. That is, that the factor structure and intercepts were equivalent for males and females.

Table 5.10 Results of multi-sample SEM for gender.

	Total χ^2	*df*	χ^2 males	χ^2 females
Configural invariance	23.58	24	16.47	7.11
Metric invariance	26.33	27	17.68	8.64
$\Delta\chi^2$	2.75	3		
Scalar invariance	28.93	30	18.83	10.10
$\Delta\chi^2$	2.61	3		
Latent mean comparison	Males	Females	(*SE*)	*z*-score
Non-verbal IQ	0	0.21	(0.77)	0.27
Working memory	0	-0.78	(0.94)	-0.83
Inhibition	0	0.63	(0.28)	2.29*

Note: **p*<0.05; ***p*<0.01; ****p*<0.001

As scalar invariance was established, latent mean comparison was possible. Table 5.10 reveals that while there was no significant difference between males and females for either the working memory or non-verbal IQ latent mean, the inhibition latent mean for the female group is significantly higher than that of the male group ($p<0.05$).

In order to control for gender differences in latent means, a multiple indicators and multiple causes (MIMIC) model was evaluated with gender included as a covariate predicting each of the latent variables in model Bi. When gender was included as a covariate, the model fit was extremely poor ($\chi^2=91.49$, $df=23$, $p<0.001$, CFI=0.78, TLI=0.66, AIC=11014.34, RMSEA=0.121, 90%CI=0.096-0.148, SRMR=0.128) showing an unacceptable level of fit. Thus subsequent analyses are carried out without gender as a covariate, however the difference in inhibition latent mean between males and females must be noted.

In order to compare the structural paths for each group, a model with all of the structural paths freely estimated was compared to a model with a specific path of interest constrained to be equal between groups (Muthén, 2010). For example the path from inhibition to word reading was constrained to be equal but all other structural paths were allowed to be free. Each structural path was constrained in turn and the resulting chi-square compared to that when all of the structural paths were free. In each case the delta-chi square was non-significant; that is, there was no difference in model fit when each path was free to when it was constrained to be equal. The unstandardised and standardised parameter estimates for each structural path for both males and females when freely estimated are shown in Table 5.11.

It can therefore be concluded that the regression coefficients from each of the executive function latent variables predicting each aspect of reading were equivalent for males and females.

Table 5.11. Unstandardised and standardised parameter estimates with standard errors in parentheses for all structural paths for males and females.

Parameter estimate	Unstandardised(*SE*)	Standardised(*SE*)
Males		
Inhibition → word reading	4.91 (4.33)	0.48 (0.34)
Inhibition → reading comprehension	4.57 (5.77)	0.30 (0.32)
Working memory → word reading	0.08 (0.56)	0.04 (0.31)
Working memory → reading comprehension	1.34 (0.76)	0.50 (0.28)
Females		
Inhibition → word reading	3.29 (1.42)*	0.49 (0.15)**
Inhibition → reading comprehension	4.51 (1.98)*	0.48 (0.16)**
Working memory → word reading	-0.42 (0.36)	-0.20 (0.15)
Working memory → reading comprehension	0.89 (0.55)	0.30 (0.16)

Note: $*p<0.05$; $**p<0.01$; $***p<0.001$

5.4 Discussion

Several key findings emerged from the present analysis. Competing measurement models were evaluated and it was found that a three factor model with indicator variables loading on latent variables of inhibition, working memory and non-verbal IQ provided the best fit to the data. When the potential moderating role of non-verbal IQ was explored, it was found that the interaction between non-verbal IQ and both inhibition and working memory did not significantly predict either aspect of reading. Furthermore, mediation analysis found that the relationship between executive functions and reading was not significantly influenced by non-verbal IQ.

When word reading and reading comprehension were included in the model, it was found that increases in inhibition significantly predicted improvements in both word reading and reading comprehension. Furthermore, working memory performance was a significant predictor of reading comprehension, with reading comprehension improving as working memory ability increased.

Furthermore, multi-sample analysis was conducted to assess whether the relationship between executive functions and reading was the same for males and females. The same three factor model provided a good level of fit for both groups and exploration of measurement invariance found that the factor structure and intercepts were equivalent. Additionally, the strength of the relationships between each executive function and reading was also equivalent, as illustrated by comparable structural path coefficients. When the latent means were compared, no difference was found between males and females for non-verbal IQ or working memory. However, the mean of the inhibition latent variable was significantly higher for females than males, thus suggesting improved inhibitory ability in females. When gender was included in the model as a covariate however, the model fit was not acceptable suggesting that controlling for gender did not lead to improved model fit. The implications of each of these findings will be discussed in turn.

5.4.1 Separability of executive functions.

The findings from the present analysis support previous conclusions that executive functions can be conceived as separable but also highly related constructs (Friedman, et al., 2008; Miyake, et al., 2000). These findings add to the current literature by identifying commonalities between the factor structure found in adults (Friedman, et al., 2007) and typically developing children (Lehto, et al., 2003) as well as studies which have included children with RD (Willcutt, et al., 2001; Willcutt, Pennington, et al., 2005). To the writer's knowledge, this is the first study which has reported this in a sample solely comprising children with RD, thus justifying research studies which have differentiated between aspects of executive functions in similar samples.

van der Sluis et al. (2007) failed to find evidence for a unique inhibition factor in children. Four tasks of inhibition were administered in their study: the Stroop task, a numerical size inhibition task, an object inhibition task and a quantity inhibition task. The authors posited that inhibitory processes may not be evident at the level of individual differences which may account for the lack of a unique inhibitory factor. However they also cautioned that inhibition may be related to individual differences in clinical samples and may indeed be useful for distinguishing clinical groups. But as their sample involved typically developing children, these individual differences were not apparent. The findings from the present study are supportive of such propositions. Furthermore, the results from the present study are in line with those reported by St Clair-Thompson and Gathercole (2006) who found evidence for separable working memory and inhibition factors using the stop signal and the Stroop task. As well as potential differences due to sample, it may be that the lack of inhibitory factor reported by van der Sluis et al. (2007) is reflective of differences in tasks employed as it may be that different aspects of inhibition were assessed (c.f. Nigg, 2000). However as the Stroop task was employed across studies this is unlikely to account completely for the discrepant findings and thus the differences in sample employed are considered a more likely candidate.

Furthermore, McCabe et al. (2010) failed to find evidence for the separability of executive functions in a study comprising adults aged 18-90. They found that a one factor “executive attention” latent variable provided the best fit to the data and suggested that this could be attributed to common attentional abilities across tasks assessed. While the present study involved children rather than adults, findings from McCabe and colleagues indicate that the factor structure may be related to developmental changes across age. While the age of participants in the present study ranged from 109 to 142 months, as age standardised tasks were employed - except in the case of the fluency measures where age predicted regression derived scores were used - any age related differences were thus controlled. However, it is possible that a different factor structure may be found in older children with reading difficulties, thus longitudinal studies are indeed warranted.

5.4.2 Non-verbal IQ scores.

While separate latent variables for non-verbal IQ and working memory were found in the present analysis, they were also found to be positively correlated. While it has been argued that the two constructs represent the same underlying processes (c.f. Chapter One, p.40), the meta-analysis conducted by Ackerman and colleagues (P. L. Ackerman, et al., 2005) concluded that the correlation between the constructs was not indicative of unity; that is, the two constructs are indeed separable. The present analysis supports this conclusion. When tasks used to assess non-verbal IQ and working memory were loaded onto a common latent variable, the model fit was depreciated compared to a model with separate latent variables. Factor loadings suggested that the non-verbal IQ tasks were similar to the non-verbal working memory tasks. This is indicative of the fact that many tasks commonly used to assess non-verbal IQ are highly confounded by the strong demands which they place on working memory skills (Denckla, 1996b). Thus, if different non-verbal IQ tasks had been employed it is possible that a different strength of correlation may have been found.

Furthermore, the non-verbal IQ latent variable was not found to be a significant mediator or moderator of the relationship between executive functions and reading, and indeed was not significantly correlated with either aspect of reading when inhibition and working memory were controlled. These findings thus indicate that the executive functions assessed contribute more to reading than non-verbal IQ in a sample of children with reading difficulties. This is supportive of findings such as those of Alloway (2009) who reported that working memory and not IQ predicted learning in children with learning difficulties.

Together, these findings have implications for the assessment of reading difficulties and are supportive of those who argue against the use of IQ/achievement discrepancy definitions of reading difficulties (e.g. Stanovich, 2005). These points are elaborated further in Chapter Eight.

5.4.3 Contribution of executive functions to reading.

Increased inhibitory processes were found to significantly predict increased performance in word reading and reading comprehension; however working memory only significantly contributed to reading comprehension. As with inhibition, as working memory processes improved so did reading comprehension. These findings are suggestive of two important areas for consideration. Firstly they highlight the importance of executive function for reading in a sample of children with reading difficulties and secondly that different aspects of executive function are important depending on which aspect of reading is being predicted. These findings are in line with those reported in Chapter Three. Many studies reported in the literature rely on either one aspect of reading or another and those which do include both aspects often report composite scores of reading (e.g. Alloway, 2009). Thus conclusions regarding the role of executive functions can vary considerably and the predictive utility can be masked. For example, while Alloway (2009) found that working memory predicted reading in a sample of children with learning difficulties, as a composite score of reading was used as the criterion variable in the regression analysis employed, the magnitude of the betas obtained may have been over or under exaggerated.

In terms of theoretical accounts, the results of the present study are supportive of theoretical distinctions regarding reading processes. In regard to word reading, spreading activation theories, for example the Triangle model (Harm & Seidenberg, 2004; Plaut, et al., 1996; Seidenberg, 2005; Seidenberg & McClelland, 1989), suggest that the grapheme/phoneme correspondences are such that several related correspondences are activated for consideration and the correct response selected from a number of competitors. For a correct correspondence to be retrieved and thus an appropriate response given, responses which are activated but incorrect must be inhibited. Thus it may be that inefficient inhibitory processes underlie the incorrect grapheme/phoneme responses and therefore the difficulties with reading experienced by some children.

In terms of reading comprehension processes, theories such as the Construction-Integration theory (Kintsch, 1998; Kintsch & Rawson, 2005) and the Landscape model (van der Broek, et al., 1996) have suggested a primary role for working memory. As competence in reading comprehension involves efficient word reading plus inference making skills, implications for inhibitory processes are to be expected, as well as strong demands being placed on working memory resources. As such the ability to hold a series of words in mind, including their semantic properties as well as grapheme/phoneme correspondences, while making correct inferences, is impeded if working memory resources are not adequate. Therefore deficient working memory abilities may underlie reading comprehension difficulties. This is supported by studies such as that of Nation and colleagues (Nation, et al., 1999; Pimperton & Nation, 2010) who found that children whose difficulty with reading centred on comprehension, displayed depressed working memory performance. The present study together with results from study two (Chapter Three) are consistent with this conclusion.

5.4.4 Gender.

A higher mean was found for the latent variable of inhibition for females compared to males; however there was gender equivalence across all other aspects assessed. The factor structure derived was identical across groups as was the predictive utility of the executive functions for reading. Given the difference observed in latent mean, a model was tested which explicitly modelled the gender of participants, however, this did not lead to an acceptable level of model fit and hence the best fitting model did not include gender as a covariate.

Lezak (1995) suggested that inhibitory responses may be influenced by gender; findings concordant with those of the present study. However, while the latent mean of inhibition was higher for girls, the extent to which inhibition predicted reading was equivalent across groups. Therefore, while girls had improved inhibitory ability in the present study this did not influence their reading level any more than it did for boys. While these findings may seem to be inconsistent with the results presented in Chapter Two, it is worth noting that effect sizes compared in Chapter Two were for comparisons between groups of children with RD and TDC, whereas the present study involved only children with RD. Thus while there may be differences between males and females who have RD in terms of the severity of the inhibitory impairment, there may be no difference between males and females when being compared to TDC.

Differences in hormone production are believed to account for differences in brain development (De Bellis, et al., 2001) and therefore potentially account for differential performance on executive tasks. The age of participants in the present study may therefore also play a contributing role to the inhibitory differences detected, as hormonal production associated with puberty begins at an earlier age for girls than boys (Pinel, 1990). Therefore it is possible that gender differences identified in the present study may disperse for older or indeed younger participants. Longitudinal analysis concerning hormonal production and executive function is therefore warranted.

5.4.5 Limitations.

One potential limitation concerns the lack of a unique fluency factor. When specifying the measurement model it was found that there was a large correlation between the latent variables of inhibition and fluency which led to an inability of the model to converge. When the fluency measures and inhibition measures were loaded onto a common latent variable it was found that the factor loadings were very similar for the non-verbal inhibition tasks and the fluency measures, suggesting that the fluency measures placed strong demands on inhibitory skills. This supposition is consistent with previous studies which argue that fluency tasks assess inhibitory skills (Mahone, Koth, Cutting, Singer, & Denckla, 2001; McCabe, et al., 2010). However, Lehto and colleagues (Lehto, et al., 2003) found that the word fluency task loaded predominately onto a latent variable which they termed shifting. They suggested that verbal fluency tasks require participants to cluster their responses in terms of initial letter or semantic category and then subsequently shift between these clusters. As such it was argued that while fluency tasks are reliant on working memory processes, as indicated by small factor loadings, that fluency primarily requires shifting ability. As the present study did not include any measures purported to assess predominately shifting skills due to the lack of consistent impairment identified in the meta-analysis reported in Chapter Two, it is not possible to assess whether the fluency measures loaded more strongly with the inhibition tasks or shifting tasks. Future research should therefore administer a wider array of tasks of executive function in order to deconstruct the underlying processes involved in a greater number of tasks.

However, while there seemed to be a strong relationship between the inhibition tasks and the fluency tasks, the best fitting model emerged when the fluency measures were removed from the model altogether. Hull et al. (2008) failed to find a distinct inhibitory factor in their study comprising adults aged 51 to 74. Three tasks of inhibition were used and only one had a significant factor loading when all loaded onto a unique factor and so the authors excluded this factor from their analysis. They argued that the inability to identify an inhibition factor reflected either sampling issues or inadequate measures. As such it is possible that the inability to identify a unique fluency factor in the present study is a reflection of the assessment tasks employed. The two fluency tasks used, the five-point test and a verbal fluency measure, were identified in the meta-analysis in Chapter Two as being consistently good at differentiating between children with RD and TDC. While medium to large effect sizes were identified (+0.54 and +0.86 respectively), it may be that alternative assessment tasks would have led to a different pattern of results, as fluency measures may differ in the extent to which they implicate other areas of executive function; this should be addressed in future studies.

A further, and related limitation, concerns the number of indicator variables for each latent variable. While two tasks for each aspect of executive function were included which is appropriate for the analysis performed (Byrne, 2001), a larger number of tasks of executive function would be desirable. Given the burden of assessment already imposed on participants and their schools, it was not possible to increase the number of tasks administered in the present study. However, future research could further investigate the relationship between tasks of executive function by including a wider array of measures, including tasks which are more strongly related to motor responses i.e. the stop signal task which is a task of motor inhibition (Hulme & Snowling, 2009).

5.4.6 Conclusions.

To summarise, the present study confirmed that executive functions of inhibition and working memory are unique but related constructs in children with reading difficulties, and that non-verbal IQ can also be conceptualised as a distinct factor. Inhibitory processes were found to be important for all aspects of reading ability assessed, however working memory only significantly contributed to reading comprehension; findings which support theoretical distinctions regarding the importance of relative processes. Furthermore, while female participants were found to have a higher mean for the inhibition latent variable, there was no difference between males and females for the extent to which executive processes predicted reading, suggesting equivalence of the predictive utility across gender.

As reading difficulties are known to be highly comorbid with other developmental disorders, the extent to which these comorbidities impact on the relationship between executive functions and reading should be taken into consideration. The issue of comorbidities will therefore be address in the following two chapters.

Chapter Six

Study 3.2: Comorbid ADHD

6.1 Introduction

As reading difficulties have been found to be highly comorbid with a range of other developmental disorders, many of which are also reported to have executive function difficulties (Willcutt, et al., 2008), identifying executive function difficulties specific to RD is problematic. The first aim of Study Three was to evaluate the underlying factor structure of executive functions and assess how far they predicted reading ability in a sample solely comprising children with RD. The results demonstrated the "unity and diversity" of executive functions (Miyake, et al., 2000) in a sample of children with RD and found that differential processes are important depending on which aspect of reading ability was assessed. Given the difficulty in attributing executive impairments solely to RD, the second aim of Study Three was to examine whether the pattern of results was the same when comorbid relationships were taken into account.

ADHD has been associated with deficits in inhibitory functioning in theory (Barkley, 1997) and research studies (Slaats-Willemse, Swaab-Barneveld, de Sonneville, van der Meulen, & Buitelaar, 2003) and given the inhibitory impairments identified for children with RD thus far in the thesis, the comorbid relationship with ADHD was examined. Furthermore, in light of the modality differences identified in Chapters Two and Four, the comorbidity with language impairment was also investigated. Results presented in this chapter examine the comorbidity between RD and ADHD, with comorbidity between RD and language impairment explored in Chapter Seven.

6.1.1 Prevalence and characteristics of ADHD.

The Diagnostic and Statistical Manual of mental disorders (DSM-IV-TR;APA, 2000) estimates the prevalence of Attention- Deficit/Hyperactivity Disorder (ADHD) as 3-5% of children. Prevalence is generally higher in boys than girls with estimated ratios ranging from 3:1 to 9:1 depending on the place of referral (i.e. community or clinic) (APA, 2000; Hulme & Snowling, 2009; Tannock, 1998). ADHD is characterised by symptoms which cluster under the banner of hyperactivity-impulsivity e.g. restlessness and fidgeting, or symptoms of inattention e.g. easily distracted and difficulty paying attention, or symptoms related to both areas (Tannock, 1998). Furthermore, symptomatology is not restricted to those with low IQ scores (T. E. Brown, Reichel, & Quinlan, 2009) but has been found to have a negative impact on later academic attainment (Fergusson, Horwood, & Lynskey, 1993). While several explanations have been proposed to account for ADHD, a widely held theory in the literature is that ADHD indicates an underlying impairment in executive function (Hulme & Snowling, 2009; Pennington & Ozonoff, 1996; Tannock, 1998; Willcutt, et al., 2008).

6.1.2 Executive impairments.

In a review of the literature concerning the role of executive functions in developmental disorders, Pennington and Ozonoff (1996) identified 18 published studies which had compared the performance of children and adolescents with ADHD to a control group on tasks of executive function. 83% of studies included found significantly poorer performance on executive function tasks for the ADHD group. When specific tasks were considered, consistent impairments were identified in scores on the Tower of Hanoi (TOH), the Stroop task, the Matching Familiar Figures Test (MFFT), Trials B and tasks assessing motor inhibition, tasks which are often purported to assess inhibition (Baron, 2004). In addition, the authors discussed several studies which report that the performance of participants with ADHD on tasks of executive function was no longer impaired when using stimulant medication. They concluded that the results from these studies provide evidence that children with ADHD have a central deficit in executive function heavily associated with inhibitory performance.

Further to this review, Barkley (1997) proposed a model of ADHD in which behavioural inhibition was postulated as the primary deficit. Behavioural inhibition was proposed to incorporate the ability to inhibit a prepotent response; cease ongoing responses; and control of interference. The model proposed was hierarchical in nature, with the central deficit in inhibition impacting on four other areas of executive function, namely: working memory, self-regulation of affect/motivation/arousal, internalisation of speech and reconstitution. Working memory was conceptualised as involving holding events in mind and manipulating information/responding to these events as well as perception of time and behavioural organisation. Self-regulation of affect/motivation/arousal comprised abilities such as emotional self-control; self-regulation of motivation; regulation of arousal in relation to goal-directed action; and social perspective taking. The aspect labelled internalisation of speech covers the ability to describe and reflect upon actions/events; adherence to rule-governed behaviour; problem solving; and generation of rules. The fourth aspect, reconstitution, refers to the analysis and synthesis of behaviour; verbal and behavioural fluency; the creation of goal-directed behaviour; and syntax of behaviour. Following the hierarchical nature of the model, these four executive functions were conceived as directly impacting on motor control, fluency and syntax; that is, inhibiting responses which were irrelevant to the task at hand; goal-directed response execution; performance of novel/complex actions; goal-directed persistence; sensitivity to response feedback; re-engagement with a task following disruption; and control of behaviour by internally represented information. Given the hierarchical nature of this model then, it is suggested that difficulties faced by children with ADHD are directly related to an underlying deficit in behavioural inhibition.

Support for an underlying deficit in executive function in ADHD can be found from genetic studies and cognitive neuroscientific research. Deficits in response inhibition were examined as a potential endophenotype in a study conducted by Slaats-Willemse and colleagues (Slaats-Willemse, et al., 2003). Siblings of children with ADHD who did not themselves meet diagnostic criteria were compared with their ADHD affected siblings and a group of TDC children on a number of tasks designed to assess inhibitory ability: namely the Go/No Go task, a sustained attention task and the Stroop task. The non-affected siblings displayed a pattern of performance similar to those with ADHD who in turn showed significantly poorer performance on all tasks than the TDC. The authors suggest that this indicates the utility of inhibitory performance for identifying genetic propensity for ADHD. Further to this, Castellanos and Tannock (2002) examined a number of potential endophenotypes for ADHD, arguing that supporting evidence should be gleaned from neuroscience. Reviewing the relevant neuroscientific literature, one of the potential endophenotypes which the authors suggested had potential to explain the aetiology of ADHD was a deficit in working memory. In support of this, Makris et al. (2008) examined white matter in brain areas thought to be related to executive functions in adults who had received a diagnosis of ADHD in childhood. They found that neural networks associated with executive functions were deficient in adults with ADHD, demonstrating an abnormality in the structure of the cerebrum. Thus this research collectively indicates that deficits in executive function in those with ADHD have a neuronal basis and are potentially genetic indicators of the disorder.

Further support has been gleaned for Barkley's (1997) deficient behavioural inhibition model in studies employing measures commonly found in neuropsychology. Bezdjian and colleagues (Bezdjian, Baker, Isabel Lozano, & Raine, 2009) found that performance on a commonly used task of behavioural inhibition, that of the Go/No Go task, was significantly correlated with parent and teacher ratings of ADHD symptomatology. A series of event-related potential studies (ERP) employing the same Go/No Go task were carried out by Inoue et al. (*in press*). When performance of children with ADHD was compared to a control group of TD children, they found evidence for stronger inhibitory processing in the control group and suggested that the children with ADHD may have a deficient ability to inhibit prepotent responses. The stop-signal task is another task often cited in the literature and is generally employed to assess behavioural inhibition in children (Baron, 2004). Alderson, Rapport and Kofler (2007) conducted a meta-analysis of previous research which had compared stop-signal task performance of children with ADHD to TDC. Mean effect size for stop-signal reaction time (SSRT) was 0.63 (95% CI 0.52-0.74) indicating poorer performance in those with ADHD compared to TDC; these results thus signified a deficit in what the authors described as "attention/cognitive processing" (p. 745).

In addition to deficits in inhibition, difficulties in other area of executive function have been reported for children with ADHD. Berlin, Bohlin, Nyberg and Janols (2004) report deficiencies in tasks assessing inhibition, working memory and self-regulation for children with ADHD. The WCST is generally employed as a measure of set-shifting, although as with all executive tasks, it assesses several aspects of executive functioning: concept generation, problem solving, abstract reasoning and response inhibition (Baron, 2004). In a meta-analytic review of performance on the WCST of children with ADHD (amongst other developmental disorders), Romine et al. (2004) concluded that children with ADHD have general impaired performance on the WCST compared with TDC. Subsequently, in a meta-analysis of a range of executive function tasks, Willcutt, Doyle, Nigg, Farone and Pennington (2005) reported depressed performance for those with ADHD on all executive function tasks evaluated. Effect sizes varied however (+0.43 to +0.69), with the largest effects found for measures of inhibition, vigilance, working memory and planning. This finding is in concordance with expectations of the model proposed by Barkley (1997), where deficiencies with behavioural inhibition exert an influence on other aspects of executive functioning.

However, while deficits with some aspects of executive functioning have been observed, not all studies report deficient inhibition in children with ADHD (Marzocchi, et al., 2008). In a study comparing results from neuropsychological tasks with those from "real world" measures with greater ecological validity, Lawrence et al.(2004) reported that children with ADHD were impaired on only some aspects of the Stroop and the WCST and in addition, that some performance indicators from the neuropsychological tasks were significantly related to the "real-world" activities employed (that is, a videogame and a zoo task). However, this impairment was not uniform across all derived scores; children with ADHD were comparable to TDC on Stroop interference score. The results thus suggest that findings of general executive function difficulties in children with ADHD are not always consistent. In line with these inconsistencies, while Carter, Krener, Chaderjian, Northcutt and Wolfe (1995) found increased interference on the Stroop task amongst children with ADHD compared to TDC, contrary to intuitive predictions, interference scores on the Stroop were not significantly correlated with either the WCST or the Continuous Performance Test. In addition, studies which had administered the Stroop task to children and adolescents with ADHD were reviewed in a meta-analysis conducted by van Mourik, Oosterlaan and Sergeant (2005). Seventeen studies were included in the meta-analysis and while effect sizes reflected deficient performance on some aspects of the Stroop (e.g. colour naming), the effect size for the interference score ranged from -0.29 to +2.00. However the overall mean effect size was +0.35, that is, a small effect (J. Cohen, 1988). The effect sizes for the interference score were found to vary depending on the method of its calculation. For example, whether the interference score was calculated by controlling for colour naming, or whether colour naming and word reading were controlled using regression predicted scores or theoretical formula i.e. the Golden method[21]. The authors argued that claims for a primary deficit in interference control in ADHD as determined by low scores on the Stroop could be questioned.

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[21] The Golden method argues that the time to read a colour word is a combination of the time to read a word and the time to name a colour (Golden, 1978).

Further to this, a review by Castellanos, Sonuga-Barke, Milham and Tannock (2006) distinguished between "hot" and "cool" tasks of executive function in relation to ADHD (see Chapter One, section 1.2.2). They concluded that deficits with "cool" executive functions were incontrovertibly associated with ADHD but that the centrality of inhibition was less conclusive. As there still remains a paucity of research which has examined "hot" executive functions in this sample, clear conclusions can not currently be drawn. However Castellanos and colleagues proposed that initial exploration suggests that "hot" executive functions may be associated with symptoms reflecting hyperactivity/impulsivity as opposed to symptoms of inattention which are related to deficiencies with "cool" aspects. Consistent with this, Martinussen and Tannock (2006) found that inattention symptomatology predicted working memory performance but that symptoms of hyperactivity/impulsivity did not.

While support has been amassed for an association between executive function deficits and ADHD, findings from the literature have not been consistent. One possibility is that underlying deficiencies in executive function may be related to deficits other than ADHD (McGee, et al., 1989). Savage, Cornish, Manly and Hollis (2006) compared children rated as having high levels of attention problems to those at the bottom end of the rating scale i.e. no attention problems, on measures of executive function, IQ and reading ability. They found that measures of inhibition and working memory loaded onto a common latent variable and that this variable predicted reading ability but not attention group membership. The authors argued that their results demonstrate that functions which are generally assumed to be related to attention problems are actually more strongly reflective of reading-related processes. An additional confound in the exploration of executive deficits specific to ADHD could therefore be that ADHD is commonly found in the presence of RD.

6.1.3 Comorbidity.

It is has been suggested that more than 50% of children with ADHD qualify for a comorbid diagnosis with another developmental disorder (Pennington & Ozonoff, 1996). Estimates of comorbidity between ADHD and RD range from 15-45% (Purvis & Tannock, 2000) to as much as 80% (McGee, et al., 1989). While children with RD show improvements in attentional tasks over time, those with additional ADHD show little developmental change and seem unable to develop compensatory strategies thus demonstrating the problematic nature of comorbidity (Kupietz, 1990). Some authors have suggested the executive function deficiencies displayed by those with reading difficulties may be reflective of comorbid ADHD (Savage, et al., 2007). Furthermore, while it has been suggested that children with ADHD display difficulties with reading due to the attentional demands of the task (Savitz & Jansen, 2003) a number of studies have examined the pattern of executive impairment related to the high rates of comorbidity and three competing explanations have been posited: the phenocopy hypothesis, the etiological subtype hypothesis and the common etiology hypothesis.

6.1.3.1 The phenocopy hypothesis.

Pennington and colleagues (Pennington, et al., 1993) examined the nature of comorbidity between RD and ADHD in a sample of 70 boys aged between 7 and 10 years. Sixteen of the participants qualified as having ADHD only, determined by scores on three parent rating scales, 15 met diagnostic criteria for RD only as determined by a significant discrepancy between observed and expected reading levels based on age, IQ and educational experience, 16 met criteria for both ADHD and RD and 23 had neither disorder. All participants were administered a battery of tasks designed to assess executive functioning and phonological processing; areas believed to be central to ADHD and RD respectively. Results found that the RD group performed comparably to the TDC group on tasks of executive function and that the ADHD group demonstrated performance comparable to the TDC group on the measures of phonological processing. In terms of the comorbid group, task performance most closely resembled that of the RD only group. The findings are therefore suggestive of the fact that reading failure led the participants in the comorbid group to display the overt behavioural symptoms of ADHD e.g. fidgeting and lack of attention as indicated by parental reports, which the authors argued may be a manifestation of frustration due to the underlying RD; however they did not present the underlying associated cognitive profile. This was thus termed the phenocopy hypothesis.

Support for the phenocopy hypothesis has been found in a number of subsequent studies. For example, Adams and Snowling (2001) report findings from a study with children reported by their class teacher as hyperactive on the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997). The hyperactive participants were found to perform more poorly than a control group matched for age, gender and non-verbal ability on measures of reading ability. When the groups were further categorised by low reading scores it was found that there was a main effect of group (i.e. hyperactive or not) on tasks assessing executive function and a main effect of the reading group on tasks of reading; importantly, there were no interactions. That is, the group who were both hyperactive and poor readers did not perform any differently from those who were hyperactive and normal readers on tasks of executive function and those who were poor readers and hyperactive had comparable performance on tasks of reading as those who had reading difficulties but were not hyperactive. The authors interpreted their findings as evidence that attention problems and reading difficulties are independent in the sample studied. That is, there were no additive difficulties in those who were classed as both hyperactive and having RD thus supporting the phenocopy hypothesis.

Palladino (2006) examined the role of inhibition in working memory tasks in children with ADHD and a group with comorbid RD and ADHD. Participants were administered a working memory span task and a lexical decision task and results revealed that those in the comorbid group with poorer working memory ability had more difficulty inhibiting irrelevant information than both the control group and the ADHD only group. The authors argued that the association between ADHD and working memory difficulties can be attributed to the presence of RD. As no group with RD-only took part it is not possible to determine complete support for the phenocopy hypothesis, however as the comorbid group did not perform as the ADHD only group, the results can be interpreted as supportive.

6.1.3.2 The etiological subtype hypothesis.

An alternative to the phenocopy hypothesis which has been proposed is the etiological subtype hypothesis. This hypothesis states that those with comorbid ADHD and RD will display a cognitive profile which is similar to both groups thus evidencing the additive effects of both disorders. In an attempt to evaluate these two competing hypotheses, Purvis and Tannock (2000) examined the nature of comorbid ADHD and RD. As in the study conducted by Pennington et al. (1993), four groups of participants took part: 17

children with an ADHD diagnosis, 17 with RD only, 17 children who met criteria for both disorders and 17 unaffected children. Participants completed two tasks assessing inhibitory control and three tasks assessing phonological processing; in each case one of the tasks had been administered in the study of Pennington et al. (1993). Results demonstrated that both the RD only group and the comorbid group were impaired on the measures of phonological processing and that the ADHD-only group and the comorbid group showed deficient performance on the inhibition measures. Interestingly, the comorbid group displayed deficits in a similar way to both disordered groups in an additive manner, thus supporting the etiological subtype hypothesis. The authors suggest that differences in sample referral (i.e. clinic referred or university recruited) may have contributed to the contradiction between their findings and those who found support for the phenocopy hypothesis (e.g. Pennington, et al., 1993) and advocated the use of larger samples sizes in such studies.

Evidence for the etiological subtype hypothesis has also been found using tasks other than those assessing inhibition. For example, tasks of time perception (McGee, et al., 2004) the WCST, and Trail-making task and also tasks assessing rapid automatised naming (RAN) (Närhi & Ahonen, 1995). These findings are consistent with the model proposed by Barkley (1997) where inhibitory deficits influence abilities related to working memory, including those related to time perception.

The etiological subtype hypothesis is further supported, but also extended, by findings from Rucklidge and Tannock (2002). Children with ADHD, RD, comorbid RD/ADHD and also TDC participated in a number of tasks assessing RAN and inhibition. The comorbid RD and ADHD group exhibited a pattern of performance consistent with the etiological subtype hypothesis in that they had deficits related to both impairments. However they also had additional deficits with naming, leading the authors to suggest that there may be a pattern of impairment specific to those with comorbid disorders, in that only when both disorders are apparent will certain deficits be demonstrated.

Consistent with this proposition are the findings reported for Hebrew speaking children by Bental and Tirosh (2007). Four groups of children participated: RD only, ADHD only, RD/ADHD and TDC. Tasks of reading, phonological processing and RAN were administered as well as several aspects of executive function, namely inhibition, planning, shifting, working memory and fluency. In concordance with the findings of Rucklidge and Tannock (Rucklidge & Tannock, 2002), the comorbid group displayed deficits consistent with both the RD only group and also the ADHD only group and in addition had a specific impairment in RAN. Furthermore, they also had a more severe pattern of difficulties than the pure RD group on measures of verbal working memory. Thus it may be that specific deficits in naming are apparent in comorbid cases, although deficits specific to comorbid groups have also been found in a competing programs task (Hall, et al., 1997).

However, a recent ERP study with adults by Dhar, Been, Minderaa and Althaus (*in press*) found no support for the additive nature of comorbidity on a Continuous Performance Test. While differences were initially detected between the control group and the RD group and also between the comorbid group and the control group, these statistical differences disappeared when externalising behaviour as assessed by the adult self report version of the DSM-IV-TR criteria was controlled for. The authors concluded that group ERP differences were ascribed to these external behaviours, thus refuting the etiological subtype hypothesis. As the study included only adult males and relied solely on one task, caution must be taken when generalising the findings to comorbid relationships in children however.

6.1.3.3 The common genetic etiology hypothesis.

Further to the etiological subtype hypothesis, Willcutt and colleagues (Willcutt, et al., 2001; Willcutt, Pennington, & DeFries, 2000; Willcutt, Pennington, et al., 2005) found evidence for what they termed the common genetic etiology hypothesis. This hypothesis states that RD and ADHD share an underlying genetic cause which increases propensity for both disorders. While the resulting disorder experienced will be influenced by a range of factors, both genetic and environmental, deficits in some common areas will be experienced. Thus those with comorbid RD/ADHD will demonstrate the additive effect of both disorders but no deficits specific to that group only as in the proposition of Rucklidge and Tannock (Rucklidge & Tannock, 2002). In 2001, Willcutt and colleagues conducted a large scale study of the comorbidity between RD and ADHD. Ninety three children with RD, 52 with ADHD, 48 with both RD and ADHD and 121 control children participated in the study and completed a number of tasks assessing phonemic awareness and executive function. While the RD/ADHD group displayed deficits on the majority of tasks, the authors did not identify a deficit which was specific to that group, nor was a deficit common across all disordered groups displayed. However, both the RD/ADHD group and the ADHD only group were impaired on tasks of inhibition and while the group with RD only were not significantly impaired, there was a trend towards significance even when FSIQ and ADHD symptoms were controlled. The authors argue that the trend indicates that a statistically significant impairment may be apparent with a larger sample, thus inhibitory deficits could be a potential explanatory variable of the comorbid relationship. In a subsequent study by the same group, Willcutt et al. (Willcutt, Pennington, et al., 2005) employed an even larger sample of twins: 109 with RD, 113 with ADHD, 64 with a diagnosis of both RD and ADHD and 151 TDC. As with their earlier study, the comorbid group were impaired on tasks assessing executive function and reading and also on measures of processing speed. In addition, several areas of difficulty common to all of the groups with disorders were identified: response inhibition, verbal working memory and processing speed. While each of these areas has the potential to be an endophenotype indicating comorbidity, the authors suggested that processing speed may be the most probable, although they cautioned that more research is required before this can be conceived as definitive. Additional support for this hypothesis was provided by Kibby and Cohen (2008), however they suggested that focused attention/verbal span may be the endophenotype for comorbidity, although caution must be taken in light of studies which report no deficit on tasks of working memory for children with RD only (e.g. Roodenrys, et al., 2001).

6.1.4 Confounding issues.

While support has been found for each of the three different hypotheses purported to account for the comorbid relationship between RD and ADHD, no one theory goes completely unchallenged. A further contributory factor to the lack of consensus concerning the nature of the executive impairment in children with comorbid RD and ADHD is the procedure used to select participants for each group in studies with a factorial design. For example, in the studies reported by Willcutt and colleagues (2001,

2005) described previously, four different groups of participants took part: groups of children with ADHD only, RD only, comorbid ADHD and RD, and neither disorder. While the RD group and the ADHD group had differing areas of executive function difficulty, both groups showed more symptoms of the other disorder than the control group. That is, while the RD group did not meet clinical cut-offs on assessment of ADHD, they did show more symptoms than the control group and vice versa with the ADHD group showing symptoms of RD. This therefore indicates that groups of children with RD may display subclinical presentations of other disorders. As executive function difficulties are thought to occur in both of these disorders, it is difficult to attribute executive impairments solely to RD or to ADHD thus complicating further the interpretation of poor executive function task performance in studies which have employed factorial designs.

While many studies attempt to recruit groups of children with disorders who are free from comorbid difficulties, Willcutt, Sonuga-Barke, Nigg and Sergeant (2008) advocate recruiting participants with a given disorder regardless of comorbid difficulties. They argue that assessing comorbid disorders and controlling for them statistically allows for a greater understanding of the neuropsychology of the disorder in question. The present study adopts such an approach in attempting to explain the relationship between executive functions and reading in children with RD while taking account of the comorbidity between RD and ADHD.

6.1.5 The present study.

The high rates of comorbidity make isolating groups of children with RD with no reported comorbid symptomatology exceedingly problematic. Thus the large sample of children with RD recruited for study three and described in Chapter Five were assessed for ADHD symptomatology. The group were then categorised into those who had RD and showed many ADHD related symptoms and those who had RD but few ADHD related symptoms. Multi-sample SEM was then employed to evaluate the comparable nature of the role executive functions have in predicting reading using the model previously determined in Chapter Five (model Bi shown in Figure 5.6). Therefore, the study aimed to assess whether the role that executive functions have in predicting reading ability is comparable for children with reading difficulties and those who have reading difficulties and show comorbid ADHD symptomatology.

6.2 Method

6.2.1 Participants.

The participants previously described in Chapter Five took part in the present study but were categorised into two groups: those who showed significant levels of ADHD symptomatology and thus were at risk of receiving a diagnosis of ADHD (the ADHD group) and those who were without significant ADHD symptoms and were thus not at risk (the Without ADHD group). In order to identify those with significant ADHD symptoms, the Conners teachers rating scale was administered (Conners, 2008)[22], with scores above 70 indicating significantly high levels of ADHD symptoms (see Chapter Five, section 5.2.2.4, p. 171 for reliability information). Following this criterion, 111 participants (54 males and 57 females) comprised the Without ADHD group and 96 of the participants (65 males and 31 females) comprised the ADHD group.

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[22] Four class teachers did not complete the rating scale

6.2.2 Instrumentation and procedure.

All instrumentation employed and procedures adopted are described in Chapter Five.

6.3 Results

6.3.1 Descriptive statistics.

Age-corrected standardised scores for the word reading and reading comprehension subtests, for the oral language measures and the non-verbal ability tasks for both groups are shown in Table 6.1.

Table 6.1. Mean standard scores and standard deviations for reading, oral language and non-verbal ability measures.[23][24]

	Word reading	Reading comprehension	Receptive language	Expressive language	Block design	Matrix reasoning
Without ADHD						
Mean	72.65	75.62	6.16	5.84	43.96	42.21
SD	9.72	13.87	2.16	2.19	7.74	9.50
ADHD						
Mean	72.13	77.01	5.88	5.49	43.09	38.07
SD	8.92	13.58	2.07	2.41	6.32	10.08

As indicated by Table 6.1, performance of the groups on the word reading and reading comprehension subtests were comparable; an independent t-test found no significant

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[23] Word reading & reading comp: M=100, *SD* = 15; Oral language, M=10, *SD* = 3; NVIQ, M=50, *SD* =10 Working memory measures, M =100, *SD* = 15; Inhibition measures, M=10, *SD* = 3

[24] Means given are excluding outliers as are all analyses

difference in word reading or reading comprehension between these groups (*p* values >.1).

Table 6.2 shows the mean and standard deviations for all executive function measures for both groups[25].

Table 6.2. Mean and standard deviations for all executive function tasks.

	Verbal working memory	Visuospatial working memory	Verbal inhibition	Non-verbal inhibition
Without ADHD				
Mean	80.47	90.79	8.08	7.81
SD	11.75	16.10	2.36	1.85
ADHD				
Mean	82.15	89.98	7.73	7.49
SD	12.54	15.13	2.35	2.06

Table 6.2 reveals similar performance for both groups on all executive function tasks employed. The mean standard scores of the Without ADHD group were higher across all tasks with the exception of the verbal working memory task where the mean of the ADHD group was two standard score points higher.

6.3.2 Model employed.

The final model (Bi) determined in Chapter Five was employed for the present study. This model is illustrated in Figure 6.1.

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[25] As fluency measures were excluded from the final model, information about these tasks is not included

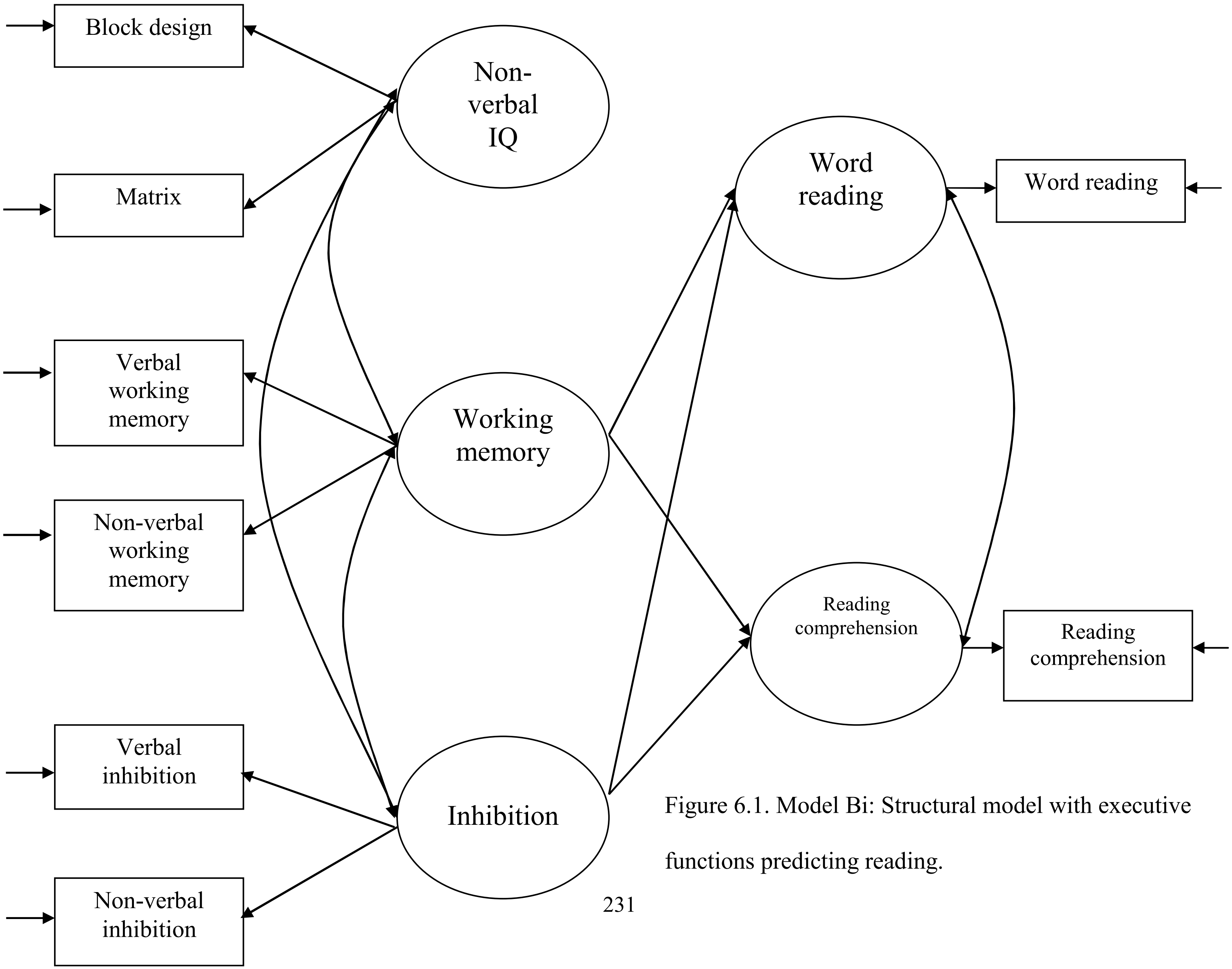

Figure 6.1. Model Bi: Structural model with executive functions predicting reading.

6.3.3 Multi-sample SEM.

In order to assess whether model Bi was comparable for the ADHD group and the Without ADHD group, a multi-sample SEM was performed. The procedure for comparing groups using SEM as outlined in Chapter 5 section 5.3.4 (p.196) was adopted. A baseline model was initially established for each group separately with a three factor model as shown in Figure 6.1 evaluated. The three factor model provided an acceptable level of model fit for both the ADHD group (χ^2=15.78, *df*=12, *p*=0.20 CFI=0.97, TLI=0.94, AIC=4925.64, RMSEA=0.058, 90%CI=0.00-0.13, SRMR=0.05) and the Without ADHD group (χ^2=6.69, *df*=12, *p*=0.88, CFI=1.00, TLI=1.07, AIC=6101.24, RMSEA=0.00, 90%CI=0.00-0.048, SRMR=0.03).

Following this, configural, metric and scalar invariance were each assessed. The resulting chi-square statistics are shown in Table 6.3.

Table 6.3. Results of the multi-sample SEM for the ADHD and the Without ADHD group.

	Total χ^2	*df*	χ^2 Without ADHD	χ^2 ADHD
Configural invariance	21.02	24	5.77	15.28
Metric invariance	23.14	27	6.52	16.61
$\Delta\chi^2$	2.09	3		
Scalar invariance	26.73	30	8.23	18.50
$\Delta\chi^2$	3.59	3		

As the chi-square difference tests were non-significant, it can be concluded that both metric and scalar invariance were established. That is, that the factor structure and intercepts were equivalent for the ADHD and the Without ADHD groups. Parameter estimates are detailed in Table 6.4.

Table 6.4. Unstandardised and standardised parameter estimates with standard errors in parentheses.

Parameter estimates	Unstandardised	Standardised
Factor structure		
Non-verbal IQ→ Block design (X1)	1.00	0.57 (0.07)***
Non-verbal IQ→ Matrix (X2)	1.68 (0.24)***	0.75 (0.08)***
Working memory → Verbal working memory (X3)	1.00	0.39 (0.09)***
Working memory → Non-verbal working memory (X4)	2.50 (0.70)***	0.72 (0.12)***
Inhibition → Verbal inhibition (X5)	1.00	0.51 (0.10)***
Inhibition → Non-verbal inhibition (X6)	0.99 (0.26)***	0.63 (0.11)***
Word reading → Word reading (X7)	1.00	0.99(0.001)***
Reading comprehension → Reading comprehension (X8)	1.00	0.98(0.003)***
Intercepts		
Block design	0.82 (0.62)	0.11 (0.08)
Matrix	1.30 (0.90)	0.14 (0.10)
Verbal working memory	-0.39 (0.95)	-0.03 (0.08)
Non-verbal working memory	0.43 (1.52)	0.03 (0.10)
Verbal inhibition	0.09 (0.20)	0.04 (0.09)
Non-verbal inhibition	0.22 (0.17)	0.12 (0.09)
Word reading	0.12 (0.94)	0.01 (0.10)
Reading comprehension	-0.69 (1.35)	-0.05 (0.10)

Note: $*p<0.05$; $**\ p<0.01$; $***p<0.001$

As scalar invariance was established, latent mean comparison was possible. Table 6.5 reveals that while there was no significant difference between the ADHD group and the Without ADHD group for either the working memory or inhibition latent mean, the non-verbal IQ latent mean for the ADHD group is significantly lower than that of the Without ADHD group.

Table 6.5. Latent mean comparison for the ADHD and Without ADHD groups.

Latent mean comparison	Without ADHD	ADHD	*SE*	*z*-score
Non-verbal IQ	0	-1.78	0.78	-2.27*
Working memory	0	-0.07	0.87	-0.08
Inhibition	0	-0.27	0.24	-1.13

Note: **p*<0.05; ** *p*<0.01; ****p*<0.001

In order to compare the structural paths for each group, a model with all of the structural paths freely estimated was compared to a model with a specific path of interest constrained to be equal between group, e.g. the path from inhibition to word reading was constrained to be equal but all other structural paths were allowed to be free. Each structural path was constrained in turn and the resulting chi-square compared to that when all of the structural paths were free. In each case the delta-chi square was non-significant; that is, there was no difference in model fit when each path was free to when it was constrained to be equal. Therefore it can be concluded that the regression coefficients from each of the executive function latent variables predicting each aspect of reading were equivalent across both groups. The unstandardised and standardised parameter estimates for each structural path for both groups when freely estimated are shown in Table 6.6.

Table 6.6. Unstandardised and standardised parameter estimates with standard errors in parentheses for all structural paths for the ADHD and the Without ADHD groups.

Parameter estimate	Unstandardised(*SE*)	Standardised(*SE*)
ADHD		
Inhibition → word reading	2.93 (4.34)	0.33 (0.47)
Inhibition → reading comprehension	0.78 (6.46)	0.06 (0.49)
Working memory → word reading	0.10 (0.59)	0.07 (0.40)
Working memory → reading comprehension	1.37 (0.86)	0.63 (0.40)
Without ADHD		
Inhibition → word reading	3.63 (1.60)*	0.44 (0.16)**
Inhibition → reading comprehension	3.93 (1.99)*	0.33 (0.15)*
Working memory → word reading	0.06 (0.37)	0.02 (0.15)
Working memory → reading comprehension	1.75 (0.68)*	0.51 (0.13)***

Note: *$p<0.05$; ** $p<0.01$; ***$p<0.001$

As indicated by Table 6.6 and the non-significant changes in chi-square, each of the structural path coefficients shows across group equivalence. However, the paths from inhibition to both aspects of reading were significant for the Without ADHD group, as was the path from working memory to reading comprehension; these paths were not statistically significant for the ADHD group though. This difference in significance reflects the larger variability for the ADHD group, something which is characteristic of children with ADHD (Berlin, et al., 2004; Dhar, et al., *in press*). However it does not negate the fact that the extent to which the executive functions predicted reading is comparable for each group.

6.4 Discussion

The present analysis evaluated whether the role executive functions have in predicting reading ability is comparable for children with RD and those who have RD and demonstrate inflated levels of comorbid ADHD symptomatology. Multi-sample SEM confirmed that the factor structure was equivalent for both groups, in turn substantiating the separability of executive functions for children with these sample characteristics. Furthermore, it was found that the predictive utility of the executive function latent variables was equivalent across groups, therefore indicating that inhibition and working memory contribute to reading performance at a level which is irrespective of whether children have RD alone or also show comorbid ADHD symptoms.

Latent mean analysis found that the means for inhibition and working memory were comparable for each group; however the non-verbal IQ latent mean was significantly lower for the ADHD group when compared to the Without ADHD group. Therefore this demonstrates a more severe impairment in non-verbal IQ for children who have RD and comorbid ADHD symptoms; however it indicates that deficits in inhibition and working memory which are identified for children with RD are not due to comorbid ADHD symptomatology. This therefore substantiates previous suggestions that impairments in inhibition and working memory are associated with RD.

In terms of non-verbal IQ, the group with RD and comorbid ADHD symptoms had a latent mean score which was two standard deviations lower than the mean of the RD only group. This finding is consistent with previous studies such as that of McGee et al. (1989) who reported that children with ADD had lower performance IQ and indeed full scale IQ than the remainder of the sample which they assessed, which included children with RD and typically developing control children. McGee and colleagues however suggested that once the lower IQ scores for those with ADD had been controlled for that there were no deficits in executive function specific to children with ADD. The findings from the present study lend support to this conclusion.

Further to this Kuntsi et al. (2004) reported that 86% of the association between ADHD symptoms and low IQ in a sample of five year olds could be accounted for by shared genetic aetiology. While the sample in the present study was older than those assessed by Kuntsi and colleagues, and was assessed on non-verbal IQ as opposed to full scale IQ, the findings are still suggestive of the fact that an underlying genetic disposition may explain the lower IQ latent mean of the group with comorbid RD/ADHD in the present study.

However, the considerable overlap between non-verbal IQ and working memory should be taken into consideration in an explanation of the present findings, as it may be that if different tasks of non-verbal IQ had been used a different pattern of results would have ensued. Thus the current results may reflect deficits that children with comorbid RD/ADHD have with non-verbal working memory, which would be consistent with findings of deficits for children with ADHD in non-verbal working memory (Martinussen & Tannock, 2006; Rhodes, Coghill, & Matthews, 2005; Rhodes, Riby, Matthews, & Coghill, 2010). However, as the latent mean of working memory, which included a non-verbal working memory indicator, was equivalent across groups this is unlikely to offer a complete explanation.

In further regard to working memory, the results from the present study are consistent with those reported by Martinussen and Tannock (2006) who found that children with reading difficulties and/or language learning disorder demonstrated deficient performance on tasks of working memory regardless of whether they had comorbid ADHD or not. Indeed Denckla (1996a) suggested that working memory may be one area of cognitive function for which both children with ADHD and also those with learning disabilities have impairments. However, in terms of comorbidities, Bental and Tirosh (2007) reported exacerbated deficits on measures of working memory for children with comorbid RD/ADHD. The results of the present study lend little support for this as there was no difference in the latent mean for the RD only group and the ADHD group. However, the fact that the participants in their study were Hebrew speakers may account for this discrepancy (c.f. Chapter Two, section 2.4.5 for a discussion).

Results by Savage and colleagues (Savage, et al., 2006) found that a combined working memory and inhibition latent variable predicted reading ability but not whether children were rated as having attention problems or not, thus suggesting that these areas of executive function reflect reading-related processes. The present findings are in agreement with this conclusion as the addition of ADHD symptoms in the presence of RD did not influence the pattern of results for either working memory or inhibition.

6.4.1 Explaining comorbidity.

In terms of theoretical accounts of comorbidity, the methodology adopted in the present study does not allow for unequivocal support for one theoretical model over another. While this was in fact not the aim of the present study, this issue is addressed further in the limitations and future directions section (page 240). In regard to the phenocopy hypothesis (Pennington, et al., 1993), this argument states that a child who has difficulties with reading may display symptoms which are considered characteristics of children with ADHD, thus children can be categorised as hyperactive/inattentive when parental or teacher ratings are used. However, while displaying behaviours similar to children with ADHD, children with comorbid difficulties do not show the cognitive profile associated with ADHD, that is, there are no additive impairments. The present study did not find any additive difficulties for the comorbid group for either aspect of executive functioning assessed, but found that the mean for the non-verbal IQ latent variable was depressed. While this latent mean is thought, to some extent, to reflect non-verbal working memory skills, non-verbal IQ is still considered to be a distinguishable construct (P. L. Ackerman, et al., 2005). Therefore, while the findings of the present study cannot completely refute the proposition of the phenocopy hypothesis they can question its conclusions, at least in respect to non-verbal IQ.

The etiological subtype hypothesis suggests that there may be additional deficits associated with comorbid RD/ADHD that are not evident when either impairment is examined in isolation. While the absence of an ADHD only group makes it difficult to support this one way or the other, as the comorbid group presented with additive impairments in non-verbal IQ when compared to the RD only group, it is possible that they may have difficulties in areas of executive function which were not examined.

Further to this the common genetic etiology hypothesis (Willcutt, et al., 2001; Willcutt, et al., 2000; Willcutt, Pennington, et al., 2005) suggests that those with comorbid RD/ADHD show the additive effects of both disorder but no impairments specific to that group. The theory suggests that RD and ADHD share an underlying genetic cause which manifests in the differing disorders as a consequence of further genetic and environmental factors. Willcutt et al. (2001) proposed that inhibitory deficits could potentially be an endophenotype which indicated comorbidity. This proposition was supported by findings presented by Slaats-Willemse and colleagues (2003) who argued that deficits in inhibition can be indicative of genetic propensity for ADHD. Further to this however, Castellanos and Tannock (2002) suggested that working memory deficits may explain the etiology of ADHD and in addition, Kibby and Cohen (2008) proposed attention/verbal span as an endophenotype. Thus while deficits in inhibition and working memory have been proposed as endophenotypes for ADHD and in fact comorbidity with RD, no consensus has yet been reached. As results in the present study found no difference in either inhibition or working memory for the RD group and those who had comorbid ADHD symptoms, it is possible that either of these areas reflect an endophenotype. However, the addition of a group of children with ADHD only and a group of TDC would allow for more conclusive findings.

6.4.2 Limitations and future directions.

While the present analysis found that there was no difference between groups for the means of the executive function latent variables, emphasis must be placed on the fact that only latent variables of inhibition and working memory were included in the present study; thus findings cannot be generalised to all aspects of executive functioning. While inhibition and working memory are the most severely impaired aspects of executive function for children with RD, deficits in other areas of executive function may be apparent for children who have a primary diagnosis of ADHD. For example, Willcutt and colleagues (Willcutt, Doyle, et al., 2005) identified deficits in planning for children with ADHD; however these deficits were not echoed for children with RD as reported in the meta-analysis in Chapter Two. Thus it may be that additional deficits for children with comorbid ADHD and RD are apparent if a wider array of aspects of executive functioning are assessed. Therefore suggestions that deficits in executive function for children with RD reflect underlying ADHD may not be completely refuted for areas other than working memory and inhibition. Future research should address this issue.

The present study aimed to evaluate the relationship between executive functions and reading for children with RD while taking into account comorbid ADHD symptoms. In order to address this line of investigation, no group of children recruited based on a clinical diagnosis of ADHD and free from RD was required. However, in order to disambiguate theoretical propositions concerning the nature of comorbid relationships, it is essential to include a group of children with ADHD who do not display difficulties with reading. Therefore, future research involving the addition of such a group would generate support for one theoretical model over another.

In addition, the present study identified participants as having significantly high levels of ADHD symptoms by using a ten item rating scale completed by class teachers; thus a categorical distinction was employed rather than a clinical diagnosis, which would involve both teacher and parent ratings. As such, it was not possible to assess reliably whether some participants had a more severe presentation of ADHD symptomatology or not. In order to investigate whether severity of symptomatology has an impact on results, future research using robust clinical indications should be employed.

Furthermore, suggestions have been made in the literature concerning the differential impairments associated with definitions of ADHD; that is, whether a participant’s diagnosis with ADHD concerns symptoms primarily related to inattention or hyperactivity, or combined type. Inattentive symptoms have been found to be more strongly related to deficits in both working memory (Martinussen & Tannock, 2006; Willcutt, Pennington, et al., 2005) and inhibition (Chhabildas, Pennington, & Willcutt, 2001) than hyperactive symptoms, and in fact Castellanos et al. (2006) suggested that inattentive symptomatology might be consistent with deficits with "cool" aspects of executive function. Therefore, an investigation of whether this extends to those with comorbid RD/ADHD is a worthy area of further exploration, as this would highlight whether comorbidity is associated with a unique presentation of cognitive difficulties.

6.4.3 Conclusions.

The present study found that children with RD who are also had significant levels of ADHD symptoms do not have differential deficits on inhibition and working memory when compared to children with RD only. However, the results reveal a more severe impairment with non-verbal IQ. Furthermore there was no difference between groups regarding how far the executive functions predicted reading ability. Therefore deficits reported in executive function for children with RD cannot be attributed to the presence of comorbid ADHD, at least in respect to inhibition and working memory.

Willcutt et al. (2008) advocate that when comorbid conditions are assessed in participants and controlled for statistically, a greater understanding of the neuropsychology of disorders is gleaned. By adopting such a procedure, the present analysis has demonstrated that while deficits in inhibition and working memory have been identified for children with RD only (see Chapter One, p.42) and also for children with ADHD only (section 6.1.2 in the present chapter), when these conditions are comorbid with each other, impairments in these areas are not impacted.

In addition to high rates of comorbidity with ADHD, RD also commonly occurs in the presence of language difficulties. Given the modality differences for performance on tasks of executive function identified in Chapters Two and Four, Study Three also examined the comorbidity between RD and language impairment. Chapter Seven therefore examines whether the pattern of results is the same as those presented in the preceding chapters when impairments with language are controlled for.

Chapter Seven

Study 3.3: Comorbid Language Impairment

7.1 Introduction

The second aim of Study Three was to examine whether the pattern of results presented in Chapter Five was the same when comorbid relationships were taken into account. Results presented in Chapter Six examined the comorbidity between RD and ADHD and found that addition of comorbid symptoms did not influence the pattern of results, except in the case of non-verbal IQ which was more severely impaired for those with comorbid ADHD symptoms. Thus it was concluded that the predictive utility of executive functions for children with RD was not attributable to ADHD symptomatology. Given that RD is also highly comorbid with language impairment, the present chapter examines whether the pattern of results is the same when difficulties with oral language are taken into account

7.1.1 Prevalence and characteristics of Language Impairment.

Specific Language Impairment (SLI) is thought to affect approximately 7% of the population (Tomblin, et al., 1997, p. 148) with greater numbers of males than females affected at the rate of approximately 2.8:1 (Leonard, 1999). Children with SLI characteristically are late to begin using language and their language skills are generally slow to develop and cannot be explained by other causes such as hearing impairment (Hulme & Snowling, 2009). The DSM-IV- TR (APA, 2000) distinguishes between Expressive Language Disorder, where difficulties relate to the production of language, and Mixed Receptive-Expressive Language Disorder, where difficulties with both the production and/or comprehension of language are demonstrated. Indeed the DSM-IV-

TR suggests that prevalence rates are variable depending on the nature of the language difficulties, with Expressive language difficulties affecting 3-5% of children and Mixed Receptive-Expressive difficulties affecting 3% of children of school-age (APA, 2000).

In order to meet diagnostic criteria for SLI, children must have a reported non-verbal IQ in the normal range (i.e. a standard score above 85) (Leonard, 1999). However it has been suggested that deficits with language can negatively impact on the ability of children to employ verbal reasoning skills in order to solve reasoning problems, reasoning problems which may for all intents and purposes appear non-verbal (Leonard, 1999). Therefore, it is conceivable that performance on non-verbal IQ scores will actually decrease with increases in age for children with SLI. This supposition was confirmed by Botting (2005) who demonstrated a 23 point decrease in non-verbal IQ in children with SLI over a seven year period. Combined with studies which demonstrate that children with language difficulties and lower non-verbal IQ scores improve on tasks assessing grammatical knowledge comparably to children with SLI (e.g. Fey, Long, & Cleave, 1994), this finding suggests that researchers should be circumspect with the use of non-verbal IQ in the diagnosis of SLI.

In a 14 year follow-up of children with SLI, Johnson et al. (1999) also reported decreases in non-verbal IQ. However in addition to this, they found that children with SLI had continual difficulties with language, academic and cognitive assessments. Thus it seems that language problems in children can in fact be indicative of serious and pervasive problems of development which may have a detrimental impact on other aspects of functioning (Hulme & Snowling, 2009; Oliver, Dale, & Plomin, 2004; Snowling, Bishop, Stothard, Chipchase, & Kaplan, 2006).

While evidence suggests that SLI shows high rates of heritability and genetic etiology (c.f. Hulme & Snowling, 2009) research has also led to the formation of a number of cognitive theories. For example, it has been suggested that difficulties with auditory processing leads to SLI in children (Tallal, 1980) that is, that children with SLI are unable to process auditory information such as speech, in the same way as TDC. However, findings reported by Bishop and colleagues (Bishop, Carlyon, Deeks, & Bishop, 1999) suggest that deficits with temporal processing are not apparent in all cases with SLI thus leading them to conclude that it is not a necessary or sufficient causal variable.

A deficit in phonological memory has also been proposed to account for the difficulties encountered by children with SLI. In a series of five experiments, Gathercole and Baddeley (1990) found evidence for an impairment in phonological memory for children with SLI compared to children in both a verbal ability matched control group and a non-verbal ability matched control group. This deficit was demonstrated by impaired performance in recall of word lists and non-word repetition and could not be explained by a series of other factors such as difficulties in auditory perceptual processes, articulation rate and encoding or rehearsal failure. The authors therefore concluded that there is a direct causal relationship between SLI and deficits in phonological memory. Support for this conclusion was amounted by Conti-Ramsden and colleagues (Conti-Ramsden, Botting, & Faragher, 2001) who reported that non-word repetition and sentence repetition significantly distinguished children with SLI from a group of TDC. Results found that these tasks were useful in identifying children with SLI even when their language problems were resolved; it was therefore suggested that task performance may be useful as a clinical marker of SLI, a conclusion in concordance with previous findings reported by Bishop et al. (Bishop, North, & Donlan, 1996). As these tasks are believed to assess phonological memory (Dollaghan & Campbell, 1998), it is possible that deficits in this area might therefore be paramount in SLI and intricately related to language and literacy skills (Conti-Ramsden & Durkin, 2007). However, deficits in non-word repetition have been reported for children with disorders other than SLI, for example, developmental coordination disorder (DCD) (Archibald & Alloway, 2008). Furthermore, it has been argued that not all children with SLI demonstrate deficits in phonological memory as assessed by non-word repetition tasks (e.g. Catts, Adlof, Hogan, & Weismer, 2005; van der Lely & Howard, 1993). Catts et al. (2005) failed to find a deficit in non-word repetition specifically for children with SLI. When a group of children with SLI only were compared with a group with dyslexia only, a group with comorbid SLI/dyslexia and a group of TDC, it was found that the SLI only group did not demonstrate significant impairments on tasks of phonological processing. As this group did have a lower performance than the TDC group, the authors suggested that children with SLI may have a “mild deficit” in phonological processing. On the other hand, the group with dyslexia only and the comorbid group showed significantly poorer performance on tasks of non-word rep and phonological awareness. While deficits in non-word repetition and thus phonological memory were not deemed to be a significant indicator of SLI, it may be that deficits are indicative of comorbid difficulties with reading rather than SLI per se.

7.1.2 Comorbidity.

Estimates of the comorbidity between RD and SLI vary quite widely in the literature. McArthur, Hogben, Edwards, Heath and Mengler (2000) tested prevalence rates and found that 53% of their sample could be classified as having either a specific reading disability or an SLI. Furthermore they found that 55% of the children with specific reading disabilities had oral language impairment, and 51% of children with SLI had reading difficulties. Thus the rate of comorbidity was approximately 50%. Other studies have also reported approximately 50% comorbidity (e.g. Catts, Fey, Tomblin, & Zhang, 2002). However, Catts et al. (2005) reported that only 17-29% of children in their sample who were diagnosed with SLI also met criteria for dyslexia and that 15-20% of children with dyslexia met the criteria for SLI. The authors proposed that the disparities between their findings and those of McArthur et al. (2000) were potentially due to recruitment differences suggesting that participants recruited from clinical settings generally have more profound difficulties thus evidencing high rates of concomitant difficulties. However, while these estimates are lower, they still signify a considerable degree of overlap between RD and SLI.

In an investigation of the relationship between SLI and RD, Bishop and Adams (1990) report findings from a longitudinal study of children who had been referred for difficulties with language at 3/4 years of age. Children were assessed at several time points: at age 3/4, at age 5 and at age 8. When children were assessed at 8 and a half, it was found that those whose language problems had resolved by age 5 had no difficulties with reading at 8. However, the subset of the original sample who had remaining oral language difficulties at 5 years old had continuing problems with oral language when assessed at 8 and also had difficulties with reading. Findings of increased risk for reading difficulties have also been reported for children initially assessed for SLI in kindergarten and then followed up at first and second grade (Catts, 1993) and also those followed up at fourth grade (Catts, et al., 2002). Interestingly however, Bishop and Adams (1990) found that the reading difficulties of their sample tended to be in the area of comprehension as opposed to reading accuracy. This finding thus suggests that children initially diagnosed with SLI who continue to have difficulties with oral language may go on to develop reading problems consistent with the "poor comprehender" profile, rather than the "dyslexia" profile.

However, the participants from the study reported by Bishop and Adams (1990) were followed up again at 15 years of age and their reading skills subsequently assessed. Thus Snowling, Bishop and Stothard (2000) report findings from 56 adolescents who had been assessed as having a SLI at 3/4 years old. This sample comprised 26 whose language difficulties had resolved by age 5 and 30 for whom language difficulties had still been apparent at age 5. Results found that 43% of the adolescents who had had SLI at four had difficulties with reading accuracy at age 15 and 23% had difficulties with comprehension. Thus while comprehension difficulties had been more prevalent at age eight, accuracy problems were more apparent at age 15. One especially striking finding reported by Snowling et al (2000) is that participants whose language problems had been reported as resolved at age five and who had no reported difficulties with reading at age eight (Bishop & Adams, 1990), had difficulties with word recognition and phonological processing at age 15. This suggests that while initial language problems may appear to be resolved, they can still have a marked impact on subsequent reading proficiency.

Furthermore, children whose difficulties with language are persistent across age are not always those whose difficulties are the most severe initially (Oliver, et al., 2004) suggesting that it is not necessarily possible to identify children who may have ensuing difficulties with reading.

Findings such as these have led some to question the separability of the two disorders. However in a review of the relevant literature pertaining to the behavioural characteristics, the cognitive difficulties, the neurobiology and etiology of both disorders, Bishop and Snowling (2004) argued that while children with RD and SLI may both have impairments with reading, the nature of the difficulties is not equivalent. That is, children with SLI have equivalent difficulties with both phonology and semantics; however children with RD demonstrate deficits with phonological skills in combination with relatively spared semantic skills. Furthermore they suggested that while phonological abilities in combination with other language skills can be a useful way of conceptualising the relationship between RD and SLI, other factors also have a contributory role in the development of reading ability, for example, speed of processing, visual perception and attentional skills. Thus they concluded that SLI and RD are not the same disorder.

Given that there is such a strong relationship between RD and SLI then, it is of little surprise that children with SLI are at an increased risk of behavioural disorders (Oliver, et al., 2004), in particular ADHD (Tomblin, et al., 1997) and attention problems (Snowling, et al., 2006), as these difficulties are commonly reported in children with RD (Menghini, et al., 2009; Tannock, 1998). Furthermore in a study which examined social cognition in children with SLI, Marton and colleagues (Marton, Abramoff, &

Rosenzweig, 2005) suggested that the social difficulties exhibited by children with SLI were indicative of executive function impairments. Thus it seems that SLI may also be related to executive function difficulties (Montgomery, Magimairaj, & Finney, 2010).

7.1.3 Impairments in executive function for children with SLI.

While much evidence has accumulated to investigate the premise that children with SLI have difficulties with phonological memory, not all aspects of executive function have been studied so extensively. Furthermore, while there is evidence that children with SLI have impairments with verbal aspects of working memory (Alloway & Archibald, 2008; Montgomery, 1995, 2000; Montgomery, et al., 2010; Van Daal, Verhoeven, van Leeuwe, & van Balkom, 2008), even after language abilities have been controlled for (Archibald & Gathercole, 2006a), additional explanatory factors have been found to influence findings. For example, Mainela-Arnold and Evans (2005) found that while children with SLI had impaired performance on tasks assessing verbal working memory, that the frequency of the words to be recalled was an influencing factor. That is, children with SLI demonstrated impairments compared to children the same age when asked to recall words which were not used often (i.e. low frequency) but did not differ when asked to recall high frequency words. Thus the stimuli used may have an impact on whether significant impairments in verbal working memory emerge.

In terms of visuospatial working memory, discrepant findings have also emerged. Several studies report that children with SLI show no deficits on visuospatial working memory tasks (Alloway & Archibald, 2008; Archibald & Gathercole, 2006b; Van Daal, et al., 2008). However, contrary to this, Archibald and Gathercole (2006a), for example, reported deficits for the majority of their sample of children with SLI on tasks of visuospatial short term memory. Furthermore, in a series of experiments examining non-verbal executive function performance of children with SLI, Marton (2008) reported deficits on all tasks of visuospatial working memory for children with SLI when compared to TDC. However when the SLI group were subdivided based on parent and teacher ratings of attention skills, it was found that those who had SLI and poor attentional performance were more impaired on the visuospatial working memory tasks than those who had SLI and good attention skills. In addition, the children with SLI and good attention skills had comparable performance to the TDC on two of the tasks of visuospatial working memory. In a subsequent experiment, 25 children with SLI and good attention skills were compared to 25 TDC on the WCST and the TOL. It was found that the group with SLI had significantly poorer performance across all scores derived from the WCST compared to the TDC, that is, more errors and greater number of perseverations. In terms of performance on the TOL, the SLI group had significantly poorer total score, lower accuracy and significantly more rule violations than the TDC group. Thus the results found that attention skills impacted the performance of children with SLI on visuospatial tasks of working memory and also that even when children with SLI had good attention skills, they demonstrated impairments in attention and inhibition. The authors interpreted their findings as suggestive of the fact that inhibition and attention skills can have a great impact on working memory performance of children with SLI and it is unlikely therefore that deficits in executive function shown by children with SLI can be purely attributed to their language deficit. This conclusion is consistent with the premise that deficient attentional control has a negative impact on working memory ability for this population (Ellis Weismer, et al., 1999; Montgomery & Evans, 2009).

Further to this are emerging findings of deficits in attention and inhibition for children with SLI. For example, Bishop and Norbury (2005b) report impaired performance for children with SLI on both verbal and non-verbal inhibition tasks. In an ERP study, Stevens, Sanders and Neville (2006) found evidence for deficits with selective attention for children with SLI using auditorily presented stories. They suggested that their results are evidence that deficits in this area “may predispose, but not condemn, a child to language deficits” (p. 148). Furthermore, Spaulding, Plante and Vance (2008) examined the attentional skills of a group of 23 four year old children with SLI compared to 23 TDC matched for chronological age and gender. Participants were presented with three tasks assessing sustained selective attention but using differing stimuli: visual stimuli, linguistic stimuli and non-verbal auditory stimuli (i.e. keys rattling). Each task had two different conditions: a high load condition and a low load condition. Results found impairments for the linguistic and non-verbal auditory sustained selective attention tasks, but only under the high load condition. Performance was comparable to the TDC under the low load condition. Furthermore, there was no difference between the groups for the visual stimuli regardless of attentional load. This was taken as evidence that while children with SLI may show deficits on tasks of sustained attention, that performance may vary as a function of load and task modality. However, contrary findings to this are reported by Im-Bolter, Johnson and Pascual-Leone (2006). When children with SLI aged between 7 and 12 were compared to a group of TDC matched for age, gender and non-verbal IQ, it was found that they had deficient performance on tasks of attention, irrespective of the modality of the stimuli. Furthermore, the participants with SLI also demonstrated deficits on tasks of inhibition and updating but interestingly, not for tasks assessing shifting (c.f. Chapter Two). Therefore it can be concluded that the executive impairment was not uniform across all aspects of executive function assessed in this study. This is in line with studies which have found unimpaired performance on other aspects of executive function e.g. fluency skills (Bishop & Norbury, 2005a).

To summarise, deficits on tasks assessing working memory, inhibition, attention and updating have been reported for children with SLI, however these deficits are not completely consistent and factors such as load, frequency and modality of stimuli have all been found to contribute to the results. Given that there is such a high degree of comorbidity between SLI and RD then, it is conceivable that executive function deficits identified in children with RD are exacerbated when participants also have comorbid SLI which will influence the nature of the relationship between executive functions and reading in this sample. Thus the present study aims to take account of comorbid language difficulties in this relationship.

7.1.4 Aims.

The study aimed to assess whether the role that executive functions have in predicting reading ability is comparable for children with reading difficulties and those who have reading difficulties and show comorbid language impairment. As previously discussed, high rates of comorbidity make isolating groups of children with RD with no reported comorbid symptomatology exceedingly problematic. Thus the large sample of children with RD recruited for study three and described in Chapter Five were assessed for difficulties with oral language. The group were then categorised into those who had RD and had oral language problems and those who had RD but did not have profound difficulties with oral language. The model previously determined in Chapter Five (model Bi shown in Figure 5.6) was employed for multi-sample SEM in order to assess this. The following research questions were addressed

1) Is the role that executive functions have in predicting reading ability comparable for children with reading difficulties and those who have reading difficulties and show comorbid language impairment (LI versus No LI)?
2) Is the performance of those with LI influenced by the nature of their impairment i.e. whether their difficulties are with expressive and/or receptive language?
3) Do the definitional criteria underpin measurable differences in executive performance i.e. is there a difference between those with an SLI and those with a LI?

7.2 Method

7.2.1 Participants.

The same participants previously described in Chapter Five took part in the present study, categorised into groups based on oral language ability. Using a criteria of one *SD* below the mean on the measure of oral language (total score) to signify oral language problems (Conti-Ramsden, et al., 2001; Johnson, et al., 1999), it was found that 138 (77 male and 61 female) of the participants would have problems with oral language in addition to their difficulties with reading thus comprising the Language Impairment (LI) group[26]. The No Language Impairment (No LI) group comprised the 73 participants (45 male and 28 female) who did not meet this criterion for oral language problems.[27] As the measure of oral language had both a receptive and expressive component, it was possible to categorise participants further based on low performance on these task components. Using criteria of one *SD* below the mean on the expressive component of the oral language measure or on the receptive component of the oral language measure (Conti-Ramsden, et al., 2001; Johnson, et al., 1999), the number of participants to have an expressive problem only and the number to have an expressive and/or receptive problem were calculated. One hundred and nine participants (63 male and 46 female) were thus categorised as having Mixed expressive and/or receptive language problems (the Mixed LI group) and 36 (18 male and 18 female) as having Expressive language problems only (the Expressive LI group)[28][29].

In addition to this initial categorisation, it was possible to classify participants into those with a Specific Language Impairment (SLI) and those without (LI). Using a criteria of a 15 standard score point discrepancy between an oral language score, which was at least one *SD* below the mean, and a non-verbal IQ score above 85, it was found that 52 of the sample (30 male and 22 female) fulfilled the criteria for a SLI and 86 (47 male and 39 female) of those with an oral language score at least one *SD* below the mean did not fulfil this discrepancy criteria (LI). When those who fulfilled the

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[26] 64 of the participants in this group also has significant levels of ADHD symptoms

[27] Data from two participants was removed as multivariate outliers in data screening described in Chapter Five.

[28] These numbers do not directly correspond to those classified as having oral language problem based on low total score as that is a combination of both components not just one component of the oral language measure.

[29] 49 of the Mixed LI Group were ADHD and 15 of the Expressive LI group

discrepancy criteria were examined in isolation (SLI), it was found that 38 of them (23 male and 15 female) could be classified as having Mixed expressive and/or receptive language problems (the Mixed SLI group) and 14 of them (7 male and 7 female) could be classified as having Expressive problems only (the Expressive SLI group)[30].

7.2.2 Instrumentation and procedure.

All instrumentation employed and procedures adopted are described in Chapter Five.

7.3 Results

7.3.1 Descriptive statistics.

Age-corrected standardised scores for the word reading and reading comprehension subtests, for the oral language measures and the non-verbal ability tasks for the LI, SLI and No LI groups are shown in Table 7.1.

As revealed by Table 7.1, the mean word reading and reading comprehension scores of the No LI group were higher than both the SLI and the LI groups. While the same was true for both of the oral language task scores and the block design task as expected, the mean of the SLI group was two standard score points higher than the No LI group for the Matrix reasoning task and more than 12 standard score points higher than the LI group.

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[30] 12 of the Mixed SLI group were ADHD and 4 of the Expressive SLI group

Table 7.1. Mean and standard deviations for reading, oral language and non-verbal ability measures.

	Word reading	Reading comprehension	Receptive language	Expressive language	Block design	Matrix reasoning
SLI (*n*=52)						
Mean	69.90	73.29	5.04	4.23	46.42	46.08
SD	10.83	12.04	1.67	1.23	6.39	6.62
LI (*n*=86)						
Mean	71.59	70.16	5.07	4.44	39.23	33.74
SD	9.45	12.69	1.08	1.66	4.41	7.61
No LI (*n*=73)						
Mean	75.40	85.51	7.89	8.16	46.47	44.14
SD	7.06	11.01	1.42	1.30	7.70	9.88

The mean score and standard deviations for all executive function tasks for each of the three groups can be seen in Table 7.2[31].

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[31] As fluency measures were excluded from the final model, information about these tasks is not included

Table 7.2. Mean and standard deviations for all executive function tasks.

	Verbal working memory	Visuospatial working memory	Verbal inhibition	Non-verbal inhibition
SLI				
Mean	80.37	91.73	7.33	7.77
SD	11.95	15.41	2.37	1.87
LI				
Mean	78.74	84.03	7.96	7.32
SD	11.02	15.30	2.39	2.06
No LI				
Mean	84.76	96.34	8.22	7.95
SD	12.62	13.81	2.36	1.84

As shown in Table 7.2, the No LI group had higher mean scores than both the LI group and the SLI group across all executive function tasks.

7.3.2 Modality differences.

In order to assess whether modality was influencing task performance, paired-sample t-tests were carried out for each aspect of executive functioning assessed for each group. For the SLI group, there was a significant difference between performance on the visuospatial working memory task and the verbal working memory task (t (51) =-4.58, p<0.001, r = .54), however there were no significant differences for the inhibition tasks (p values >0.5). For the LI group, there were significant differences between both the working memory tasks (*t* (84) =-2.81, *p*<0.01, *r*=.29) and the inhibition tasks (*t* (83) =-2.36, *p*<0.05, *r*=.25). Significant modality differences also emerged on the working memory tasks for the No LI group (*t* (72) =-6.28, *p*<0.001, *r*=.59) but not for the inhibition tasks. Thus all groups demonstrated significantly improved performance for the visuospatial working memory task compared to the verbal working memory task.

7.3.3 Model employed.

The final model (Bi) determined in Chapter Five was employed for the present study. This model is illustrated in Figure 7.1.

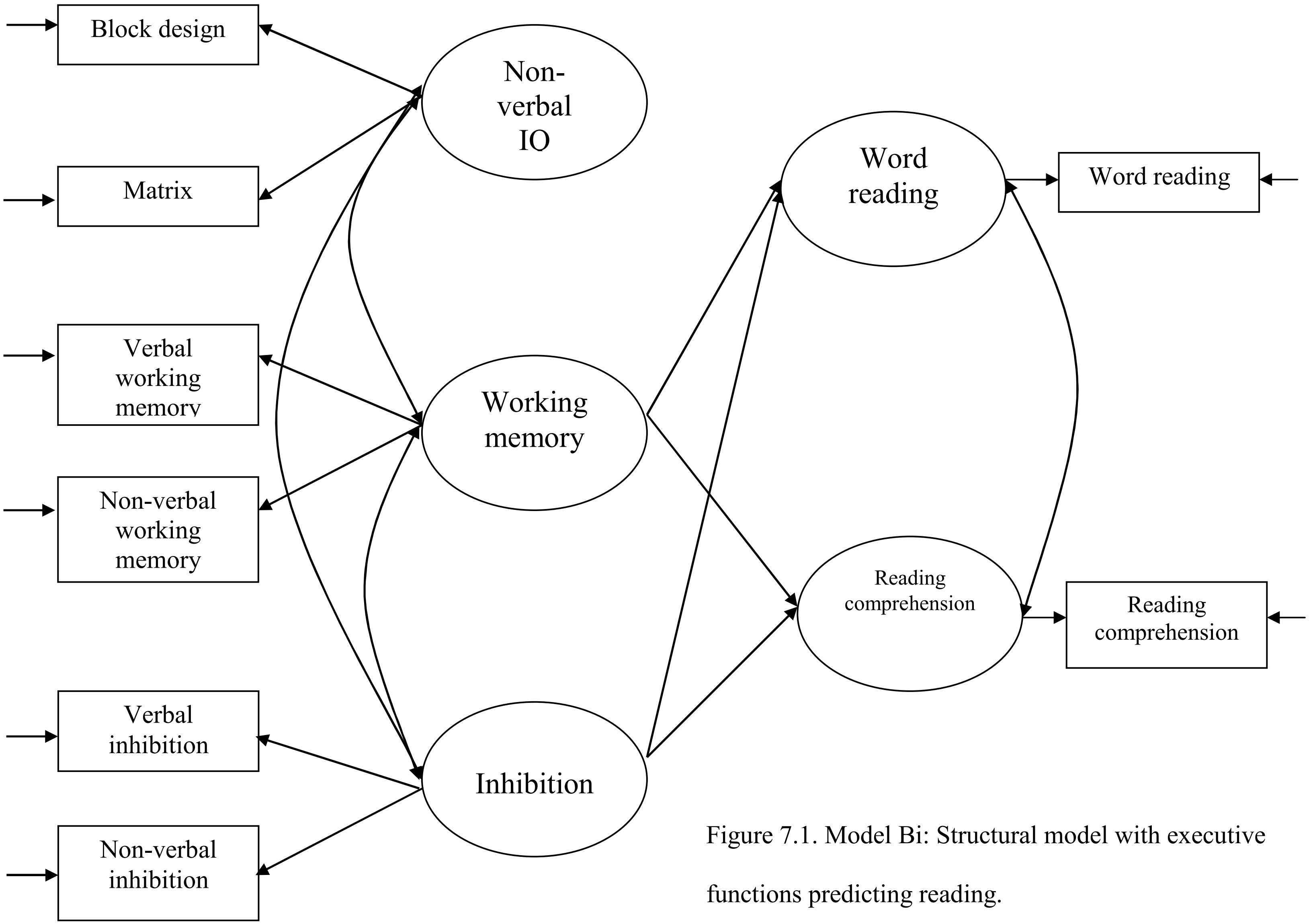

Figure 7.1. Model Bi: Structural model with executive functions predicting reading.

7.3.4 Multi-sample SEM: LI compared to No LI.

In order to address the first research question, multi-sample SEM was carried out comparing all those who fulfilled criteria for a LI (combined LI and SLI groups) to those in the No LI group. The procedure for using SEM to compare groups as outlined in Chapter Five section 5.3.4 was employed. The three factor model illustrated in Figure 7.1 was evaluated as the initial baseline model for each group. This model provided an acceptable level of fit for both the LI group (χ^2=9.48, *df*=12, *p*=0.66, CFI=1.00, TLI=1.04, AIC=7296.37, RMSEA=0.000, 90%CI=0.00-0.07, SRMR=0.037) and the No LI group (χ^2=17.03, *df*=12, *p*=0.15, CFI=0.93, TLI=0.83, AIC=3834.14, RMSEA=0.076, 90%CI=0.00-0.15, SRMR=0.064).

Configural, metric and scalar invariance were each subsequently assessed. The resulting chi-square statistics are shown in Table 7.3.

Table 7.3. Results of the multi-sample SEM for the LI and the No LI group.

	Total χ^2	*df*	χ^2 No LI (*n*=73)	χ^2LI (*n*=138)
Configural invariance	25.76	24	16.38	9.37
Metric invariance	26.23	27	16.72	9.51
$\Delta\chi^2$	0.47	3		
Scalar invariance	28.16	30	17.53	10.64
$\Delta\chi^2$	1.93	3		

Chi-square difference tests were non-significant, revealing that both metric and scalar invariance have been established i.e. the factor structure and intercepts were equivalent for the LI and the No LI groups. Parameter estimates are detailed in Table 7.4.

Table 7.4. Unstandardised and standardised parameter estimates with standard errors in parentheses.

Parameter estimates	Unstandardised	Standardised
Factor structure		
Non-verbal IQ→ Block design (X1)	1.00	0.66 (0.09)***
Non-verbal IQ→ Matrix (X2)	1.47 (0.24)***	0.73 (0.09)***
Working memory → Verbal working memory (X3)	1.00	0.34 (0.09)***
Working memory → Non-verbal working memory (X4)	2.60 (0.79)**	0.81 (0.19)***
Inhibition → Verbal inhibition (X5)	1.00	0.37 (0.11)**
Inhibition → Non-verbal inhibition (X6)	1.19 (0.38)**	0.62 (0.19)**
Word reading → Word reading (X7)	1.00	0.98 (0.003)***
Reading comprehension → Reading comprehension (X8)	1.00	0.97 (0.006)***
Intercepts		
Block design	2.54 (0.86)**	0.35 (0.12)**
Matrix	3.91 (1.14)**	0.40 (0.12)**
Verbal working memory	1.96 (1.26)	0.16 (0.10)
Non-verbal working memory	6.63 (1.63)***	0.49 (0.13)***
Verbal inhibition	0.27 (0.23)	0.11 (0.10)
Non-verbal inhibition	0.46 (0.20)*	0.28 (0.12)*
Word reading	2.97 (0.86)**	0.42 (0.13)**
Reading comprehension	8.67 (1.31)***	0.81 (0.14)***

Note: *$p<0.05$; **$p<0.01$; ***$p<0.001$

Furthermore, as scalar invariance was established, latent mean comparison was possible. As indicated in Table 7.5, there was no significant difference between the LI and the No LI groups for the inhibition latent mean however the means of the non-verbal

IQ and the working memory latent variables were significantly lower for the LI group compared to the No LI group.

Table 7.5. Latent mean comparison for the LI and No LI groups.

Latent mean comparison	No LI	LI	*SE*	*z*-score
Non-verbal IQ	0	-4.05	0.98	-4.11***
Working memory	0	-3.78	1.33	-2.84**
Inhibition	0	-0.45	0.23	-1.90

Note: *p<0.05; **p<0.01; ***p<0.001

In order to compare the structural paths for each group, a model with all of the structural paths freely estimated was compared to a model with a specific path of interest constrained to be equal between groups, e.g. the path from inhibition to word reading was constrained to be equal but all other structural paths were allowed to be free. Each structural path was constrained in turn and the resulting chi-square compared to that when all of the structural paths were free. In each case the delta-chi square was non-significant; that is, there was no difference in model fit when each path was free to when it was constrained to be equal. The unstandardised and standardised parameter estimates for each structural path for both groups when freely estimated are shown in Table 7.6.

Table 7.6. Unstandardised and standardised parameter estimates with standard errors in parentheses for all structural paths for the LI and the No LI groups.

Parameter estimate	Unstandardised(*SE*)	Standardised(*SE*)
LI		
Inhibition → word reading	4.31(1.97)*	0.46(0.18)**
Inhibition → reading comprehension	4.04 (2.13)	0.35 (0.17)*
Working memory → word reading	-0.37(0.55)	-0.12 (0.17)
Working memory → reading comprehension	1.33 (0.73)	0.35 (0.15)*
No LI		
Inhibition → word reading	2.36 (3.55)	0.41 (0.41)
Inhibition → reading comprehension	2.33 (5.43)	0.26 (0.47)
Working memory → word reading	-0.03 (0.52)	-0.02 (0.40)
Working memory → reading comprehension	0.81 (0.83)	0.40 (0.39)

Note: **p*<0.05; ***p*<0.01; ****p*<0.001

Therefore it can be concluded that the regression coefficients from each of the executive function latent variables predicting each aspect of reading were equivalent across groups.

7.3.5 LI: Mixed LI v's Expressive LI.

In order to address research question two, a number of analyses were conducted comparing the Mixed LI group to the Expressive LI group.

7.3.5.1 Executive function task performance.

A one way ANOVA was performed to compare the scores on tasks of executive function of those in the Mixed LI group to those in the Expressive LI group and those in the No LI group. Significant differences emerged for all tasks except the verbal inhibition task (all other F values >3). Post-hoc Tukey tests revealed that there were significant differences between the Mixed LI group and the No LI group on tasks of verbal working memory (*F* (2, 207)=7.70, *p*<0.005; Mixed LI group mean=78.22 *SD* = 10.32, No LI group mean= 85.19 *SD*=12.77), non-verbal working memory (*F* (2, 207)=15.24, *p*<0.001; Mixed LI group mean=84.96 *SD* = 15.81, No LI group mean= 97.37 *SD*=13.27) and non-verbal inhibition (*F* (2, 207)=7.08, *p*<0.005; Mixed LI group mean=7.20 *SD* = 2.04, No LI group mean= 7.95 *SD*=1.73). Furthermore significant differences in task performance emerged between the Mixed LI group and the Expressive LI group on tasks of non-verbal working memory (Mixed LI group mean=84.96 *SD* = 15.81, Expressive LI group mean= 92.88 *SD*=13.96) and also non-verbal inhibition (Mixed LI group mean= 7.20 *SD* = 2.04, Expressive LI group mean= 8.44 *SD*=1.73).

7.3.5.2 MIMIC model: Mixed LI or Expressive LI group predict latent means.

To evaluate whether the nature of the language impairment influenced the executive function latent means identified in Figure 7.1, a MIMIC model was assessed with type of language impairment (i.e. Mixed LI or Expressive LI) coded as a categorical predictor of the executive function latent variables. Overall, the model did not provide an acceptable level of fit (χ^2 =59.71, *df* =21, *p*<0.0001, CFI=0.74, TLI=0.55, AIC=8372.98, RMSEA=0.12, 90%CI 0.08-015, SRMR=0.12) thus indicating that controlling for type of language impairment did not improve the model fit. The unstandardised path estimates and standard errors are illustrated in Figure 7.2 however, for diagrammatical clarity indicator variables and errors are not included.

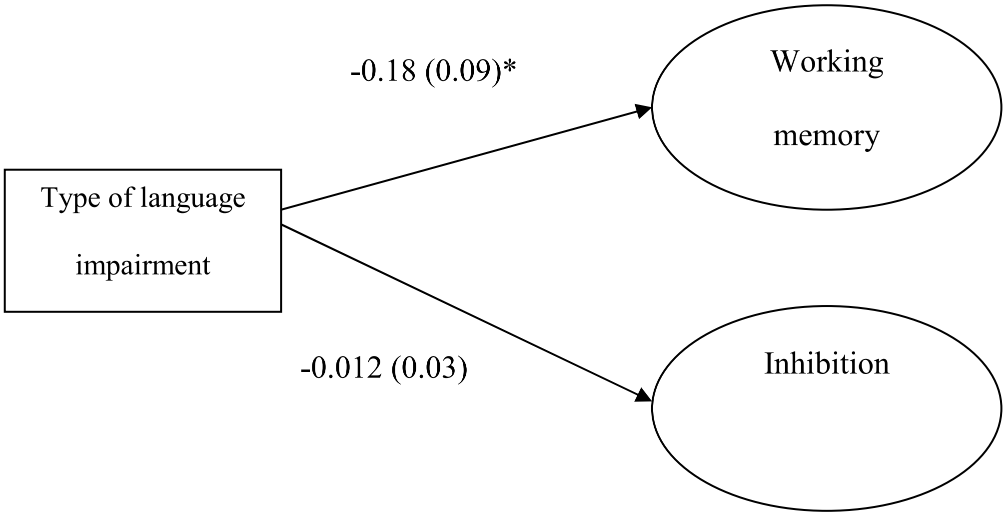

Figure 7.2. MIMIC model with type of language impairment as a covariate.

Inspection of the unstandardised path coefficients demonstrates that the type of language impairment significantly predicted the mean of the working memory latent variable but not the inhibition latent variable. As the Mixed LI group were coded 0 and Expressive LI group coded as 1, the path coefficients show that those in the Expressive LI group have a lower mean on the working memory latent variable than those in the Mixed LI group (T. A. Brown, 2006; Kline, 2005)[32]. That is, that the Mixed LI group have a working memory mean 0.18 higher than the Expressive LI group[33]; however caution must be taken as the overall model fit was not acceptable.

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[32] See Kline (2005, p.310) and also Brown (2006, p.313) for interpretation

[33] Following procedure identified in Brown (2006) modification indices were inspected. No modification indices >4 were identified involving the group variable thus no direct effects on any indicator variables were identified.

7.3.6 SLI.

In order to address research question three, a number of analyses were performed which compared those in the SLI group to those in the LI group.

7.3.6.1 Logistic regression predicting SLI or LI.

Logistic regression analysis was carried out using performance on tasks of executive function as predictors of whether participants were in the SLI group or the LI group. The overall model fit was significant ($\chi^2 = 12.93$, *df* = 4, $p<0.05$). The model accounted for between 9.1% and 12.3% of the variance with 66% of the sample correctly classified. The resulting beta coefficients and Exp B statistics are presented in Table 7.7.

Table 7.7. Results of logistic regression predicting either SLI or LI.

			95% CI for Exp B	
	B (*SE*)	Exp B	Lower	Upper
Constant	3.44(1.69)	31.07		
Verbal working memory	-0.005 (0.17)	1.00	0.96	1.03
Non-verbal working memory	-0.032 (0.01)*	0.97	0.94	0.99
Verbal inhibition	0.18 (0.09)*	1.20	1.01	1.43
Non-verbal inhibition	-0.15 (0.11)	0.86	0.70	1.06

Note: *$p<0.05$, ** $p<0.01$, *** $p<0.001$; [SLI=0, LI=1]

When all of the predictors were entered simultaneously, only performance on the non-verbal working memory and the verbal inhibition task significantly distinguished between the groups. Table 7.7 demonstrates that a one unit increase in non-verbal working memory increased the likelihood of membership of the SLI group rather than the LI group (a decrease in the odds of being in the LI group by a factor of 0.97) and a one unit increase in the verbal inhibition task increased the likelihood of being in the LI group rather than the SLI group (increase in odds of 1.2). No difference was found when tasks were entered in pairs (i.e. both working memory tasks or both inhibition tasks) using a step-wise procedure, that is, only non-verbal working memory and verbal inhibition task performance continued to be a significant predictor when the other variables were entered, regardless of the order in which the blocks were entered into the model.

7.3.6.2 MIMIC model: SLI or LI group predict latent means.

A MIMIC model was evaluated to see if those in the SLI group differed on latent means from those in the LI group. Definitional criteria was entered as a categorical predictor of the executive function latent variables (illustrated in Figure 7.3) with SLI group coded as 0 and LI group coded as 1.

Overall, the model did not provide an acceptable level of fit (χ^2= 55.28 *df* = 21 *p*= 0.001, CFI = 0.76 TLI = 0.59, AIC=7951.63, RMSEA = 0.11 90% CI 0.076-0.15, SRMR=0.12) thus indicating that controlling for definitional criteria did not improve the model fit. The unstandardised path estimates and standard errors are illustrated in Figure 7.3 however, for diagrammatical clarity indicator variables and errors are not included.

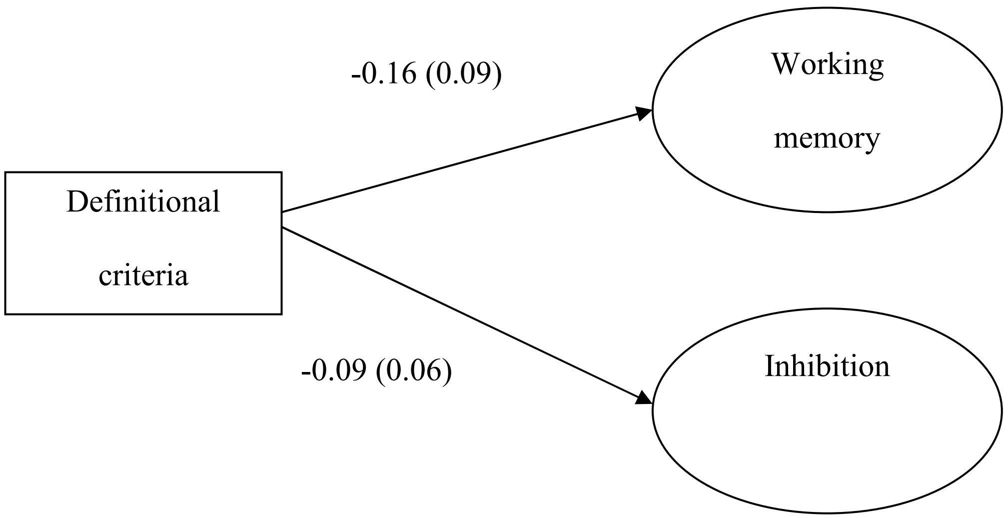

Figure 7.3. MIMIC model with definitional criteria as a covariate.

Inspection of the unstandardised path coefficients demonstrates that the definitional criteria used did not significantly influence the executive function latent variables, that is, there was no difference between those who were categorised as having a SLI or those with a LI.

7.3.6.3 Assessing task performance in the Mixed SLI group and the Expressive SLI group.

Performance on the executive function tasks for the Mixed SLI group and the Expressive SLI group was subject to comparative analysis. Independent t-tests found no statistically significant differences in executive function task performance between these groups (all p values >0.05) implying that the nature of the language impairment did not influence tasks performance for those who met criteria for a SLI.

7.4 Discussion

To summarise the results, performance on working memory tasks involving verbal material were found to be more impaired than performance on visuospatial working memory tasks for all participants, regardless of comorbidity with language difficulties. Multi-sample SEM was carried out to assess whether the relationship between the executive function latent variables and reading was the same for those with a LI and those with No LI. The model was comparable between groups and the strength of the relationship between executive functions and reading was equivalent. When latent means were compared, the LI group were significantly lower on the working memory and non-verbal IQ latent means.

When the type of LI was evaluated, it was found that the Mixed LI group scored significantly lower on the verbal and non-verbal working memory tasks and the non-verbal inhibition task than the No LI group. Furthermore, the Mixed LI group also demonstrated lower performance than the Expressive LI group on the non-verbal working memory task and the non-verbal inhibition task. When the type of LI was used to predict the executive function latent means, it was found that it was a significant predictor of working memory only; however caution must be exercised as the overall model fit was not acceptable with the addition of this predictor.

The impact of definitional criteria was also assessed and it was found that as performance on the non-verbal working memory task increased, participants were more likely to be in the SLI group. In addition, as performance on the verbal inhibition task increased, participants were more likely to be in the LI group. When this criterion was used to predict the executive function latent variables, no differences were found. Furthermore, there was no difference in executive function task performance between those with a Mixed SLI and those in the Expressive SLI group.

7.4.1 Executive functions and comorbidity.

The results of the study found that those participants who had RD and comorbid difficulties with oral language demonstrated no differences in the extent to which executive functions predicted reading than those participants who had difficulties with reading only. However, it was found that the comorbid group had additional difficulties in working memory and non-verbal IQ. In regards to the deficit in non-verbal IQ, initially this may appear unexpected given that the demands placed on participants' expressive language skills are reduced when using non-verbal IQ tasks. However, as all tasks place demands on participants' receptive language skills as a consequence of having task instructions and rules to be followed, this is perhaps more expected than initially believed. This finding supports previous studies such as those of Botting (2005), whose results demonstrate that language impairment can have a detrimental impact on IQ performance, even when using tasks which appear non-verbal in nature (Leonard, 1999).

In regard to the more pronounced deficit in working memory for those with RD and comorbid language difficulties compared to those with only RD, this is supportive of the extant literature which suggests deficits on working memory for children with language difficulties (Alloway & Archibald, 2008; Archibald & Gathercole, 2006a; Mainela-Arnold & Evans, 2005; Montgomery, 1995, 2000; Montgomery, et al., 2010; Van Daal, et al., 2008). Deficient performance on tasks of non-word repetition has often been used to demonstrate difficulties with phonological memory (Dollaghan & Campbell, 1998). Catts and colleagues (Catts, et al., 2005) however suggested that deficits in non-word repetition may be indicative of comorbid difficulties with reading rather than SLI per se. It is plausible therefore that reported deficits in working memory actually signify comorbidity; the results of the present study certainly support this conclusion. Further to this, in a longitudinal study of children initially diagnosed as having SLI at age three and four, Snowling and colleagues (Snowling, et al., 2000) reported that at 15 years old, 43% of the sample had deficits with reading accuracy and 23% had difficulties with reading comprehension. While this may signify a high degree of overlap between the two disorders, Bishop and Snowling (2004) argue that the difficulties with reading of children with SLI are qualitatively different from those with RD; these conclusions come from the fact that children with RD have phonological difficulties whereas those with SLI have both phonological and semantic difficulties. Children with RD therefore, are able to use both semantic and syntactic information to compensate for their phonological deficits. While the extent to which working memory and inhibition were important for reading was not found to vary between participants with RD and those with comorbid LI, those with comorbid LI were more impaired on working memory. If the ability to use semantic cues is related to working memory processes, then the additional semantic deficits faced by those with comorbid RD/LI are perhaps causally related to working memory impairments, difficulties which are also thought to signify comorbidities. This proposition is consistent with previous results such as those of Montgomery and Evans (2009) who argued that the comprehension problems exhibited by children with SLI can be attributed to limitations in working memory capacity.

Reports in the literature concerning deficits in non-verbal working memory for children with SLI have been less conclusive than reports of verbal working memory deficiencies. For example, while several studies have reported no deficits on visuospatial working memory tasks (Alloway & Archibald, 2008; Archibald & Gathercole, 2006b; Van Daal, et al., 2008), other studies have reported impaired performance (Archibald & Gathercole, 2006a; Marton, 2008). While the present study found that verbal working memory performance was more depressed than visuospatial working memory performance, the mean score on the visuospatial task was still significantly lower than would be expected for a typically developing group of participants, where a mean score of 100 would be the norm. The use of latent variable analysis in the present study reduces the impact of task demands and implies deficits in the underlying processes of working memory, not impairments which are causally related to task modality. This therefore precludes arguments that the deficits in working memory exhibited by children with difficulties with oral language are due purely to the language demands of the tasks. This is consistent with results presented by Marton (2008) who argued that children with SLI demonstrate impairments in executive function which are irrespective of their language difficulties. Further to this, however, are suggestions that deficient working memory performance of children with SLI is related to inhibition and attention skills (Ellis Weismer, et al., 1999; Marton, 2008; Montgomery & Evans, 2009).

There are emerging reports in the literature concerning deficits in inhibition for children with SLI (Bishop & Norbury, 2005b; Im-Bolter, et al., 2006; Stevens, et al., 2006). The present study however found that participants with comorbid RD/LI had no additional impairments with inhibition than participants with RD only. This suggests that deficits reported in inhibition may reflect underlying RD rather than difficulties specific to those with impairments in language. However, Spaulding and colleagues

(Spaulding, et al., 2008) investigated sustained attention in children with SLI using visual, linguistic and non-verbal auditory stimuli. They reported impaired performance when linguistic and non-verbal auditory stimuli were employed but only under high load conditions, suggesting that deficient performance is a function of stimuli and attentional load. While the sustained selective attention tasks place strong demands on participants' inhibition abilities, the tasks' requirements implicate skills different from the type of prepotent response inhibition required for tasks in the present study. However given the variation in results reported due to load, it may be that the tasks in the present study did not involve sufficient load to detect any impairments for the comorbid group. While this is one possible interpretation, as the participants in the study reported by Spaulding and colleagues were distinctly younger than those in the present study (i.e. 4 years old), it is possible the impact of attentional load has dissipated and in fact that deficits in inhibitory skills reflect RD rather than LI. Future research involving inhibitory tasks with both high and low load would help to disambiguate this finding.

7.4.2 Does the nature of the language impairment have an impact?

Differences in task performance were found depending on the nature of the language impairment of those in the RD/LI group. Those in the Mixed LI group were more impaired than participants in the Expressive LI group on non-verbal inhibition and non-verbal working memory tasks. What is of particular interest is the fact that the groups showed comparable performance on the language based tasks. As the two groups were distinguished based on receptive language scores, differential performance would be expected on the tasks which overtly implicate language ability. As performance differences were found for the non-verbal tasks, this illustrates that these tasks implicate receptive language skills more than the other tasks. Therefore these results suggest that severity of language difficulty affects performance on non-verbal cognitive tasks. In addition to differences in task performance, the type of impairment that participants had predicted the mean of the working memory latent variable, but not the other latent variables. However as the model did not provide an acceptable level of model fit this result should be interpreted with caution.

These results are consistent with previous demonstrations that children with language impairment incorporating receptive difficulties are those most severely affected and at greater risk for continued difficulties (Law, Boyle, Harris, Harkness, & Nye, 2000). In addition, children with expressive-receptive language difficulties have shown little benefits from interventions (e.g. Boyle, McCartney, O'Hare, & Law, 2010; W. Cohen, et al., 2005). It has been suggested that training in working memory which targets visuospatial aspects may be of the highest utility for children with SLI (Montgomery, et al., 2010), however as results of the present study have shown those with Mixed receptive-expressive difficulties to be more impaired than those with expressive only problems on visuospatial tasks, it is unclear whether there may be differential benefits associated with such targeted training. Therefore future research incorporating visuospatial stimuli should consider the nature of the language difficulties of participants.

7.4.3 Definitional criteria.

Improved performance on the non-verbal working memory task indicated participants were more likely to be in the SLI group whereas better performance on the verbal inhibition task signified membership of the LI group. In regard to working memory, by definition the group of children with SLI have higher non-verbal IQ scores. As there is a significant correlation between non-verbal IQ and working memory, and as tasks of non-verbal IQ are thought to implicate working memory skills, it is intuitive to suggest that the difference reported for non-verbal working memory is in part reflective of the definitional criteria used.

But increased performance on the verbal task of inhibition reported for those in the LI group is more difficult to explain. The use of latent variable analysis explicitly reduces the impact of task demands and instead allows for an understanding of the underlying processes involved. When a term for definitional criteria was included as a covariate, no differences in latent means were found, suggesting that the use of discrepancy criteria for language impairment does not add to an understanding of the underlying cognitive processes which were assessed. As the addition of the covariate depreciated the model fit, results must be interpreted with caution, however; they could be interpreted as being supportive of suggestions against the use of specificity criteria, that is, against the use of non-verbal IQ in the diagnosis of SLI (Boyle, 2010).

7.4.4 Limitations.

One potential limitation of the present study concerns the use of only one measure of oral language to measure difficulties. The Word Classes subtest from the CELF 4 ^{uk} (Semel, et al., 2006) comprises both an expressive and a receptive component and has the greatest correlation with core language score from those available in the CELF 4 ^{uk} . Thus it provides an accurate and robust assessment of difficulties with both receptive and expressive oral language for research purposes. The full range of separate subtests assessing each aspect of oral language from the CELF 4 ^{uk} was not employed due to the existing and substantial burden of assessment imposed on participants in the present study. Furthermore, in a meta-analysis of the literature aimed to estimate the prevalence of SLI, Law and colleagues (Law, et al., 2000) noted that there was little substantive difference between studies which had employed composite scores based on a number of different assessment tasks and those which used single language measures incorporating different aspects of language, as in the present study; this therefore provides justification for the use of a single assessment task.

7.4.5 Conclusions.

In conclusion, the present study found that the degree to which executive functions accounted for reading ability in a sample of children with RD was not influenced by whether children had additional difficulties with oral language. However, participants who did have comorbid RD and language difficulties had more severe difficulties with working memory and non-verbal IQ that those with RD only. Furthermore, those whose oral language difficulties involved receptive language had more pronounced difficulties with non-verbal tasks of executive function than those whose difficulty was restricted to expressive aspects.

Johnson and colleagues (Johnson, et al., 1999) argued against the use of exclusionary criteria which are commonly employed by researchers when investigating LI. They suggested that as many children with LI have comorbid difficulties and difficulties with language which may be secondary in nature, clinicians rarely encounter children with isolated impairments. This thus makes it essential that they have an understanding of the differential nature of these comorbidities. By investigating one of the most prevalent comorbidities related to language difficulties, that between RD and language impairment, the present study goes some way to address this issue and suggests that there may be underlying cognitive difficulties which should be taken into consideration.

Chapter Eight

Study 3.4: The Additive Risk of Reading Difficulties

8.1. Introduction

Chapters Six and Seven explore the relationship between RD and comorbid conditions; that is RD with ADHD symptomatology or oral language difficulties respectively. However, a number of participants had more than one additional area of difficulty and fulfilled criteria for oral language difficulties and ADHD symptomatology, as well as the RD for which they were recruited. This chapter explores the possibility that these comorbid conditions may combine to increase the severity of reading difficulties using the additive risk model (Dodge & Pettit, 2003).

8.1.1 An additive risk model.

The principle of additive risk states that the more risk factors are present, the greater the chances of an outcome occurring (Rutter, Cox, Tupling, Berger, & Yule, 1975; Rutter, Yule, et al., 1975); that is, there is a linear increase in the probability of an outcome in relation to the increase in risk factors, such that a single risk factor is not as predictive as several factors. This principle has been applied to a number of complex psychosocial problems including behavioural difficulties in children and adolescents (B. P. Ackerman, Schoff, Levinson, Youngstrom, & Izard, 1999; Deater-Deckard, Dodge, Bates, & Pettit, 1998; Jessor, Van Den Bos, Vanderryn, Costa, & Turbin, 1995). Indeed, Dodge and Pettit (2003) proposed a biopsychosocial model of conduct problems in adolescence. This model implies that biological disposition and sociocultural context place some children at risk of developing conduct problems; however this risk is influenced by life experiences. By employing the principles of the additive risk model they suggested that children with several characteristics, such as problematic temperament and history of physical abuse, were at increased risk of developing conduct problems.

In their analysis of the outcome of language difficulties, Whitehurst and Fischel (1994) proposed that the number of language areas impaired and the child's age predict school outcome in an additive fashion. For example, a four year old child with impairments in semantics, vocabulary, syntax and phonology would be at increased risk of negative school outcome compared to a two year old with difficulties in phonology only. The authors argued that while taking cost-benefit analysis into account, that the additive risk model may be beneficial when treatment provision is being considered.

8.1.2 Additive risk for RD.

Wolf and Bowers (1999) applied the additive risk model to their double deficit hypothesis of RD. This hypothesis holds that deficits in the phonological system and in naming speed represent two separable and independent causes of RD and that children with impairments in both areas will have the most severe difficulties with reading. Support for this model was reported by Compton, Defries and Olson (2001), who evaluated the double-deficit hypothesis of RD in relation to written language. Four hundred and seventy six participants with RD with a mean age of 11 years were assessed on a comprehensive battery of tasks assessing phonological awareness, rapid automatised naming (RAN), word and non-word reading, orthographic processing, reading comprehension and spelling. Their results found that those participants with double deficits in both phonological processes and RAN were more impaired than participants with single areas of difficulty on tasks of reading and spelling.

However, there are some findings which are inconsistent with the double deficit hypothesis. In a review of the evidence, Vukovic and Siegel (2006a) concluded that there was limited support for a deficit in naming speed which was independent of the phonological difficulties encountered by children with RD. As the double-deficit hypothesis argues that these processes are separable, this questions one of the main underlying principles. However, Vukovic and Siegel (2006a) suggested that there is tentative evidence in favour of the proposition that children with impairments in both areas demonstrate the most severe impairments with reading, although caution that statistical artefacts may be contributory. Therefore, while there is a lack of evidence supporting the double deficit hypothesis per se (Cain, 2010), the principles of the additive risk model have not been refuted.

8.1.3 The present analysis.

In terms of the additive risk model, if comorbidity between RD and one further developmental condition predicts the severity of a child's difficulty with reading, then it follows that comorbidity with multiple conditions will be predictive of increased impairment in RD. The present analysis will therefore explore whether the number of comorbid conditions does indeed predict the severity of children's RD and whether executive function tasks performance is also impacted by the number of comorbid conditions.

8.2 Method

All methodology employed is described in Chapter Five. Classification of participants into those who were had significantly high levels of ADHD symptoms is described in

Chapter Six and Chapter Seven describes the procedure for classifying participants as SLI or LI.

8.3 Results

The number of participants to fulfil criteria for each diagnostic category is illustrated in Table 8.1. Furthermore Table 8.1 reveals the number of participants to have more than one area of difficulty.

Table 8.1. Number of participants with each area of difficulty

Area of difficulty	*N* (%)
RD only	38 (18.4%)
RD and ADHD	34 (16.4%)
RD and LI	39 (18.8%)
RD and SLI	34 (16.4%)
RD, LI and ADHD	46 (22.2%)
RD, SLI and ADHD	16 (7.7%)
Total	207 (100%)
One area of difficulty (RD)	38 (18.4%)
Two areas of difficulty	107 (51.7%)
Three areas of difficulty	62 (30.0%)

As revealed in Table 8.1, while over 50% of the sample employed in study three had RD and a comorbid condition, 30% had two comorbid conditions. Thus a third of the sample employed had RD plus high levels of ADHD symptomatology and oral language difficulties. This is further illustrated in Figure 8.1.

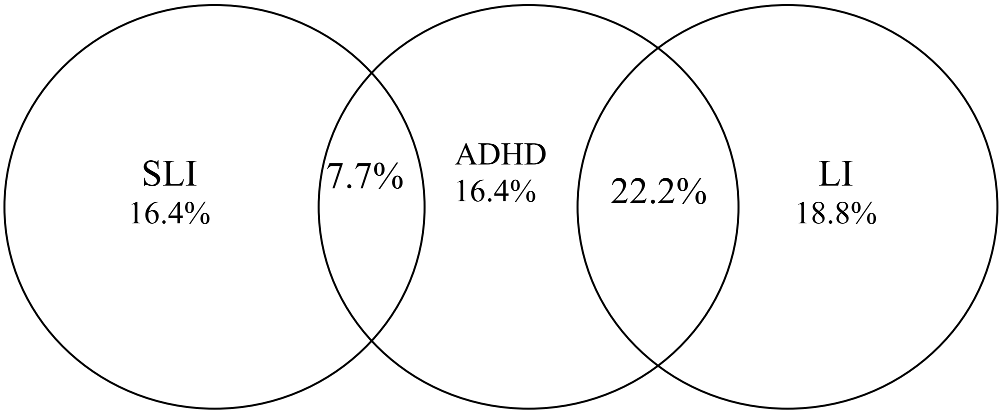

Figure 8.1. Venn diagram illustrating number of participants with each comorbid condition.

Mean word reading and reading comprehension scores for participants who have one condition, two conditions and three conditions are shown in Table 8.2.

Table 8.2. Mean (*SD*) word reading and reading comprehension scores per condition

	One condition	Two conditions	Three conditions
Word reading	75.71 (7.58)	72.25 (9.43)	70.65 (9.75)
Reading comprehension	83.95 (12.50)	76.23 (13.60)	71.61 (12.69)

As shown in Table 8.2, the mean reading scores were lower for participants who had more than one condition. Mean scores for each of the working memory and inhibition tasks are shown in Table 8.3.

Table 8.3. Mean (*SD*) executive function task scores per condition

	One condition	Two conditions	Three conditions
Verbal working memory	81.46 (11.47)	82.58 (12.86)	78.84 (10.96)
Visuospatial working memory	97.81 (14.25)	89.44 (15.46)	87.52 (15.56)
Verbal inhibition	8.21 (1.70)	8.06 (2.74)	7.49 (1.94)
Non-verbal inhibition	8.29 (1.29)	7.56 (2.12)	7.46 (1.95)

Table 8.3 reveals a similar pattern for executive function task scores; participants with a greater number of comorbid conditions had lower means scores on all tasks.

In order to explore whether the number of comorbid conditions influenced the severity of reading difficulty, two separate regression analyses were performed: one with word reading as the criterion variable and one with reading comprehension. Dummy variables were created, with one dummy variable representing those who had two areas of difficulty and the other representing those who had three areas of difficulty.

When word reading was included as the criterion variable a significant model emerged (F (2, 204) =3.58, p<0.05). This model explained 2% of the variation in word reading scores (Adjusted R^2 = .024). Information regarding predictor variables included in the model is illustrated in Table 8.4.

Table 8.4. Beta coefficients obtained when predicting word reading

Variable	B	*SE* B	β
Two areas of difficulty	-3.46	1.74	-0.19*
Three areas of difficulty	-5.07	1.90	-0.25**

Note: *$p<0.05$; **$p<0.01$; ***$p<0.001$

The standardised beta coefficients shown in Table 8.4 reveal that the more areas of difficulty a participant had the more severe their difficulty with reading was. Indeed, when participants had difficulties in two areas word reading decreased by 0.19 units, however when participants had three areas of difficulty, word reading decreased by 0.25 units.

When reading comprehension was employed as the criterion variable a similar pattern emerged. A significant model was found (F (2, 204) = 10.38, $p<0.001$) which explained some 8% of the variation in reading comprehension scores (Adjusted R^2 = .083). Table 8.5 contains information regarding the predictor variables included.

Table 8.5 Beta coefficients obtained when predicting reading comprehension

Variable	B	*SE* B	β
Two areas of difficulty	-7.71	2.48	-0.28**
Three areas of difficulty	-12.33	2.71	-0.41***

Note: *$p<0.05$; **$p<0.01$; ***$p<0.001$

As with the prediction of word reading, the standardised beta coefficients in Table 8.5 reveal that reading comprehension scores were predicted to decrease as the number of areas of difficulty increased. When participants had two areas of difficulty, reading comprehension scores decreased by 0.28 units, but when they had three areas of difficulty reading comprehension scores decreased by 0.41 units. Therefore it can be concluded that comorbidity predicted severity of reading problem regardless of which aspect of reading was being predicted.

In order to determine whether executive function task scores varied as a function of the number of comorbid conditions a participant had, a one way ANOVA was performed[34]. No significant difference in task score was found for participants with one, two or three conditions on the verbal working memory task and both of the inhibition tasks (all *p*-values >0.05). However a significant difference in task score was found for the visuospatial working memory task: *F* (2, 203) = 5.78, *p*<0.01. Post-hoc Tukey tests revealed that participants with one condition (mean = 97.81, *SD* = 14.25) scored significantly higher than participants with two conditions (mean = 89.44, *SD* = 15.46; *p*<0.05) and participants with three conditions (mean = 87.52, *SD* = 15.56; *p*<0.01), however there was no statistically significant difference between task score for participants with two and three conditions (*p*>0.05). The results therefore demonstrate that comorbidity is related to differential executive function task performance, but that it is limited to specific tasks.

8.4 Discussion

The present analysis has demonstrated that reading ability decreases as the number of areas of difficulty increases. That is, participants who had RD, ADHD symptoms and

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[34] As there are four continuous outcome variables, four separate regression analyses would have to be performed and as analysis should be performed with the executive function tasks predicting comorbid conditions and vice versa, this would substantially increase the number of comparisons being performed and increase the likelihood of type 1 error. While this analysis can be performed using SEM, due to the small group sizes this was not possible in the present chapter.

oral language difficulties were more impaired in reading than participants who only had RD with one comorbid condition and indeed participants who only had RD. Thus the severity of a child's difficulties with reading is influenced by the number of comorbid conditions which a child has. While visuospatial working memory task performance was found to decrease when participants had RD and a comorbid condition, there was not a significant linear decrease as the number of comorbidities increased. Thus while the findings indicate that executive function task performance may be related to comorbidities, the results are not conclusive. In terms of severity of RD however, these findings are consistent with the propositions of additive risk made by Rutter and colleagues (Berger, Yule, & Rutter, 1975; Rutter, Cox, et al., 1975; Rutter, Yule, et al., 1975) in their examination of behaviour difficulties and psychiatric problems in children; an outcome is more likely if more risk factors are present (Dodge & Pettit, 2003).

Previous hypotheses concerning the underlying principles of additive risk as applied to RD in the double-deficit hypothesis of Wolf and Bowers (Wolf & Bowers, 1999) demonstrate that impairments across multiple areas are associated with the most severe impairments in reading. While the present analysis does not explicate controversies surrounding the double-deficit hypothesis as a causal understanding of RD (Vukovic & Siegel, 2006a), it is consistent with the understanding that severity of impairment is related to increasing areas of deficit (Compton, et al., 2001); a finding mirrored in studies of language impairment (Whitehurst & Fischel, 1994) and conduct problems (B. P. Ackerman, et al., 1999; Deater-Deckard, et al., 1998; Dodge & Pettit, 2003; Jessor, et al., 1995).

Whitehurst and Fischel (1994) advocate that additive risk models be consulted within the context of cost-benefit analysis when determining treatment provision for language difficulties. While they concede the subjective nature of deciding on treatment and intervention, they argue that while following the principle of additive risk which suggests that children with impairments across a range of areas of language will have poorer outcomes at school than children with fewer numbers of affected areas, it is more justifiable to provide effective treatment to a child with wider language impairments than to provide treatment which is not known to be effective to a child with less expansive difficulties. As the present chapter demonstrates that children with RD and a comorbid condition will have more severe RD than a child with RD only and that the severity of the RD will increase as the number of comorbid conditions increase, the present findings therefore suggest that practitioners should take account of this additive risk when determining intervention for RD. One possibility is that children with comorbid difficulties and thus more severe RD would benefit more from intervention than children with RD only, although this will be impacted by the responsivity to intervention of children with such difficulties (see section 8.4.1 for further discussion).

8.4.1 Limitations and future directions.

One limitation concerning the present analysis is that while the severity of RD was found to be predicted by the number of comorbid conditions, it was not possible to assess whether the extent to which the executive function latent variables identified in Chapter Five as predictive of reading level were influenced by the number of comorbid conditions. Multi-sample SEM of all three of the groups identified in the present chapter would go some way towards increasing our understanding; however due to the small number of participants in each group this was not possible in the present thesis. Further research involving increased numbers of participants would allow for such an evaluation.

In addition, as previous research has advocated that additive risk models may inform decision making regarding the provision of treatment and intervention (Whitehurst & Fischel, 1994), a further avenue for investigation concerns the response to intervention. If participants with difficulties across a number of areas have more severely impaired RD than those with a single impairment, differential response to treatment may be found. As such this may have implications for which children are involved in intervention programmes and who may receive additional learning support. As intervention may be limited within a cost benefit framework, an evaluation of whether children with RD and comorbid difficulties respond to treatment in the same way as children with RD only would benefit practitioners when making decisions regarding which children receive an intervention. While the present study has determined that comorbidity influences severity of RD, without a complete understanding of how children respond to treatment it is not possible to advocate whether this should impact on the treatment decision.

8.4.2 Conclusion.

The present chapter demonstrates the additive risk of having RD and comorbid conditions; the more areas of difficulty a child has, the more severely impaired their reading ability will be. While these findings do not indicate whether children with increased difficulties will respond differently to intervention, they do highlight that practitioners should be aware of the increased difficulties which may be encountered by children who have a number of areas of impairment.

Chapter Nine

General Discussion

The present thesis aimed to evaluate the explanatory role that executive functions have in children's RD, through a series of three studies investigating nine research questions. A meta-analysis of previous research was presented in Chapter Two which concluded that children with RD have a general impairment with executive functioning. However this impairment was found to vary as a function of assessment task suggesting that the impairment may not be uniform across all aspects of executive function. Furthermore, this impairment was influenced by a number of moderator variables, including the definitional criteria used to determine RD. That is, for some tasks, children whose RD was diagnosed based on a discrepancy between IQ and reading attainment were less impaired compared to TDC than children whose diagnosis was based on low reading level alone. However this pattern of results was not found for all tasks, suggesting that there may be little fundamental difference in executive function profile between these diagnostic categories. In addition, there was no difference in the magnitude of effect size found when comparing children with RD-WR to those with RD-RC; although due to the disparate sample sizes this finding cannot be seen as unequivocal. The modality of the assessment task employed also influenced the magnitude of effect found, as children with RD were more impaired on tasks which required a verbal response. However, large effect sizes were still obtained when non-verbal tasks were employed, indicating that the executive impairment could not be solely attributed to the verbal demands of the tasks.

The second study of the thesis was presented in Chapters Three and Four. Chapter Three evaluated how far working memory and inhibition predicted reading in a heterogeneous group of children and whether this was independent of the role of FSIQ. Furthermore, differences in regard to whether word reading or reading comprehension ability were being predicted were also evaluated. Results found that both inhibition and IQ independently predicted word reading, but that working memory was not a unique predictor. However, when reading comprehension ability was being predicted both inhibition and working memory made unique contributions, but not when FSIQ was also included. These results therefore demonstrate that executive functions and FSIQ are distinct processes that have a differential impact on reading ability; one which varies depending on the aspect of reading being assessed.

When the participants in study two were differentiated based on reading ability (i.e. an RD group, an age matched group and a reading level matched group) performance on tasks of inhibition and working memory which required a verbal response significantly discriminated between each of the groups, with lower task performance being associated with the RD group. However, when non-verbal tasks were employed, only inhibition task performance discriminated between the groups. In addition, the non-verbal model was a more sensitive predictor of reading group. This was indicative of a more pervasive deficit in inhibition for children with RD, one which was not attributable to slower developing reading skills and which was independent of the influence of non-verbal IQ. Furthermore, those who fulfilled non-verbal IQ/achievement discrepancy criteria did not differ from those who did not on executive function task performance, supporting the findings of Chapter Two.

Study three moved on from looking at specific task performance and employed latent variable analysis as a means of reducing the impact of task impurity and evaluating the underlying executive processes. The initial analysis of study three, as presented in Chapter Five, evaluated whether executive functions are distinct but highly related constructs in children with RD as they are in TDC and adults. A series of alternative models were examined and it was found that a model with separable but correlated factors representing inhibition, working memory and non-verbal IQ provided the best fit to the data. This finding is the first known report of the “unity and diversity” of executive functions in children with RD and demonstrates that while executive functions may be impaired in children with RD, distinct constructs are still represented as they are in other populations. Strong correlations were found between the aspects of executive function being assessed and non-verbal IQ; however separable latent variables continued to provide the best fit to the data supporting previous conclusions from study two regarding the distinct nature of these constructs. Furthermore, non-verbal IQ did not moderate or mediate the relationship between executive functions and reading ability suggesting that executive functions may be more influential for reading performance than non-verbal IQ. This finding is consistent with the results of study two, suggesting that executive functions make a unique contribution to reading ability. They are also commensurate with previous results presented in study one and two which indicate that the use of non-verbal IQ/achievement discrepancy criteria does not add to our understanding of the nature of RD. In addition, increased inhibitory performance was found to significantly predict improvements in both word reading and reading comprehension in this sample of children with RD and a similar relationship emerged between working memory and reading comprehension. These findings echo the results obtained for a heterogeneous sample of children discussed in Chapter Three and furthermore highlight the necessity to discriminate between the differential underlying processes involved in alternative aspects of reading ability. The results presented in Chapter Five regarding gender differences in the extent to which executive functions predicted reading scores revealed a higher inhibition latent mean for females. However there were no further differences between males and females and the inclusion of gender as a covariate did not result in an appreciable improvement in model fit, suggesting that the model should not be differentiated by gender.

Given the extent to which RD is found to be comorbid with other developmental disorders, including disorders for which a high rate of executive difficulties are also thought to occur, there have been suggestions in the research literature that deficits in executive function observed in children with RD are attributable to these comorbid conditions and not the RD itself (c.f. Nigg, 2000; Savage, et al., 2007). Therefore study three also examined whether the pattern of results presented in Chapter Five persisted when comorbidities were taken into consideration. Two disorders commonly found to be comorbid with RD are ADHD and SLI. Results reported in the previous two studies have identified issues regarding inhibition, which is believed to be one of the primary deficits in ADHD (Willcutt, et al., 2008). Furthermore, task modality was also deemed to influence the pattern of the executive deficit observed, suggesting that the investigation of the comorbidity with language impairment would also prove prolific.

Chapter Six presented the examination of the effects of comorbidity of RD and ADHD symptoms. The results revealed no difference between children with RD only and those with high rates of ADHD symptoms on either working memory or inhibition. However, the group with comorbid difficulties were found to have significantly lower non-verbal IQ scores. Of particular interest, however, was the similarity in the extent to which executive functions predicted reading ability; findings which suggest that deficits in inhibition and working memory identified for children with RD are not attributable to the presence of comorbid ADHD symptoms. Consistent with these findings are those presented in Chapter Seven which examined the comorbidity between RD and oral language difficulties. While participants in the comorbid group had poorer scores for working memory and non-verbal IQ than those with RD only, there was no difference in the degree to which reading difficulties were accounted for by executive functions. Differences were however identified for non-verbal tasks of executive function between participants who had difficulties with receptive oral language and those whose difficulties were more expressive in nature thus indicating the nature of the language difficulty may impact on executive function task performance.

Finally, Chapter Eight explored the impact that having comorbid conditions had on the severity of participants' RD. Using an additive risk model, it was found that the more areas of difficulty a participant had, the more severe their RD; participants who had several comorbid conditions had more depressed reading scores than participants who only had one comorbid condition and indeed participants who had RD only. Thus the severity of RD was influenced by comorbidity.

Together these findings indicate that children with RD have profound difficulties with both inhibition and working memory, which predict the severity of the RD. However, at least for the present sample, these impairments are not attributable to general cognitive ability, slower developing language skills or indeed influenced by comorbid conditions. Rather, they are impacted by underlying demands of tasks of working memory and inhibition. These findings therefore have a number of implications.

9.1 Executive Functions and RD

While a number of theoretical models of executive functions have been proposed the present findings are consistent with the view that inhibition and working memory are integral aspects of executive functioning (Denckla, 1996b; Pennington, et al., 1996; Roberts & Pennington, 1996). The findings presented throughout this thesis are also consistent with theoretical suggestions that higher order cognitive processes may be important for word reading and reading comprehension (c.f. Chapter One, section 1.1).

In regard to the role of inhibition in word reading, the DRC model (Coltheart, et al., 2001) suggests that decoding an orthographic representation involves accessing phonological information and thus the correct pronunciation through (a) the indirect route, (b) the direct lexical route which bypasses semantic information, or (c) the lexical semantic route which involves the access of stored semantic knowledge. The model suggests that excitatory and inhibitory processes interact in order to select the correct response from a series of competitors (Coltheart, 2005). While fundamentally different from the DRC model in terms of the existence of a lexicon, the Triangle model (Plaut, et al., 1996; Seidenberg & McClelland, 1989) is consistent in the proposition that inhibition is an integral part of the word reading process. Layers relating to orthography, phonology and semantics concurrently activate and inhibit other layers and so activation spreads through the model in order to elicit the appropriate response. The results of the thesis are consistent with the intuitive suggestion that if inhibition is an integral part of the word reading process as these models suggest, that deficits in inhibition would be related to impairments in word reading. The most prevalent explanation for RD is that it reflects a primary deficit in the phonological system (Hulme & Snowling, 2009; Velluntino, et al., 2004). However, it has been suggested that adequate inhibitory functioning may be necessary for the phonological system (Palmer, 2000a); a proposition which seems to be supported by the present thesis.

In regard to reading comprehension, the present thesis has found that both inhibition and working memory are important factors and indeed are predictive of the severity of difficulties with reading comprehension. In regard to inhibitory processes, theoretical accounts of reading comprehension such as the Structure Building Framework (Gernsbacher, 1990) argue that when a word is read, multiple meanings are activated, many of which are not contextually relevant. Thus the processes of excitation and inhibition are employed to select the semantic representation which is appropriate for the context. Further to this, Gernsbacher (1993) suggested that difficulties with reading comprehension are the result of an inability to suppress semantic and contextual information; deficits which may lead to the impairments on tasks assessing semantics which have been reported throughout the literature (Landi & Perfetti, 2007; Nation, et al., 2001; Nation & Snowling, 1998, 1999) and which are consistent with the present findings.

In terms of working memory, the comprehension process is believed to involve the integration of word meanings and inferences in context (Kintsch, 1998) as well as maintaining attention (Montgomery, et al., 2010), processes which places significant demands on working memory (Cain, 2010; Kintsch & Rawson, 2005; van der Broek, et al., 1996). Furthermore, impairments in working memory have been identified for those with reading comprehension difficulties (Cain & Oakhill, 2006; Nation, et al., 1999) as have deficits with inhibition (Cain, 2006; Carretti, et al., 2005; De Beni & Palladino, 2000; Palladino, et al., 2001; Pimperton & Nation, 2010). In addition, it has been suggested that deficits with task performance in general reflect impairments in working memory for those with comprehension difficulties (Cain, 2010); thus the present thesis adds to the growing body of literature which suggests that working memory deficits may have an explanatory role in impairments in reading comprehension.

9.2 Non-verbal IQ and the Diagnosis of RD

Findings reported throughout the thesis indicate that the measures of non-verbal IQ did not add to an understanding of the cognitive difficulties experienced by children in studies in this thesis with RD. This is consistent with suggestions that definitions of RD should not be reliant on non-verbal IQ (Fletcher, et al., 1994; Hoskyn & Swanson, 2000; Jiménez, et al., 2009; Restori, et al., 2009; Stanovich, 2005; Stuebing, et al., 2002; Velluntino, et al., 2004). Stanovich and colleagues (Stanovich, 2005; Stanovich & Siegel, 1994), for example, advocate that RD be defined without the use of IQ, thus IQ/achievement discrepancy definitions should not be employed. As it is conceivable that executive processes may underpin RD (Facoetti, et al., 2003) it may be more informative to utilise depressed performance on tasks of executive function rather than non-verbal IQ. Furthermore it has been suggested that an evaluation of working memory in children with RD is more informative than examination of IQ test performance (Jiménez, et al., 2009) and is indeed the case for more general learning disabilities too (Maehler & Schuchardt, 2009). Bishop and Snowling (2004, p. 879) advocate that the procedure used to define RD should be dependent on the purpose of the definition and indeed the present findings reported throughout the thesis chime with conclusions which advocate the removal of IQ/achievement discrepancy criteria from guidelines for diagnosis which are issued to practitioners (Restori, et al., 2009).

9.3 Modality

A further consistent finding reported throughout the present thesis concerns the influence of task modality. Differences in magnitude of effect relating to verbal and non-verbal tasks were reported in Chapter Two and Chapter Four also reported potential modality dependent working memory impairments although also found deficits with inhibition which were not influenced by the nature of the assessment task. If deficits in oral language were an influential factor in the executive deficit of children with RD, it would be expected that there should be profound differences between those with and without oral language problems. The results presented in Chapter Seven thus refute this proposition in part, as deficits were only found in the severity of the working memory and non-verbal IQ latent variables. This result is consistent with the findings reported in Chapter Four, arguing that inhibitory deficits in children with RD are not dependent on task modality but that working memory impairments may be exacerbated by oral language difficulties and therefore more severe for verbal tasks. Thus these results consistently indicate a more pervasive deficit in inhibition for children with RD.

These findings support results found for children with RD-RC which demonstrated impairments related to verbal working memory tasks (Nation, et al., 1999; Pimperton & Nation, 2010) and indeed potentially conflict with the working memory model proposed by Baddeley and Hitch (1974) by illustrating a fractionation of the central executive component of the model. However, the results are also consistent with deficits which are identified for children with RD regardless of the stimuli employed (Boden & Brodeur, 1999; Gernsbacher, 1993). Palmer (2000b) suggested that inefficient inhibitory skills impair the ability to verbally encode visual material which subsequently hinders performance on visual tasks. As inhibitory deficits were identified in the present thesis, the supposition that children with RD are not verbally encoding and are thus relying on visual encoding may be supported. Thus it can be argued that the results of deficits in non-verbal inhibition are not attributable to verbal recoding of the stimuli therefore suggesting profound impairments in this aspect of executive functioning; a finding which is consistent with theoretical propositions regarding the primacy of inhibition (Barkley, 1997).

9.4 Comorbidity

Results of study three demonstrated that while comorbid conditions did not influence the extent to which executive functions accounted for severity of difficulties with reading, the severity of the impairment with working memory was exacerbated by comorbid language difficulties. Furthermore, comorbidity with language difficulties and ADHD symptomatology contributed to depressed performance with non-verbal IQ. These results suggest that executive deficits demonstrated by children with RD cannot be attributed to comorbid difficulties, at least in the sample recruited for the present study. The methodology employed throughout the thesis does not allow for a direct comparison with participants free from RD, which would be necessary in order to glean support for theoretical models concerning comorbid conditions. Such models require participants with both single and comorbid difficulties for each condition under examination in order to evaluate the pattern of impairments which may be unique to both single conditions and indeed comorbidities. However the results do suggest that when investigating some aspects of executive function, the possibility of comorbid conditions should be taken into consideration.

Johnson and colleagues (1999) argue that while exclusionary criteria are often employed by researchers to ensure that participants under investigation are free from conditions other than the primary one under investigation, it may be more informative to consider additional impairments as clinicians rarely encounter children with difficulties in only one area of functioning. The present thesis supports this proposal in as far as severity of executive deficit identified in RD may be influenced by certain comorbidities. However it has been argued that deficits in executive function may be ubiquitous in childhood disorders (Willcutt, et al., 2008). While deficits across a number of areas of functioning were identified for a range of disorders, Willcutt and colleagues (Willcutt, et al., 2008) argued that no single deficit could be deemed causal. This finding was in agreement with the proposition of Purvis and Tannock (2000) who argued that difficulties with inhibition may be due to multiple cognitive mechanisms. Indeed Pennington (2006) suggested that developmental disorders reflect deficits in a number of areas rather than difficulties with unitary processes and suggested a potential genetic relationship between disorders. Furthermore, Willcutt and colleagues (2001) argued for the pleiotropic nature of genetic influences; that is, that one gene may directly impact an array of phenotypes. Different disorders are therefore manifestations of a common genetic influence which is impacted by further genetic and environmental factors (Willcutt, et al., 2001; Willcutt, et al., 2000; Willcutt, Pennington, et al., 2005). Consistent with this are the results presented by Friedman and colleagues (2008) which demonstrated that executive functions are 99% heritable. They proposed that this heritability accounted for the unity in executive function performance identified throughout the literature and that the separability could be accounted for by genetic influences specific to each aspect of functioning. Furthermore, it was argued that executive functions may be one of "the most heritable psychological traits" (Friedman, et al., 2008, p. 216). However, the authors suggested that their results do not negate the fact that executive functions are still influenced by environmental factors and indeed may benefit from targeted training.

9.5 Interventions

If Friedman and colleagues (Friedman, et al., 2008) are correct in the assumption that targeted training can benefit executive performance, the results of deficits observed throughout the thesis in inhibition and working memory for children with RD beg the question of whether improvements in these aspects of executive functioning would result in appreciable improvements in reading ability. A number of executive functioning training programs have been implemented in a range of populations; the results however demonstrate mixed success.

For example, Diamond and colleagues (Diamond, et al., 2007) report evidence from a classroom intervention for preschool children aimed at improving executive functions. Results found that the Tools of the Mind program (Bodrova & Leong, 2001) improved performance of children aged approximately 5 years old on tasks of inhibition, working memory and flexibility and that these functions were significantly correlated with academic attainment. However, Thorell and colleagues (Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009) report results from a computerised intervention study again with preschool children. They found that working memory training not only improved performance on the trained working memory tasks but also transferred to other working memory tasks and to attention performance. However, inhibition training only led to improvements for some of the trained inhibition tasks and did not have a positive influence on untrained tasks for any area investigated. These results thus indicate that executive function training may be influenced by the training paradigm and the aspect of executive function being trained.

In terms of ADHD, Klingberg and colleagues (Klingberg, et al., 2005; Klingberg, Forssberg, & Westerberg, 2002) report improvements in working memory following a computerised training schedule. Training was found to extend to other working memory tasks and indeed other aspects of executive functioning, including inhibition. The authors therefore suggest that working memory training might ameliorate symptoms related to ADHD. In regard to SLI, however, the findings have been mixed. Stevens and colleagues (Stevens, et al., 2006) identified attentional deficits in children with SLI and argued that their results demonstrated that language and literacy abilities in this population may show improvements following attentional training. However, Justice and colleagues (Justice, Kaderavek, Bowles, & Grimm, 2005) found that a shared-reading intervention led to improvements with some aspects under consideration but not others in children with SLI. In a recent review of the efficacy of interventions for children with Mixed Receptive-Expressive Language impairment, Boyle and colleagues (Boyle, et al., 2010) reported that there is a dearth of evidence indicating that treatment for this group may be effective, regardless of the nature of the treatment program. Thus it appears that in children with SLI, training improvements may not always be achieved. In addition however, it has been suggested that working memory impairments found in a range of disorders (i.e. Down syndrome, Williams syndrome, SLI and ADHD) might benefit from remedial support (Gathercole & Alloway, 2006). Thus these results suggest that training in executive function may be beneficial for learning and that this may be true for a number of areas of difficulty.

Recently, Holmes, Gathercole and Dunning (2010) reviewed the literature relating to children who have specific difficulties with working memory. It was argued that computerised working memory training led to significant improvements in working memory performance and indeed general learning ability, although the endurance of this improvement has not yet been substantiated. Additionally, the authors discussed as yet unpublished results demonstrating improvements in reading performance for a group of children with dyslexia following computerised working memory training (Holmes, Dunning, & Gathercole, *In preparation*). Consistent with this, Chenault and colleagues (Chenault, Thomson, Abbott, & Berninger, 2006) report that children with dyslexia demonstrate improvements in written composition following 10 sessions of attention training. Furthermore, Facoetti et al. (2003) found that attentional training benefited children with RD not only on attention and inhibitory processes but also in their reading performance. The authors therefore argued that there may be a causal relationship between inhibition and reading in children with RD.

These results therefore indicate that training which targets working memory and inhibition may lead to improvements in executive function and in turn have beneficial effects on reading and learning; these findings are consistent with results demonstrating the predictive utility of executive function for reading in the present thesis. However, as there are inconsistent results regarding the extent to which training transfers to other tasks and whether or not it leads to sustained improvements, further research is required before unequivocal support can be obtained for the efficacy of executive function training.

9.6 Limitations and Future Directions

Deficits were observed throughout the present thesis on tasks of inhibition which did not require a verbal response. While it can be argued that the language demands of tasks are reduced as far as possible by employing non-verbal tasks, it is conceded that the language demands can never be completely eliminated. This is due to the fact that in order to follow the task requirements, participants' language skills are implicated, regardless of whether task instructions are presented in written format or are read to the participants. All of the tasks employed throughout the present series of studies involved a practice session so that participants' understanding of the task requirements were evaluated and deemed adequate before testing sessions began. Therefore, the task procedure was not hindered by their initial instruction processing. While the possibility of verbal encoding and as such placing strong demands on language skills is certainly viable, as the ability to verbally encode is thought to be related to sufficient inhibitory skills (Palmer, 2000b) this explanation seems unlikely. The use of motor tasks of inhibition, for example the stop signal task, may produce an alternative pattern of results; however the initial processing of the task requirements will remain an issue. Further research employing a range of tasks, including motor tasks, which implicate each aspect of inhibition identified by Nigg (2000) and the use of latent variable analysis to assess underlying commonalities may be a fruitful avenue for further investigation.

One further limitation concerns the lack of recruitment of children with RD-RC only. The Simple View of Reading (Gough & Tunmer, 1986; Hoover & Gough, 1990) suggests that reading comprehension is the product of word reading and listening comprehension. As inhibition was found to be predictive of word reading throughout the thesis, it is of little surprise that it was also found to be predictive of reading comprehension. While a role for inhibition in the comprehension process has been suggested, as the present thesis involved children whose RD was related to word reading only, it is not possible to claim unequivocal support. Employing a group of participants with RD-RC would permit the investigation of the role of inhibition in comprehension independently of its role in word reading and would thus allow for a more complete conclusion regarding the role of inhibition to be drawn. In addition, it would permit a disentanglement of the underlying processes which may be important for each area of difficulty.

Furthermore, the present thesis does not allow an evaluation of theoretical accounts of comorbidity between developmental disorders as groups of participants free from RD were not recruited, thus limiting the conclusions which can be drawn in this regard. In addition, it may be informative for further studies to evaluate the pattern of impairment when children have RD plus comorbid ADHD symptoms and also comorbid LI symptoms as it was not possible to conduct latent variable analysis given the number of participants which fell into each group in study three of the present thesis. Therefore, future studies should recruit larger numbers of participants with comorbid conditions, including larger numbers of participants with mixed and expressive language difficulties, in order to evaluate the impact of having multiple comorbid conditions using latent variable analysis.

One further avenue for future research concerns the use of eye-tracking paradigms. Research has demonstrated that eye-movements when reading are influenced by semantic and phonological relationships between words and objects and indeed that children with poorer language scores evidence reduced sensitivity to context (Brock, Norbury, Einav, & Nation, 2008). Given that participants have demonstrated inhibitory deficits it would prove fruitful to examine whether these deficits extend to competing words within a sentence which may impact their context processing.

9.7 Concluding Remarks

In conclusion, the present thesis has demonstrated that children with RD in the studies reported here have marked impairments with inhibition and more domain specific deficits in working memory. These impairments predict the severity of reading difficulty and are not attributable to comorbid conditions, slower developing language skills or indeed cognitive ability in general. The findings add to the existing literature which suggests that executive functions are separable but related processes (e.g. Miyake, et al., 2000) and is indeed the first known report of this separability in children with RD. In addition, findings from the present thesis lend support to theory which posits the primacy of inhibitory processes (Barkley, 1997; Denckla, 1996b; Pennington, et al., 1996; Roberts & Pennington, 1996) and indeed theories of reading in which executive functions are implicated (Coltheart, 2005; Coltheart, et al., 2001; Gernsbacher, 1990; Kintsch, 1998; Kintsch & Rawson, 2005; Montgomery, et al., 2010; Plaut, et al., 1996; Seidenberg & McClelland, 1989; van der Broek, et al., 1996). Furthermore, findings add to the growing body of literature which advocates a reform of guidelines used in the definition of RD (Fletcher, et al., 1994; Hoskyn & Swanson, 2000; Jiménez, et al., 2009; Restori, et al., 2009; Stanovich, 2005; Stuebing, et al., 2002; Velluntino, et al., 2004).

While it may be tempting to suggest support for causal mechanisms, the results of the thesis do not provide unequivocal support for the view that deficient executive functioning may be causal in RD (Facoetti, et al., 2003; Gernsbacher, 1993; Palmer, 2000a). For example, one possibility is that differing mechanisms lead to deficient phonological skills and executive impairment, which may be conceived as consistent with the proposition of developmental disorders having a common genetic etiology which manifests in differing ways due to an interaction with other genes and environmental factors. Thus longitudinal modelling is advocated which could assess whether deficient executive function in infancy leads to phonological issues which might then lead to RD, however it may be that both occur in parallel and are not in fact causally related. But as deficits have been identified in a range of disorders (Willcutt, et al., 2008) further research is necessary to extrapolate causation.

While a vast array of further research is required before a complete understanding of RD is achieved, the present thesis contributes to efforts to disentangle the complicated relationship with executive functions and suggests avenues for areas of training which may prove beneficial. Thus researchers and practitioners alike should consider the importance of evaluating executive functions in children with RD and indeed the potential impact which these processes may have in ameliorating some of the difficulties faced by a substantial number of the population.

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Appendices

Appendix A. Publication resulting from study 1 as detailed in Chapter Two.

Appendix B. Number of studies located by differing search strategies.

	Search engine				
Search key words	Psych-info	Wilson Web	Web of Knowledge	Pub-med	Total
Executive function					
Children					
Reading	52	7	40	53	152
Reading difficulties	3	4	10	8	25
Dyslexia	6	4	11	25	46
Reading disability	19	6	31	9	65
Inhibition					
Children					
Reading	77	11	65	70	223
Reading difficulties	0	3	19	7	29
Dyslexia	16	2	21	23	62
Reading disability	19	4	39	12	74
Inhibitory skills					
Children					
Reading	0	1	8	6	15

Search key words	Search engine Psych-info	Wilson Web	Web of Knowledge	Pub-med	Total
Reading difficulties	0	0	2	2	4
Dyslexia	0	0	1	3	4
Reading disability	0	0	4	2	6
Working memory					
Children					
Reading	357	43	498	331	1229
Reading difficulties	32	16	140	52	240
Dyslexia	47	10	165	183	405
Reading disability	94	10	144	42	290
Total	722	121	1198	828	2869

Note: Several papers were located using more than one search strategy and in more than one search engine.

Appendix C. Table indicating method of retrieval for studies included.

Method of retrieval	Included
PsychInfo	Altemeier et al. (2007); Brosnan et al. (2002); Jeffries & Everatt (2004); Nation et al. (1999); Reiter et al. (2005); Swanson & Ashbaker (2000); Swanson & Berninger (1995); Swanson et al. (2004); van der Sluis et al (2004)
PubMed	Cain (2004); Carretti et al. (2005); Censabella & Noel (2005); Helland & Asbjornsen (2000); Kupietz (1990); McGee et al.(1989); Miller-Shaul (2005); van der Schoot et al (2004); Willcutt et al. (2001)
Web of Knowledge	Bayliss et al (2005); Cain & Oakhill (2006); Condor et al (1995); De Beni & Palladino (2000); De Jong (1998); Howes et al. (1999); Kramer et al. (2000); Martinussen & Tannock (2006); Närhi & Ahonen (1995); Pennington et al. (1993); Roodenrys et al. (2001); Stothard & Hulme (1992); Swanson (1993); Swanson (1999); Swanson & Alexander (1997); Swanson et al. (1996); Swanson & Jerman (2007); Willcutt et al. (2005)
Wilson Web	McGee et al. (2004); Purvis & Tannock (2000); Savage & Frederickson (2006); Swanson et al. (2006); van der Sluis et al. (2005)
Reference citations	Everatt et al. (1997); Hall et al. (1997); Nyden et al. (1999); Pickering & Gathercole (2004)
Author request	Everatt et al. (2008); Protopapas et al. (2007)
Unpublished/in press	Booth & Boyle (2009)

Note: Several papers were located in more than one search engine.

Appendix D. Details of tasks included in upper bound and lower bound analyses by modality and definitional criteria.

	Criteria	Modality	Task	Study	Hedge's g (SE)	Z-Value
Upper Bound	Discrepancy	Verbal	California verbal leaning test	Kramer et al. (2000)	0.18 (0.16)	1.13
			Naming	Narhi & Ahonen (1995)	1.05 (0.41)	2.56 *
			Rapid automatic shifting	Altemeier et al. (2007)	0.96 (0.18)	5.33 ***
			Sentence span	Willcutt et al. (2001)	0.36 (0.18)	2.00 *
		Non-verbal	Conflict task	Nyden et al. (1999)	0.87 (0.47)	1.85
			Continuous performance task	Kupietz (1990)	1.05 (0.45)	2.33 *
				Pennington et al. (1993)	0.42 (0.34)	1.24
			Five-point test	Reiter et al. (2005)	0.54 (0.23)	2.35*
	Non - discrepancy	Verbal	Backward digit span task	Jeffries & Everatt (2004)	1.48 (0.30)	4.93 ***
				Martinussen & Tannock (2006)	1.44 (0.37)	3.89 ***
				McGee et al. (2004)	0.29 (0.25)	1.16
				Savage & Frederickson (2006)	1.00 (0.26)	3.85 ***

Criteria	Modality	Task	Study	Hedge's g (SE)	Z-Value
		Listening span	Cain & Oakhill (2006)	0.71 (0.30)	2.37 *
			Nation et al. (1999)	1.38 (0.41)	3.37 **
			Stothard & Hulme (1992)	0.55 (0.39)	1.41
		Listening span - intrusions	De Beni & Palladino (2000)	0.92 (0.43)	2.14 *
		Object shifting task	Van der Sluis et al (2004)	0.81 (0.33)	2.46 *
		Story recall	Swanson & Berninger (1995)	1.76 (0.32)	5.50 ***
		Updating task	Carretti et al. (2005)	1.11(0.15)	7.40 ***
		Word recall	Cain 2004	1.32 (0.43)	3.07 **
	Non-verbal	Coding task	Miller-Shaul (2005)	6.03 (0.67)	9.00***
		Continuous performance task	Hall et al. (1997)	0.54 (0.31)	1.74
		Numerical Stroop	Authors (under revision)	0.52 (0.28)	1.86
		Stop task	Purvis & Tannock (2000)	0.41 (0.35)	1.17
		Symbol search	Willcutt et al. (2005)	0.67 (0.13)	5.15***
		Trail making task	McGee et al. (1989)	0.35 (0.31)	1.13
		Visuospatial working memory task	Bayliss et al. (2005)	0.23 (0.20)	1.15

Criteria	Modality	Task	Study	Hedge's g (SE)	Z-Value
Unsure	Verbal	Auditory serial addition task	Roodenrys et al. (2001)	1.41 (0.40)	3.53 ***
		Backward digit span	Pickering & Gathercole (2004)	0.32 (0.19)	1.68
		Backward letter span	Howes et al. (1999)	0.83 (0.26)	3.19 **
		Letter naming	Swanson et al. (2006)	1.62 (0.40)	4.05 ***
		Listening span	van der Sluis et al. (2005)	0.19 (0.31)	0.61
		Reading span	De Jong (1998)	1.62 (0.38)	4.26 ***
		Rhyming task	Swanson & Jerman (2007)	1.36 (0.35)	3.89 ***
			Swanson et al. (2004)	0.20 (0.22)	0.91
		Semantic association	Swanson (1993)	0.85 (0.26)	3.27 **
		Sentence span	Swanson et al. (1996)	1.48 (0.29)	5.10 ***
			Swanson (1999)	1.46 (0.38)	3.84 ***
			Swanson & Ashbaker (2000)	2.68 (0.36)	7.44 ***
		Sentential priming task (% errors)	van der Schoot et al. (2004)	1.35 (0.39)	3.46 **

	Criteria	Modality	Task	Study	Hedge's g (SE)	Z-Value
			Stroop	Everatt et al. (1997)	1.61 (0.36)	4.43 ***
				Helland & Asbjornsen (2000)	1.20 (0.30)	4.00 ***
				Protopapas et al. (2007)	0.86 (0.30)	2.87 **
			Verbal span	Everatt et al. (2008)	0.71 (0.28)	2.54 *
		Non-verbal	Concurrent digit colour	Swanson & Alexander (1997)	0.72 (0.23)	3.13 **
			Flanker letters	Censabella & Noel (2005)	1.57 (0.42)	3.74 ***
			Group embedded figures test	Brosnan et al. (2002)	1.15 (0.28)	4.11 ***
			Tower of Hanoi	Condor et al. (1995)	0.72 (0.34)	2.12 *
Lower bound	Discrepancy	Verbal	California verbal leaning test	Kramer et al. (2000)	0.18 (0.16)	1.13
			Inhibition/switching task	Altemeier et al. (2007)	0.56 (0.18)	3.11 **
		Non-verbal	Continuous performance task	Kupietz (1990)	1.05 (0.45)	2.33 *
			Executive task	Närhi & Ahonen (1995)	0.45 (0.39)	1.15

Criteria	Modality	Task	Study	Hedge’s g (SE)	Z-Value
		Matching family figures test	Pennington et al (1993)	-0.03 (0.33)	-0.09
		Stop-signal task	Willcutt et al. (2001)	0.13 (0.15)	0.87
		Tower of London	Reiter et al. (2005)	-0.13 (0.22)	-0.59
		Wisconsin Card Sorting Task	Nyden et al. (1999)	0.17 (0.45)	0.38
Non-discrepancy	Verbal	Backward digit span	De Beni & Palladino (2000)	0.22 (0.41)	0.54
		Delayed recall	McGee et al. (1989)	0.03 (0.31)	0.10
		Digit reading task	Cain & Oakhill (2006)	0.15 (0.30)	0.50
		Listening span	Stothard & Hulme (1992)	0.55 (0.39)	1.41
		Object naming	Miller-Shaul (2005)	0.68 (0.29)	2.35 *
			Savage & Frederickson (2006)	0.19 (0.24)	0.79
		Stroop	Jeffries & Everatt (2004)	0.04 (0.27)	0.15
		Updating task (Delayed intrusions)	Carretti et al. (2005)	1.11 (0.15)	7.40 ***
		Verbal working memory task	Bayliss et al. (2005)	0.10 (0.20)	0.50

Criteria	Modality	Task	Study	Hedge's g (SE)	Z-Value
		Word recall intrusions	Cain (2006)	1.32 (0.43)	3.07 **
	Non-verbal	Continuous performance task	Hall et al. (1997)	0.54 (0.31)	1.74
			McGee et al. (2004)	0.05 (0.24)	0.21
			Purvis & Tannock (2000)	-0.31 (0.35)	-0.89
		Matrix	Swanson & Berninger (1995)	0.22 (0.28)	0.79
		Reverse finger windows task	Martinussen & Tannock (2006)	1.07 (0.34)	3.15 **
		Spatial span	Nation et al. (1999)	0.01 (0.37)	0.03
		Tower of London	Authors (*under revision*)	0.42 (0.28)	1.50
		Trail making task	van der Sluis et al.(2004)	0.08 (0.32)	0.25
		Wisconsin Card Sorting test	Willcutt et al. (2005)	0.22 (0.13)	1.69
Unsure	Verbal	Auditory digit sequence	Swanson & Ashbaker (2000)	0.01 (0.26)	0.04
		Backward digit span	van der Sluis et al. (2005)	0.07 (0.31)	0.23
		Computation span	De Jong (1998)	0.45 (0.34)	1.32
		Counting span	Swanson (1999)	1.20 (0.36)	3.33 **

Criteria	Modality	Task	Study	Hedge's g (SE)	Z-Value
		Letter generation	Swanson et al. (2004)	-0.17 (0.22)	-0.77
		Listening span	Pickering & Gathercole (2004)	0.07 (0.19)	0.37
		Listening sentence span	Swanson et al. (2006)	0.16 (0.35)	0.46
		Number generation (2sec/item)	Roodenrys et al. (2001)	0.43 (0.36)	1.19
		Phrase sequence	Swanson (1993)	0.22 (0.25)	0.88
		Sentential priming task (% errors)	van der Schoot et al. (2004)	1.35 (0.39)	3.46 **
		Stroop	Censabella & Noel (2005)	0.63 (0.37)	1.70
			Everatt et al. (1997)	1.61 (0.36)	4.43 ***
			Protopapas et al. (2007)	0.86 (0.30)	2.87 **
		Updating task	Swanson & Jerman (2007)	0.64 (0.32)	2.00 *
	Non-verbal	Facial memory	Howes et al. (1999)	0.24 (0.25)	0.96
		Matrix	Swanson et al. (1996)	-0.28 (0.28)	-1.00
			Swanson & Alexander (1997)	0.46 (0.23)	2.00 *

Criteria	Modality	Task	Study	Hedge’s g (SE)	Z-Value
		Recognition	Brosnan et al. (2002)	0.49 (0.36)	1.36
		Spatial memory	Everatt et al. (2008)	-0.32 (0.28)	-1.14
		Tower of Hanoi	Condor et al. (1995)	0.72 (0.34)	2.12 *
		Wisconsin Card Sorting Task	Helland & Asbjornsen (2000)	0.41 (0.27)	1.52

Note: * p<0.05; **p<0.01; ***p<0.001

Appendix E. Descriptions of tasks identified.

Task	Description
Abstract visual memory	Distinguish meaningless figures previously presented from six distractors. Non-verbal response.
Animal test	Semantic fluency test –name as many animals as possible within 2 mins
Arithmetic task	Subtest from WISC-r: Solve a series of mental arithmetic problems (In addition to basic maths, this task provides a measure of verbal working memory)
Auditory digit sequence	Recall numbers previously presented in sentences in sequential order.
Auditory serial addition task	Single digits presented every 2 seconds. Add each pair of successive numbers and immediately give the answer aloud.
Backward digit span	Recall a set of digits in reverse order (lists of increasing length).
Backward letter span	Recall a set of letters in reverse order (lists of increasing length).
California verbal learning test	Learn a 15 word list in 5 learning trials and complete a free recall test. An interference list is then presented and both free and cued recall tests given. Following a 20 minute delay, there is a further free and cued recall test and also a recognition test. The score used was the number of false-positive errors, that is, the number of distractors incorrectly endorsed as this measures interference.
Coding task	WISC III: transcribing a digit-symbol code as quickly as possible for two minutes
Computation span	Make a series of computations (either addition or subtraction) and after each computation a digit is presented. The presented digits had to be recalled in order.

Task	Description
Concurrent digit colour	Cards with pictures of shapes were sorted into four piles. At the same time shown a different colour square every 2 secs. Task is to point to the order of colour squares from an array of colours.
Concurrent digit semantic	Digit sequences are presented. Sort cards into categories at the same time as listening to digits. Then asked to recall digits.
Concurrent digit shape	Digit sequences are presented. Sort cards into piles placing identical pictures of shapes on top of each other at the same time as listening to digits. Then asked to recall digits.
Conflict task	Responds twice when one stimuli is presented and once when two stimuli are presented
Contingency naming test	3 rows of 9 different coloured stimuli. Each stimuli has large outside shape and a smaller inside shape (either congruent or incongruent). First – name either colour or large shape. Second – name colour if two shapes are the same or shape if two shapes are different. Third – rule the same but 9 stimuli have a backward arrow which indicates that the rule is reversed.
Continuous performance task	Presented with 500 letters. 1st- press a key each time a white *S* is presented. 2nd - press the key only when a white *S* is followed by a blue *T*.
Counting span	Count the number of dots presented in a series of arrays and recall the dot totals in serial order.
Delayed recall - ROCF	Copy a complex figure using a different colour pencil for each section. There is a delay between recall trials.
Digit naming	Name an array of digits as quickly as possible.
Digit reading task	Read groups of three digits and recall the final digit.

Task	Description
Executive task	Complete the WCST and the trail making task using the standard procedure. The Executive task score is based on the mean of t-scores of WCST perseverative errors and the trail making task – part B.
Facial memory	Recognise and identify black and white photos of faces of individuals of various ages, gender and ethnicity from a set of distractors.
Five-point test	Connect the dots in a pattern of 5 symmetrically arranged dots with one or more straight lines to make as many different designs as possible.
Flanker digits	Name a target digit flanked by either congruent or incongruent digits
Flanker letters	Name a target letter flanked by either congruent or incongruent letters
Flexibility task	A letter and a digit are presented at the same time on a computer screen. Press a button corresponding to the same side of the screen as the number and then press a button on the same side as the letter.
Go/NoGo	Respond once every time two stimuli are presented.
Group embedded figures test	Locate a simple figure within a complex visual array ignoring distracters.
Inhibition/switching test	Using the Stroop colour/word test: participants are required to switch between naming the colour in which words are printed and reading words that are printed within a box.
Letter generation	Generate as many letters as possible in a non-systematic random order (requires inhibition of responses that would not be random)
Letter naming	Name an array of letters as quickly as possible.

Task	Description
Listening span	Judge the veracity of sentences and then recall the last word from each sentence in sequence
Listening span – intrusions	Judge the veracity of sentences and then recall the final word from each sentence. Score is based on the number of intrusion errors.
Mapping	Participant given a street map to study (lines and dots). Asked a process question and then asked to draw on another blank map, the lines and dots from the first map. Get progressively more complex.
Matching family figures test	Choose from 6 different pictures, one that is identical to a target picture.
Matrix	1) Presented with a matrix with a number of shaded squares. Asked a processing question, then put an X in the squares which were shaded. 2) Given a matrix with dots in it to study. Asked a process question and then has to reproduce the pattern of dots.
Memory updating (2 updates)	Repeat back the last three digits from a list.
Naming	1st- name 50 letters presented in 5 rows. 2nd- name 50 letters, numbers and coloured squares presented in 5 rows in a random order.
Non-verbal sequencing	Presented with a series of cards with pictures of shapes and line drawings. Organise the cards into rows; a certain number of cards have to be presented in each row. A process question is asked and the strategy used to remember the sequence is selected. Two distracter cards are inserted into the pack and the participant then has to reproduce the rows of cards.
Number generation	Generate as many numbers as possible in a non-systematic random order

Task	Description
Number naming	Name each number presented in a table of 50 different numbers. .
Numerical Stroop – verbal	Name the number of x's or digits presented on a screen, the identity being either congruent or incongruent.
Numerical Stroop- non-verbal	Underline specific numbers on a page and ignore distractors, inhibiting the 1st trial in the 2nd trial.
Object- inhibition-shifting task	Figure are presented with smaller figures inside. Participants had to alternate between naming the inner figure or outer figure depending on the colour.
Object interference (Stroop)	Participants name blocks of colours on a page. Then they are presented with colour associated objects but printed in incongruent colours and instructed to name the colour of the ink.
Object naming	Name an array of objects as quickly as possible.
Object shifting	A series of geometric objects with a digit inside are presented. Participants have to either name the object or the figure depending on the colour of the stimuli.
Object-inhibition task	A series of geometric objects with a smaller geometric object inside are presented. Participants have to inhibit the larger object and name the smaller object.
Phrase sequence	An increasing number of phrases is presented, and the participant has to recall the phrase following a processing question.
Picture sequence	A series of cards with pictures of shapes on them are presented. Following a process question the participant has to arrange the cards in the correct order.
Quantity inhibition task	Arrays of digits are presented which are incongruent to the actual digits (e.g. 222). Participants had to name the quantity in the array.

Task	Description
Quantity naming task	Different numbers of triangles are presented and participants have to name the number (quantity) of shapes.
Rapid automatic shifting	Alternate between rapidly naming a word and a double-digit number.
Reading span	Read a series of sentences then store a presented word. Recall the presented words in order.
Recognition task	A series of pictures is presented and a recall trial with distracters is carried out.
Reverse finger windows task	Watch the examiner point to a series of windows on a card. Reproduce the sequence exactly, but in reverse order.
Rhyming task	Listen to a set of words that rhyme. Then given a recognition task and asked to recall the previously presented words in order.
Semantic association task	Organise sequences of words into abstract categories: Presented with a set of words, then asked a discrimination question, then asked to recall the words which go together.
Semantic categorisation	One word presented every 2 seconds. Recall the category name for the list of words and then any word that went into that category.
Sentence span	Participants provide the last word for a series of sentences and then have to recall the words.
Sentential priming task	Judge whether the final word of a sentence is semantically congruent or incongruent – if congruent respond with the left hand, if incongruent respond with right hand. Had to inhibit response if pseudoword.
Spatial memory	A series of black squares is presented. A specific series of squares is pointed to and the participant has to repeat the pointing. In the second condition, the participant has to point to the squares in reverse order.

Task	Description
Spatial organisation	Cards with varying shapes are presented. The participant has to replicate the correct series of cards.
Spatial span	Rectangles on are presented on a screen. Each rectangle has three white squares with target stimuli in them. Participants have to indicate the odd one out by pointing. Stimuli moved across the screen and the participant has to recall the position of all of the odd one outs.
Spatial working memory task	CANTAB –Find hidden tokens while inhibiting responses to previous locations.
Star counting test	9 rows of stars presented with a number at the beginning of each row. Count the stars from top to bottom and left to right starting from this initial number. Plus and minus signs appear between some stars indicating subsequent stars should be counted either forward or backward from this point. In the first item a plus sign indicates forward counting and a minus sign indicates backward counting, in the second item this is reversed.
Stop-signal	Letter X or O is presented on a computer monitor -press the corresponding key. In the 2nd trial-inhibit response if a tone is presented.
Story recall	Recall all the events in a story.
Stroop	Read colour words printed in black ink, then name the colour of xxx's or blocks of colour, then name the colour of the ink in which an incongruent colour word is printed.
S-word test	Name as many different words as possible beginning with the letter s.
Symbol search	WISC III: deciding if target symbols appear in a row of symbols
Temporal order	A series of pictures is shown then followed with a delayed recall task.

Task	Description
Tower of Hanoi	3 vertical posts & 3 different size disks. Move the pattern of disks to make different patterns following a series of rules.
Tower of London	3 vertical posts of different heights & 3 different coloured balls (same size). Move the pattern of balls to make different patterns following a series of rules.
Trail making task	Part a – use a pencil to connect a series of circles with numbers in them in ascending order. Part b – Connect circles in ascending order alternating between numbers and letters (e.g. 1, A, 2, B, 3, C…)
Updating task	A series of one-digit numbers presented that varies in set-lengths of 9, 7, 5 and 3. Recall the last three numbers presented.
Updating task (Delayed intrusions)	Pictures and nouns presented. Recall the highest (between positions 2-7) or lowest (between positions 9-14) pictures in the column that were named in the word list. Score is based on the number of delayed intrusion errors.
Verbal fluency	Generate as many words as possible starting with a given letter (either s or f or a).
Verbal numerical Stroop	Given page of numbers, name every digit on page. Then in second part, have to say "five" to the number 7 and vice versa.
Verbal span	A series of digits of increasing lengths is presented. 1st- recall the digits in the same order 2nd recall the digits in reverse order.

Task	Description
Verbal working memory task	9 different coloured squares forming a circle are presented with a digit in each square. Object names were presented and the participant has to think of the colour most associated with the object and touch the coloured square on the screen. Participants had to name the digit in the centre of the square they touched and recall all digits in serial order.
Visuospatial working memory task	9 different coloured squares forming a circle on it are presented with a digit in each square. Object names were presented and the participant has to think of the colour most associated with the object and touch the coloured square on the screen as quickly as possible. Participants had to remember the location of the squares they had touched and at the end recall all of the locations.
Wisconsin Card Sorting task	Sort cards either by colour, form or number of shapes. Advised whether each sort is correct or not. After correct sorting of 10 cards the rule changes so that the sorting is based on another characteristic but participant not advised, must judge new sort by response of examiner.
Word recall intrusion errors	Sets of concrete and abstract words are presented and recalled in correct serial order. The score is based on the number of intrusion errors.

Appendix F. Information sheet for schools for Study 2.

Dear Head Teacher

I am a postgraduate student undertaking a PhD in Psychology at the University of Strathclyde and am writing to request permission to carry out a research project in your primary school. The study has been approved by the Department of Psychology's Ethics Committee and by XXXXXX, on behalf of North Lanarkshire Council (see attached) and is supervised by James Boyle in the Department of Psychology at Strathclyde University who can be contacted either by telephone on 0141 548 2584 or by email at j.boyle@strath.ac.uk.

The study is investigating the relationship between reading skills and Working Memory processes. Around 30 participants from the P 3/4 and 5/6 stages would be asked to complete a short individually-administered test of reading ability followed by four standard individually-administered tasks used to assess working memory skills and a test of general ability.

The first working memory task will involve pupils naming the ink in which a colour name is printed and the second will require pupils to underline specific numbers on a page, while ignoring distracting numbers. The third task will require pupils to repeat a series of digits in reverse order and the fourth task will require pupils to memorise a map and then draw it. The procedure will involve two sessions of 45 minutes each per pupil. Male and female pupils would be involved and the participants will be sampled from across the full range of reading ability.

School staff would be asked to send out letters and consent forms to parents and pupils. The researcher would provide all of the materials and would administer the tasks. The results would be confidential and parental permission and pupil consent would be a requirement of the children's involvement.

I enclose consent forms for parents and pupils. Please let me know if you are able to support this study and do not hesitate to contact me the Department of Psychology, Graham Hills Building, University of Strathclyde, 40 George Street, G1 1QE (josephine.n.booth@strath.ac.uk) if you wish any further information.

Yours sincerely

Josephine Booth

Appendix G. Information sheet for parents for Study 2.

Information sheet
The relationship between reading skills and inhibition

Dear Parent/Guardian,

I am a postgraduate student undertaking a PhD in Psychology at the University of Strathclyde and as a requirement for my degree I am carrying out a research project looking at how children's working memory influences their reading. The study has been approved by the Department of Psychology's Ethics Committee and by XXXXX, on behalf of North Lanakshire Council and is supervised by James Boyle in the Department of Pychology at the University of Strathclyde who can be contacted either by telephone on 0141 548 2584 or by email at j.boyle@strath.ac.uk.

Those taking part will be from the P 3/4 and P5/6 stages would be asked to complete a short individually-administered test of reading ability followed by four standard individually-administered tasks used to assess working memory skills and a test of general ability.

The first working memory task will involve pupils naming the ink in which a colour name is printed and the second will require pupils to underline specific numbers on a page, while ignoring distracting numbers. The third task will require pupils to repeat a series of digits in reverse order and the fourth task will require pupils to draw a line on a map to demonstrate the route they would follow to visit specific places on the map. The procedure will involve two sessions of 40 minutes each per pupil. Male and female pupils would be involved and the participants will be sampled from across the full range of reading ability.

Participation is completely voluntary and you are under no obligation to take part. You or your child have the right to withdraw from this study at any point before, during and after the study has taken place and will not be required to give a reason. All information will be made anonymous and treated in the strictest confidence. All information will be stored in a secure location for a 5 year period and will be destroyed there after.

I would be very grateful if you would consider allowing your child to participate in this study. Please find attached a consent form for you to sign and return to school if you are happy for your child to take part. If you require any further information please do not hesitate to contact me at Department of Psychology, Graham Hills Building, University of Strathclyde, 40 George Street, G1 1QE or alternatively contact me by email on josephine.n.booth@strath.ac.uk.

Yours sincerely
Josephine Booth

Appendix H. Consent form for parents for Study 2.

University of Strathclyde
Department of Psychology

Consent Form

Dear Parent/Guardian,

Thank you for reading my information sheet and considering allowing your child to participate in this study. By signing below you show you understand and agree to the following conditions of participation:

- I understand that participation is completely voluntary and that I am under no obligation to take part.

- I understand that either myself or my child has the right to withdraw from this study at any point before, during and after the study has taken place and will not be required to give a reason.

- I understand that all information will be made anonymous and treated in the strictest confidence and that all information will be stored in a secure location for a 5 year period and will be destroyed there after.

If you agree for your child to participate please sign and date this form and return it to your child's class teacher no later than XX/XX/XX.

Thank you.

Yours faithfully

Josephine Booth James Boyle (Supervisor)

I agree to my child's participation in the above study and I have read and understood the terms of participation.

Signed ………………………………………………………Date…………

Child's name (in capitals) …………………………………………………

Class Teacher……………………………………………….....................

Appendix I. Consent form for pupils for Study 2.

University of Strathclyde
Department of Psychology

CONSENT FORM
FOR PERMISSION FOR A SCHOOL AGE PUPILTO PARTICIPATE IN A RESEARCH STUDY

Dear Pupil

We are writing to ask for your help in a research study aimed at finding out more about reading. The research is supervised by James Boyle, Department of Psychology, University of Strathclyde (0141 548 2584).

We are involving pupils in primary schools in the study. Pupils are asked to complete five memory tasks and a short reading test.

The names of the pupils who take part and the school's identity will be confidential and will not be identifiable in any report of the study.

PLEASE COMPLETE AND RETURN THIS FORM IF YOU WISH TO PARTICIPATE IN THE RESEARCH STUDY

PLEASE USE BLOCK CAPITALS

I (INSERT YOUR NAME) ______________________________,

A PUPIL IN (INSERT CLASS OR FORM) ______________________________,

OF (INSERT NAME OF SCHOOL) ______________________________,

GIVE MY PERMISSION TO PARTICIPATE IN THE RESEARCH STUDY DESCRIBED IN THE LETTER ATTACHED.

I MAY WITHDRAW FROM THE STUDY AT ANY STAGE SHOULD I WISH TO DO SO.

SIGNATURE:……………………………………… DATE:

Appendix J. Parent information sheet for Study 3.

Information sheet

The relationship between reading skills and working memory processes

Dear Parent/Guardian,

I am a postgraduate student undertaking a PhD in Psychology at the University of Strathclyde and as a requirement for my degree I am carrying out a research project looking at how children's working memory influences their reading. The study has been approved by the Department of Psychology's Ethics Committee and by XXXXXX, on behalf of XXXXX Council, and is supervised by James Boyle in the Department of Pychology at the University of Strathclyde who can be contacted either by telephone on 0141 548 2584 or by email at j.boyle@strath.ac.uk.

Those taking part will be pupils from the P 5, 6 and 7 stages. Both males and females will be taking part. Participants would be asked to complete a short individually-administered test of reading ability followed by a test of reading comprehension, one of oral language, a test of general ability and several standard individually-administered tasks used to assess working memory skills. The procedure will involve two sessions of 45 minutes each per pupil.

The first working memory task will involve pupils naming the ink in which a colour name is printed and the second will require pupils to underline specific numbers on a page, while ignoring distracting numbers. The third task will require pupils to name as many examples of a particular category as possible and the fourth will require pupils to join the dots on a grid to make as many unique patterns as possible. In addition, standard tasks of working memory will be presented on a laptop where pupils will be asked to remember words and recall patterns.

Participation is completely voluntary and you are under no obligation to take part. You or your child have the right to withdraw from this study at any point before, during and after the study has taken place and will not be required to give a reason. All information will be made anonymous and treated in the strictest confidence. All information will be stored in a secure location for a 5 year period and will be destroyed there after.

I would be very grateful if you would consider allowing your child to participate in this study. Please find attached a consent form for you to sign and return to school if you are happy for your child to take part. If you require any further information please do not hesitate to contact me at Department of Psychology, Graham Hills Building, University of Strathclyde, 40 George Street, G1 1QE or alternatively contact me by email on josephine.n.booth@strath.ac.uk.

Yours sincerely
Josephine Booth

Appendix K. Parent consent form for Study 3.

University of Strathclyde
Department of Psychology

Consent Form

Dear Parent/Guardian,

Thank you for reading my information sheet and considering allowing your child to participate in this study. By signing below you show you understand and agree to the following conditions of participation:

- I understand that participation is completely voluntary and that I am under no obligation to take part.
- I understand that either myself or my child has the right to withdraw from this study at any point before, during and after the study has taken place and will not be required to give a reason.
- I understand that all information will be made anonymous and treated in the strictest confidence and that all information will be stored in a secure location for a 5 year period and will be destroyed there after.

If you agree for your child to participate please sign and date this form and return it to your child's class teacher no later than XX/XX/XX.

Thank you.

Yours faithfully

Josephine Booth James Boyle (Supervisor)

I agree to my child's participation in the above study and I have read and understood the terms of participation.

Signed ……………………………………………………….Date…………

Child's name (in capitals) …………………………………………………

Class Teacher……………………………………………….....................

Appendix L. Pupil consent form for Study 3.

University of Strathclyde
Department of Psychology

CONSENT FORM
FOR PERMISSION FOR A SCHOOL AGE PUPILTO PARTICIPATE IN A RESEARCH STUDY

Dear Pupil

We are writing to ask for your help in a research study aimed at finding out more about reading. The research is supervised by James Boyle, Department of Psychology, University of Strathclyde (0141 548 2584).

We are involving pupils in primary schools in the study. Pupils are asked to complete several memory tasks and a reading test.

The names of the pupils who take part and the school's identity will be confidential and will not be identifiable in any report of the study.

PLEASE COMPLETE AND RETURN THIS FORM IF YOU WISH TO PARTICIPATE IN THE RESEARCH STUDY

PLEASE USE BLOCK CAPITALS

I (INSERT YOUR NAME) ______________________________,

A PUPIL IN (INSERT CLASS OR FORM) ______________________________,

OF (INSERT NAME OF SCHOOL) ______________________________,

GIVE MY PERMISSION TO PARTICIPATE IN THE RESEARCH STUDY DESCRIBED IN THE LETTER ATTACHED.

I MAY WITHDRAW FROM THE STUDY AT ANY STAGE SHOULD I WISH TO DO SO.

SIGNATURE:……………………………………… DATE: