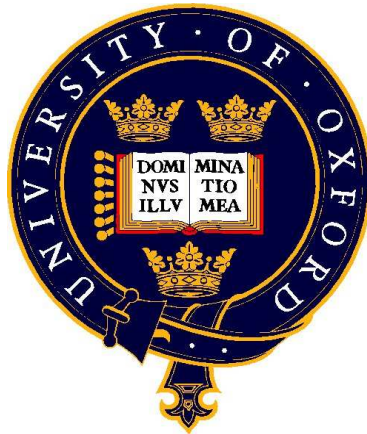


**An incomplete understanding: Clarifying some causes
and consequences of the 'poor comprehender' profile.**



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Thesis submitted for the degree of Doctor of Philosophy

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Publications arising from this thesis

Portions of this thesis appear in the following publications:

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Pimperton, H., & Nation, K. Poor comprehenders' deficits in the suppression of irrelevant information extend to the level of the mental model. *Scientific Studies of Reading*.

Short abstract

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The research presented in this thesis had two overarching aims; the first, to supplement our knowledge concerning the aetiological underpinnings of poor comprehension, and the second, to investigate the impact of being a poor comprehender on behavioural and educational outcomes in the school context. A combination of standardised test batteries, novel experimental paradigms, and questionnaire measures were used to obtain data that addressed hypotheses connected to these two aims. Poor comprehenders were found to have working memory deficits, as well as more specific deficits in suppressing irrelevant information from working memory. However, these deficits were largely confined to the verbal domain, giving credence to the theory that their poor performance on working memory and suppression tasks may be driven by underlying language difficulties. Poor comprehenders did show some evidence of broader executive deficits in both the verbal and non-verbal domains, raising the possibility that there might be subgroups of poor comprehenders with distinct aetiological profiles. In terms of behavioural and educational outcomes, poor comprehenders' deficits were found to impact selectively on these areas, producing a distinct pattern of behavioural and educational impairments. These findings highlighted the need for early identification of, and effective intervention for, poor comprehenders.

Long abstract

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A poor comprehender is a child who has significant deficits in their reading comprehension ability, despite having reading accuracy skills that are appropriate for their age. Approximately 10% of primary school-aged children meet the profile of being a poor comprehender (Nation & Snowling, 1997), but much less is known about the causes and consequences of this reading disorder than the more widely-studied specific word reading disorder, dyslexia. The research presented in this thesis therefore aimed to supplement our knowledge concerning the causal factors that may be playing a role in poor comprehension, and the behavioural and educational outcomes associated with being a poor comprehender.

One key theory of causation in poor comprehension is that poor comprehenders have difficulty with appropriately regulating the contents of working memory (cognitive inhibition), meaning that working memory gets overloaded with irrelevant information, and cannot support comprehension in the way that it should. Chapter 2 presents an experiment that followed from this strand of research into poor comprehension. Previous experiments had typically examined poor comprehenders' ability to suppress irrelevant information from working memory using simple, experimental recall tasks that involved single words or sentences. This

experiment used a newly-created narrative suppression paradigm to explore the ability of poor comprehenders and tightly-matched controls to suppress no longer relevant information at the level of the mental model. By requiring the participants to update their situation model of a narrative when new information replaced older information, it was possible to determine whether poor comprehenders' suppression deficits extended to the level of the narrative. The inclusion of comprehension questions throughout the narratives also allowed me to explore whether suppression deficits could be having a *direct* impact on the core difficulty of poor comprehenders, that is, in understanding and taking meaning from narratives. It was found that previous demonstrations of suppression deficits in simple experimental recall tasks did extend to the level of the narrative; when listening to stories, poor comprehenders seemed to find it harder than controls to update their mental model of the narrative, with earlier, interfering information that should have been suppressed impacting negatively on their ability to answer questions about the stories. These findings supported the idea that poor comprehenders' had deficits in cognitive inhibition, and provided a direct mechanism whereby suppression deficits could impact on comprehension at the level of the narrative. However, as with all previous studies of cognitive inhibition in poor comprehenders, the experiment failed to take account of the role that underlying language deficits (another important aetiological theory of poor comprehension) could be playing in the outcome.

In the experiments reported in Chapters 3 and 4 therefore, attempts were made to address this by examining links between comprehension and cognitive inhibition in both the verbal and the non-verbal domain. The reasoning behind this

approach was that if deficits in working memory and suppression are due not to central executive deficits in regulating the contents of working memory, but instead to language deficits that impact on verbal tasks, then poor comprehenders should show deficits only in working memory and suppression tasks that involve verbal information. In Chapter 3, links between comprehension and performance on two newly-created suppression tasks were examined in a large unselected sample of typically developing 7- to 8-year-olds. These tasks were based on a proactive interference paradigm, with one requiring children to suppress no longer relevant verbal information, and the other requiring them to suppress no longer relevant non-verbal information. The tasks were designed to provide a measure of children's suppression ability within both the verbal and the non-verbal domains, and so to allow us to determine whether previously-established links between suppression and comprehension were domain-specific (i.e. exclusive to the verbal domain) or domain-general. An association was found between comprehension performance and verbal, but not non-verbal, suppression ability, raising the possibility that poor comprehenders may show verbal-only deficits in cognitive inhibition and working memory. The studies reported in Chapter 4 capitalised upon the two suppression tasks developed in Chapter 3, in combination with verbal and non-verbal standardised tests of working memory, to address this possibility. Poor comprehenders showed domain-specific deficits on each of the working memory and suppression tasks they completed, supporting the idea that their difficulties on these tasks can be accounted for by underlying difficulties with the representation and processing of verbal material, rather than a failure at the level of the central executive.

Chapters 2-4 of this thesis focus on cognitive inhibition, and the links between this aspect of inhibitory control and comprehension. Cognitive inhibition however, is just one aspect of executive inhibitory control, a construct which comprises many different types of inhibitory processes. The links between these different inhibitory processes are not well specified, so it was not known whether deficits in cognitive inhibition would transfer to other aspects of executive inhibition. Chapter 5 reports a series of experiments that aimed to explore wider aspects of inhibitory control in poor comprehenders. Participants completed tasks selected to measure interference control (inhibition of an irrelevant dimension of a stimulus) and behavioural inhibition (inhibition of a prepotent response). These tasks took place in both the verbal and the non-verbal domains to enable continued exploration of the domain-specificity of any observed poor comprehender deficits. Results suggested broad deficits in executive inhibition in poor comprehenders which spanned both the verbal and the non-verbal domain, a finding that contrasted with the results reported in Chapter 4. Potential explanations for these findings, including verbal mediation of executive tasks, and the influence of aetiologically-distinct subgroups of poor comprehenders, are discussed.

Chapters 6 and 7 go on to report a series of studies that aimed to examine the consequences of being a poor comprehender. These studies were designed to supplement the paucity of information that exists concerning behavioural outcomes in poor comprehenders, and to provide a more fine-grained analysis of their educational outcomes. Chapter 6 reported the results of a questionnaire study which asked teachers to rate poor comprehenders and controls on a variety of measures of behaviour and academic performance. Behavioural measures included the SDQ

which provides information on children's behaviours, emotions and relationships within the school environment, the WMRS which identifies classroom behaviours that may be a manifestation of working memory deficits, and the CTRS-R (S) which assesses problem behaviours typically associated with attention deficits. Educational attainment was assessed with a questionnaire that asked teachers to rate the performance of the child in question relative to their same-aged peers on a range of different curriculum areas. Poor comprehenders were rated as showing both behavioural and educational deficits relative to control children, but deficits in these areas were not universal. The pattern of behavioural and educational strengths and weaknesses was consistent with previous work concerning the fundamental cognitive and language deficits that may be driving poor comprehension.

Chapter 7 presents a series of experiments which focused in on one specific curriculum area; mathematics. The specific profile of language strengths and weaknesses shown by poor comprehenders raised specific predictions about how they would perform in different types of mathematical task. These predictions were tested by administering two standardised tests, each tapping a different aspect of mathematical ability, in order to observe whether poor comprehenders displayed a dissociation in their performance on the two tasks. Poor comprehenders showed unimpaired performance on a task tapping basic arithmetic ability, which was attributed to their spared phonological processing skills. By contrast they showed deficits on a measure of mathematical reasoning, which was more dependent on verbal ability, involving items such as word problems; this was attributed to their non-phonological oral language weaknesses. Regression analyses supported the idea that group differences in verbal ability were playing a key role in the group

differences in mathematical reasoning performance. Furthermore, regression analyses using data from a large sample of typically developing children showed that verbal ability was a significant predictor of mathematical reasoning performance over and above basic arithmetic ability, confirming that verbal ability does play an important role in mathematical reasoning performance. These results highlighted how the cognitive deficits that underlie poor comprehension can impact on wider areas of the curriculum.

In summary, the research presented in this thesis aimed to make a significant contribution to the knowledge base concerning children who have specific reading comprehension difficulties; poor comprehenders. A series of experiments were designed to elucidate the complex interplay of causal factors which drive poor comprehension, and to explore the impact that being a poor comprehender has on behavioural and educational outcomes. Results from these experiments not only informed our theoretical understanding, but also produced important insights into possible avenues for education and intervention for poor comprehenders.

Chapter 1: General introduction and overview of the thesis

This chapter provides an overview of existing literature related to the fundamental questions addressed by this thesis. It discusses two core approaches to explaining the specific comprehension deficits that are observed in children who are poor comprehenders, and suggests that by uniting these two approaches within the research in this thesis, a clearer picture regarding the aetiological underpinnings of poor comprehension will be attained. This chapter also highlights the paucity of information available to us concerning the behavioural and educational outcomes of being a poor comprehender, leading to the conclusion that research included in this thesis must attempt to enhance the knowledge base in this area. The provision of this first literature review seeks to provide context to the key aims of this thesis; more specific literature reviews will be included within each chapter to appropriately frame the experiments reported therein. The final section of this chapter contains an overview of the thesis, which sets out what each chapter will include, and with what aim.

The poor comprehender profile

To be a successful reader, a child needs to master two distinct sets of skills. Firstly, they need to be able to translate the text that they see on the page into a kind of speech-based code, that is, to read words. Once they have access to that speech-based code however, they also need to be able to understand what it means; they need linguistic comprehension skills to enable them to extract meaning from what they have read. A combination of these two sets of skills allows a child to achieve the ultimate goal of reading; reading for meaning. The necessity of both word reading and linguistic comprehension skills for reading comprehension was

highlighted and formalised by Hoover and Gough (1990) in their 'Simple View of Reading' model. The Simple View suggests that an individual's reading comprehension ability results entirely from a multiplicative combination of their word reading and linguistic comprehension abilities, meaning that both of these skills are necessary for successful reading comprehension, but neither is sufficient on its own. The quadrant diagram shown in Figure 1.1 demonstrates how strengths and weaknesses in word reading (decoding) and linguistic comprehension can combine to create different profiles of reading ability.

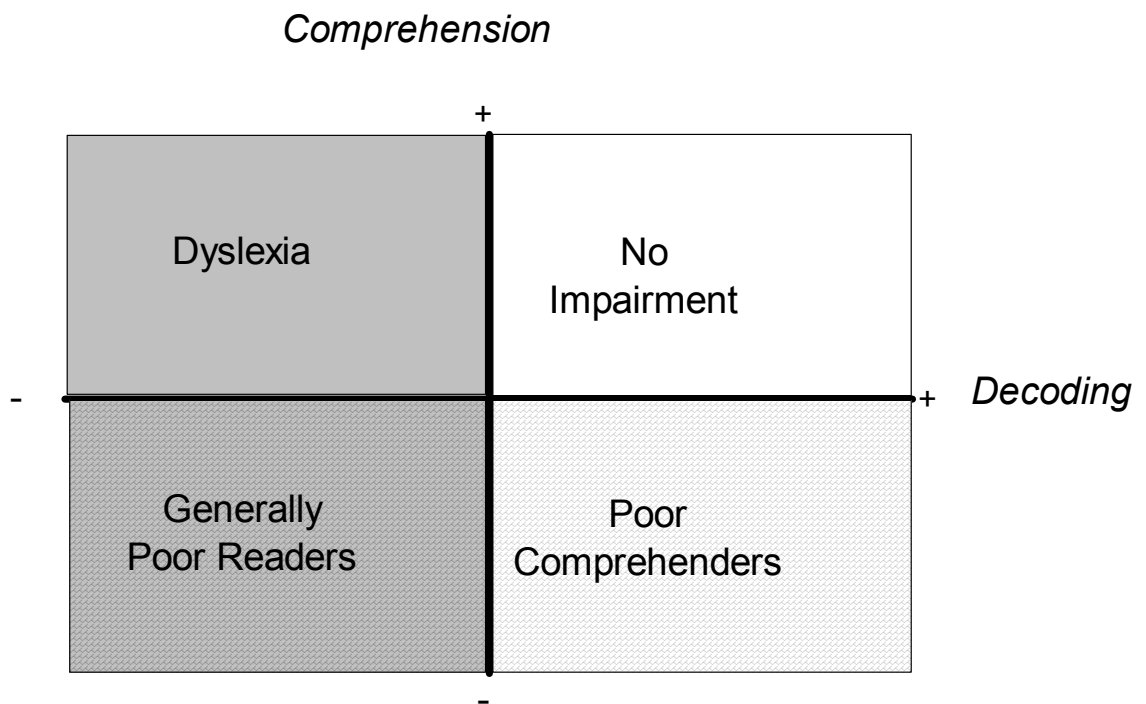


Figure 1.1. Representation of the multidimensional space around the two components of reading (decoding and linguistic comprehension) that comprise the Simple View (after Bishop & Snowling, 2004).

Although decoding and linguistic comprehension skills tend to develop in tandem (as is the case in quadrants B and C of this diagram), it can be the case that the two sets of skills dissociate, and specific deficits in one or the other can be observed. To return to Hoover and Gough's Simple View, one would assume that children in quadrants A and D would show deficits in their reading comprehension ability, but that these deficits would arise for different reasons. The poor decoding skills of the dyslexic children in quadrant A would be the sole limiting factor on their reading comprehension outcomes, given their typically-developing linguistic comprehension skills. In keeping with this, children with dyslexia tend to show spared comprehension skills if tested in a way which is independent of word reading ability (see Bishop & Snowling, 2004). Conversely, the children in quadrant D show normal word reading skills, meaning that their reading comprehension is thought to be limited exclusively by deficits in their linguistic comprehension. This thesis will focus on these children, whose reading comprehension deficits cannot be accounted for by any lower-level weaknesses in decoding ability, and will attempt to increase our knowledge base regarding this particular reading disorder. Approximately 10% of primary school-aged children show significant and specific impairments in their reading comprehension performance despite age-appropriate decoding skills (Nation & Snowling, 1997), thus fitting the profile of a poor comprehender. Despite this rate of prevalence, much less is known about the causes and consequences of being a poor comprehender, as compared with those of having specific word reading disorder; dyslexia. This chapter will review what is already known about poor comprehenders, and will outline the areas in which this thesis aims to supplement our knowledge.

Discourse-level skills in poor comprehenders

A significant body of research has established that poor comprehenders have deficits in the discourse-level skills that foster efficient comprehension (see Cain & Oakhill, 2007, for review). I will now discuss some of the research that has examined these discourse-level skills in poor comprehenders, including experiments that have focused on inference making and comprehension monitoring. Inference making in this context refers to the ability of the reader to go beyond what is explicitly stated in a text and form a coherent representation of the intended meaning of that text through the generation of inferences. Cohesive inferences involve the integration of information across different parts of a text (e.g. pronoun and anaphor resolution; inferring that 'he' in one sentence refers to the male character mentioned in the previous sentence), while knowledge-based inferences involve the reader applying their general knowledge to the information provided explicitly in the text in order to understand the implicit ideas intended by the author (e.g. bridging inferences to explain causality; inferring that James was attempting to put out the fire after reading the sentences 'The fire started to blaze out of control. James grabbed a bucket and filled it with water.'). Both of these types of inference are necessary if the reader is to build a coherent representation of the text. Work by Oakhill and colleagues (Oakhill, 1982, 1984; Oakhill & Yuill, 1986) provided the first suggestion that poor comprehenders have difficulties with inference making, with results showing that they generate fewer of both of the types of inferences described above than skilled comprehenders. Moreover, the findings that poor comprehenders

showed equivalent memory to controls for literal information contained in the text (Oakhill, 1982), and that they continued to show weaknesses in inference making when they were allowed to look back at the text (Oakhill, 1984), combined to suggest that their inference making difficulties were unlikely to be solely driven by problems with memory of the text.

More recently, Bowyer-Crane & Snowling (2005) looked in more detail at how poor comprehenders perform on different types of inferences by classifying the questions of two commonly used reading comprehension measures according to the type of inference (if any) a successful response would require. They confirmed Oakhill's findings of a lack of differences between poor comprehenders and controls on questions which assessed literal information presented explicitly in the text, and of significant deficits in poor comprehenders on questions which required the integration of world knowledge; knowledge-based inferences. The findings regarding cohesive inferences were less conclusive. The poor comprehenders did not differ significantly from the controls in terms of their ability to answer questions that required cohesive inferences. However, they did perform more poorly on cohesive questions compared to literal questions, whereas the controls did not show significant differences between these two categories, giving some suggestion of difficulties with cohesive inferences for the poor comprehender group. Further work is needed to clarify the extent to which poor comprehenders are impaired in cohesive inference generation, but what is clear is that knowledge-based inferences are particularly challenging for them. Could it be the case then that poor comprehenders' inference making difficulties are substantially driven by underlying deficits in general knowledge? Cain, Oakhill, Barnes, and Bryant (2001) explored this

question by examining links between inference making ability and comprehension outcomes when controlling for individual differences in general world knowledge. They found that poor comprehenders made significantly fewer inferences than the skilled comprehenders, even when the knowledge base of the two groups was equivalent, thus suggesting that lack of background knowledge, like lack of memory for the text, is not a key factor in poor comprehenders' inference making difficulties.

Another discourse-level skill that has been examined in poor comprehenders is comprehension monitoring, that is, the ability to monitor one's own understanding of a text and recognise inconsistencies so that action can be taken to resolve them (e.g. by checking back or re-evaluating one's interpretation of an ambiguous word). Early work by Yuill and Oakhill (1991) used inconsistency detection tasks, in which participants were required to monitor their ongoing representation of the text in order to detect inconsistencies within passages of text (e.g. conflicting sentences). They found that poor comprehenders experienced difficulties with these tasks, as well as on other more implicit measures of comprehension monitoring, such as reading times for inconsistent sentences (i.e. they showed less slowing in their reading time on these sentences than skilled comprehenders), suggesting that they have weaknesses in monitoring their own comprehension. The findings of Ehrlich, Remond, and Tardieu (1999) confirmed these earlier findings of comprehension monitoring weaknesses in poor comprehenders. They examined comprehension monitoring in the context of an anaphoric processing inconsistency detection task, which required the participants to read text and look for inconsistent anaphors. Poor comprehenders were less likely than the skilled comprehenders to identify the inconsistent anaphors, and less able

to explain why the ones they identified were inconsistent. Furthermore, the increase in time that they showed in response to reading texts with inconsistent anaphors was much smaller than that shown by the skilled comprehenders and they showed fewer look backs to the previous section of text in response to an inconsistent anaphor. Taken together these results suggest that poor comprehenders are less efficient at monitoring their own comprehension than skilled comprehenders.

The research presented above suggests that poor comprehenders have deficits in the discourse-level skills that are necessary for successful text comprehension. However, although the finding of weaknesses in inference making and comprehension monitoring provides a good description of skill deficits that may be contributing to comprehension failure in poor comprehenders, it does not explain *why* these children are experiencing such deficits. Previous research that has attempted to provide a causal account for poor comprehenders' difficulties has tended to take one of two broad explanatory approaches, emphasising either the role of language deficits or of weaknesses in certain aspects of executive function, particularly working memory, as the core deficit in children with specific reading comprehension difficulties. I will discuss each of these approaches in turn below, and will provide an overview of relevant research findings.

Language abilities in poor comprehenders

One approach to explaining comprehension failure in poor comprehenders has viewed language and verbal deficits as playing a key causal role in this reading disorder. Previous research has indicated that poor comprehenders have deficits in a

number of different language domains, and will be reviewed below. Nation, Clarke, Marshall, and Durand (2004) compared poor comprehenders with age- and decoding ability-matched controls on a battery of oral language measures, including tasks tapping the linguistic domains of phonology, semantics and morphosyntax, as well as a range of other broader language skills which required children to draw on a combination of the aforementioned three domains. They found that poor comprehenders displayed a distinct pattern of strengths and weaknesses across these language domains, showing spared phonological processing skills, as evidenced by performance comparable to the controls on the phonological tasks in the battery. This is despite impairments on all the other language measures that comprised the battery (i.e. those measuring knowledge of semantics, morphosyntax and broader oral language skills), suggesting that poor comprehenders have wide-ranging deficits in their non-phonological language skills.

Results from studies that have looked individually at each of these different domains of language ability support the findings of Nation et al. (2004). For example, Stothard and Hulme (1995) examined the phonological skills of poor comprehenders using three different phonological processing tasks, and found that they showed age-appropriate phonological performance on each of these tasks, implying unimpaired phonological processing skills in this group. Similarly, Cain, Oakhill, and Bryant (2000) administered a series of phonological processing tasks to children with specific reading comprehension difficulties, and found that these poor comprehenders showed comparable performance to control children with good reading comprehension, again suggesting that poor comprehenders do not have phonological deficits.

There is also considerable evidence to support Nation et al.'s (2004) finding of impairments in non-phonological language domains, including semantics and morphosyntax, in poor comprehenders. In the domain of semantics, Nation and Snowling (1998) found that poor comprehenders had weaknesses in semantic knowledge, as evidenced by measures of both receptive and expressive vocabulary. Furthermore, the same children showed weaknesses relative to the controls at reading low frequency and exception words despite being matched for non-word decoding ability, suggesting that they have difficulties in reading words which are typically read with support from semantics. In keeping with this idea of weak semantic representation or processing in poor comprehenders, Nation and Snowling (1999) found that the pattern of performance produced by poor comprehenders on semantic priming tasks indicated a lack of sensitivity to semantic relations in these children compared to control children with good reading comprehension. Evidence from neurophysiological studies of brain responses to semantic processing tasks also converges to suggest that poor comprehenders have atypical performance in the area of semantic processing. Landi and Perfetti (2007) examined brain responses of poor and skilled comprehenders during semantic and phonological processing tasks. While poor comprehenders did not differ from the controls in their brain responses during the phonological processing task, they did show a different pattern of electrophysiological responses during the semantic processing task, which the authors argued were indicative of weaknesses in semantic processing.

Evidence for weaknesses in the domain of morphosyntax for poor comprehenders, as indicated by the findings of Nation et al. (2004), has also been substantiated by other studies. Nation and Snowling (2000) provided early evidence

to suggest that poor comprehenders' difficulties extend to the domain of syntactic processing. They used a word order correction paradigm, in which children heard a scrambled sentence and were required to put the words in the correct order, to demonstrate that poor comprehenders had weaknesses in syntactic awareness relative to controls. This finding of difficulties with syntactic processing in poor comprehenders was corroborated by the work of Adlof and Catts (2009), who carried out a comprehensive assessment of poor comprehenders' morphosyntactic skills. They administered three different measures of morphosyntax; an irregular verb grammaticality judgement task in which children were required to judge whether a sentence including an irregular verb (e.g. 'The boy fighted at school) was a correct sentence, a be-do question grammaticality judgement task in which children were required to judge whether a sentence including the verb 'be' or 'do' (e.g. where do a boy like to play?) was a correct sentence, and a finiteness elicitation task which used cloze sentences to elicit different types of inflections (e.g. regular plurals). Poor comprehenders showed deficits relative to controls in each of these three assessments of morphosyntax, suggesting that their language deficits do encompass morphosyntax as well as semantics.

The results described above support Nation et al.'s (2004) claims of wide-ranging non-phonological oral language deficits in poor comprehenders in the face of unimpaired phonological language skills. The authors of that study concluded that poor comprehenders' deficits in oral language act as a limiting factor on their reading comprehension development, while their competence in the domain of word reading arises from their spared phonological skills. This conclusion has been supported by the findings of two important longitudinal studies that have examined

the language abilities of poor comprehenders over time. Catts, Adlof, and Ellis Weismer (2006) selected a group of 13- to 14-year-old poor comprehenders and looked retrospectively at data, collected as part of the Iowa Epidemiological Study of Language Impairment (Tomblin, et al., 1997), when the children were approximately 5.5 years old, 7.5 years old, and 9.5 years old. These data provided information on the children's phonological processing ability and their language comprehension at each time point. The poor comprehenders showed language comprehension deficits (particularly in measures of vocabulary and discourse comprehension) relative to control children at each time point, whilst showing no deficits in their phonological skills, except on one measure of phonological awareness administered at the first time point. These findings suggest that poor comprehenders have deficits in the language abilities that promote skilled comprehension from an early age, whilst the phonological skills known to support word reading development seem to develop relatively normally in these children.

A recent study by Nation and colleagues (Nation, Cocksey, Taylor, & Bishop, in press) confirmed this pattern of findings. They selected a group of 8-year-old poor comprehenders and looked back at data collected on their phonological and non-phonological language skills each year since they started school at the age of 5. As with the poor comprehenders in the Catts et al. (2006) study, these poor comprehenders showed persistent difficulties with non-phonological language tasks relative to control children from the age of 5 onwards, despite showing largely normal performance on tasks measuring phonological language ability. Taken together, these two longitudinal studies show that deficits in non-phonological oral language skills do seem to drive comprehension deficits. The finding that these

language deficits are present before children begin to learn to read suggests that it is oral language problems that lead to reading comprehension problems, rather than vice-versa. The studies also support the idea that poor comprehenders' decoding competence arises from their spared phonological processing skills.

To summarise then, this approach to explaining specific comprehension deficits in poor comprehenders argues for a fundamental weakness in non-phonological language processing which leads to comprehension deficits in both reading and language domains. Such a weakness could impact on comprehension both directly and via an influence on the discourse-level skills described above. For example, the weaknesses in poor comprehenders' syntactic and semantic processing and awareness discussed above (e.g., Nation, et al., 2004) are likely to affect their ability to successfully resolve anaphors within and across sentences (cohesive inference making) because they will be less able to use cues provided by semantics and morphosyntax to assist with this resolution process.

Working memory abilities in poor comprehenders

An alternative approach to the one described above attributes comprehension failure not to underlying language deficits, but to deficits in cognitive processes that fit within the rubric of executive function. Executive function refers to a host of higher order cognitive skills that enable goal-directed behaviour, including working memory, attentional control, planning, organising, self-monitoring, cognitive flexibility, and inhibition. Of these executive processes, working memory has been the one most often studied in relation to poor comprehension, with comprehension

failure seen as a consequence of underlying impairments in the working memory processes that are necessary for skilled reading comprehension (Daneman & Carpenter, 1980; Daneman & Merikle, 1996; Yuill, Oakhill, & Parkin, 1989). A more specific version of this hypothesis suggests that working memory impairments in poor comprehenders are a consequence of inefficient regulation of the contents of working memory, resulting from weak cognitive inhibitory skills (Carretti, Cornoldi, De Beni, & Romano, 2005; De Beni & Palladino, 2000; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Palladino, Cornoldi, De Beni, & Pazzaglia, 2001). This hypothesis will be explained in more detail below.

However, before discussing the evidence that links working memory performance with reading comprehension ability, it is first necessary to consider what is meant by working memory. Baddeley's multicomponent model (see Baddeley, 2007) is the most widely cited and researched model of working memory. It posits the existence of two domain-specific slave systems, the phonological loop and the visuospatial sketchpad, subserving short-term storage of verbal and visual information respectively. It also argues for the existence of a domain general central executive which controls the operation of the two slave systems, and plays an important role in attentional control. Based on a series of empirical findings that the original three component model was unable to accommodate, Baddeley (2000) modified the model to include an episodic buffer; a multi-modal, limited-capacity storage system that serves to integrate information from multiple mnemonic sources in order to create multi-dimensional representations, or 'episodes'.

Although other theoretical conceptualisations of working memory diverge from Baddeley's multicomponent model in many ways (Miyake & Shah, 1999a) the

central tenet of working memory seems to be that it is a system involved in the simultaneous storage and processing of information. In line with this, Miyake and Shah (1999b) suggested that the definition of working memory as ‘those mechanisms or processes that are involved in the control, regulation, and active maintenance of task-relevant information in the service of complex cognition’ is one on which the majority of working memory researchers agree. There exist large individual differences in working memory (Conway, Jarrold, Kane, Miyake, & Towse, 2007), and variation in working memory ability is an important predictor of a diverse range of cognitive, educational, behavioural, and psychological outcomes (Barrett, Tugade, & Engle, 2004; Conway, Cowan, & Bunting, 2001; Daneman & Carpenter, 1980; Gathercole, Pickering, Knight, & Stegmann, 2004; Moore, Clark, & Kane, 2008; Rasmussen & Bisanz, 2005). Importantly for this discussion of poor comprehenders, working memory ability is strongly associated with both reading and language comprehension.

Daneman and Merikle (1996) reported a large meta-analysis (77 studies, with a combined total of 6,179 participants), showing that performance on a range of verbal working memory measures predicts comprehension ability. By contrast, short-term, storage-only memory capacity was a much weaker predictor of comprehension. In line with this general relationship between working memory and reading comprehension, children with specific reading comprehension difficulties show impairments on tasks tapping working memory (Cain, 2006; Carretti, Borella, Cornoldi, & De Beni, 2009; Nation, Adams, Bowyer-Crane, & Snowling, 1999; Yuill, et al., 1989). For example, Yuill et al. (1989) examined working memory ability in poor comprehenders using a digit working memory task. Children were required to read

aloud strings of three numbers (the processing component) and then recall the final digit of each string at the end of the trial (the recall component). Poor comprehenders performed significantly less well than controls on this working memory task, and a strong correlation was evidenced between reading comprehension and working memory performance. In a more recent study, Cain (2006) confirmed these early findings using two working memory measures, both of which involved the simultaneous processing and storage of information. One was a sentence span task in which the participating children heard a sentence and had to complete the final word of that sentence, and then remember the final word of each completed sentence for recall at the end of the trial. The other was a counting span task in which children had to count an array of dots and then remember the total of each array for recall at the end of the trial. Poor comprehenders showed deficits relative to the controls on both of these working memory tasks, although group differences were larger on the sentence span task than the counting span task, suggesting that the higher the semantic content of the task the greater the poor comprehenders' impairments. This raises important questions about the role that language ability may play in determining performance on working memory tasks and will be discussed later on in this chapter, and in Chapters 3 and 4 in more detail.

To return to the working memory approach to explaining poor comprehenders' deficits, the next question concerns what cognitive processes might underpin weak working memory in these children. There are now numerous demonstrations of unimpaired phonological loop function, arguing against an impairment at the level of storage: poor comprehenders show equivalent effects of length, lexicality and phonological confusability in short-term recall to controls, and

they have normal levels of phonological short-term memory, as measured by non-word repetition (Cain, 2006; Nation, et al., 2004; Oakhill, Yuill, & Parkin, 1988; Stothard & Hulme, 1992). If Baddeley's working memory model is a correct representation of the working memory system, the finding of impaired working memory despite intact short-term memory points to some form of deficit at the level of the central executive. One suggestion advocated by De Beni and colleagues (Carretti, et al., 2005; De Beni & Palladino, 2000; De Beni, et al., 1998; Palladino, et al., 2001) is that the central executive has difficulties in regulating the contents of working memory (cognitive inhibition), that is, in inhibiting irrelevant information from entering into working memory, and suppressing no longer relevant information from working memory. In keeping with this, in recent years, evidence has accumulated pointing to weaknesses in cognitive inhibition characterizing individuals with reading comprehension difficulties. For example, adults with poor reading comprehension are worse than skilled comprehenders at suppressing irrelevant information, such as the contextually inappropriate meanings of ambiguous words or homophones (Gernsbacher & Faust, 1991; Gernsbacher, Varner, & Faust, 1990). Adults with poor comprehension also make more intrusion errors in recall tasks, producing irrelevant or no longer relevant words instead of the targets (De Beni et al., 1998; Palladino et al., 2001). This failure to efficiently regulate the contents of working memory is believed to result in overload of this limited-capacity system, and thereby to detrimentally impact on poor comprehenders' working memory performance.

Similar results have been found in children with poor reading comprehension. For example, work by Carretti et al. (2005) and Cain (2006) has

supported the idea that individuals with poor reading comprehension have problems with working memory, and that these working memory deficits are associated with difficulties in suppressing irrelevant information. Both studies revealed inhibition deficits in memory in children identified as poor comprehenders. Information that was initially relevant but then became irrelevant was particularly difficult for poor comprehenders to suppress. Taken together, these findings suggest poor comprehenders have underlying inefficient cognitive inhibition, and it is argued that these weaknesses in inhibition lead to difficulties with regulating the contents of working memory, and consequent difficulties with reading comprehension. Support for this causal hypothesis comes from the longitudinal aspect of De Beni and Palladino's (2000) study. They compared the performance of 8-year-old good and poor comprehenders on a listening span task, as well as assessing their memory for relevant and irrelevant information in a passage of text that they had read. Like adult poor comprehenders, the poor comprehenders in this experiment produced a greater number of intrusion errors in the listening span task, producing words that were present in a trial but that were not the target words (i.e. words that were no longer relevant and that should have been suppressed). Furthermore, when required to recall as much information as possible from a passage they had read, in contrast to the good comprehenders, poor comprehenders actually recalled more irrelevant than relevant information from the passage. These findings add weight to the argument that poor comprehenders have difficulties with the suppression of no longer relevant information from working memory. Importantly, this study also demonstrated that the magnitude of these suppression difficulties also predicted their reading comprehension ability one year on, adding weight to the argument that

the efficiency with which a child can regulate the contents of working memory plays a causal role in the development of reading comprehension.

To summarise, the argument of this working memory approach to explaining comprehension failure in poor comprehenders is that a problem at the level of the central executive with appropriately regulating the contents of working memory leads to working memory getting overloaded and failing to support reading comprehension in the way that it should. Studies showing that poor comprehenders' deficits in inference making and comprehension monitoring were more pronounced when there was intervening text between the propositions of interest (Oakhill, Hartt, & Samols, 2005; Yuill & Oakhill, 1988) suggest that working memory deficits could be an explanatory factor in the discourse-level deficits that are apparent in poor comprehenders. For example, Oakhill, Hartt, and Samols (2005) manipulated a comprehension monitoring task, in which participants were required to detect pairs of sentences that were inconsistent with each other, so that the two sentences that comprised each pair were either adjacent (near condition; low working memory demands) or separated by intervening sentences (far condition; high working memory demands). They found that poor comprehenders showed much greater deficits relative to skilled comprehenders in their ability to detect inconsistencies in the text in the far condition, in which the working memory demands were high, than in the near condition. This finding was consistent with the idea that working memory deficits may be playing a role in the discourse-level comprehension monitoring deficits of poor comprehenders. However, analyses revealed that the contribution of working memory ability to performance in both the near and far conditions was similar, group differences in the far condition remained even when controlling for

working memory performance, and working memory was not a significant contributor to performance in the far condition when controlling for comprehension (whereas comprehension ability was when controlling for working memory). These three results combine to suggest that another factor, one that is linked strongly with comprehension, may be influencing differences between the groups in the far condition. Again, consideration needs to be given to the role that underlying language impairments could be playing in determining performance on tasks tapping the discourse-level skills that contribute to efficient comprehension.

Aims of thesis

A substantial body of evidence was presented above in support of the idea that poor comprehenders have difficulties in regulating the contents of working memory, which lead to working memory difficulties, which in turn contribute to comprehension deficits. One aim of this thesis is to explore this idea of cognitive inhibitory deficits in poor comprehenders further by developing a paradigm to explore their ability to suppress irrelevant information at the level of the narrative. This research will go beyond the simple experimental recall tasks using single words and sentences that have been used previously to examine suppression abilities in poor comprehenders, and will seek to determine whether poor comprehenders' suppression deficits impact directly on their core area of difficulty; understanding and taking meaning from narratives. However, despite the wealth of evidence regarding cognitive inhibitory deficits in poor comprehenders, there is also a significant amount of research showing that poor comprehenders have widespread

non-phonological language impairments, including deficits in semantics and morphosyntax. Furthermore, some studies have provided early indications that poor comprehenders' language weaknesses could be influencing their performance on working memory tasks. For example, Cain (2006) found that poor comprehenders showed greater impairments relative to controls on a working memory task with higher semantic content than on one with lower semantic content. Consequently, a second aim of this thesis was to explore the domain specificity of poor comprehenders' deficits on working memory and suppression tasks. Findings of verbal-only weaknesses for poor comprehenders on these tasks would point to a performance limitation arising from deficient language ability rather than from a deficit at the level of the domain-general central executive, an idea discussed in more detail in Chapter 4 of this thesis.

Cognitive inhibition is just one aspect of executive inhibitory control (see Nigg, 2000), an umbrella term for a number of different types of inhibitory processes. The links between these different inhibitory processes are not yet well specified, so it is not known whether deficits in cognitive inhibition would transfer to other aspects of executive inhibition. An additional aim of this thesis then, was to explore broader aspects of executive inhibitory control in poor comprehenders to establish the nature and extent of any inhibitory deficits, as well as to potentially shed light on the theoretical structure of these inhibitory processes. Again the aim was to explore inhibitory processing in both the verbal and the non-verbal domains, in order to clarify the role that underlying language weaknesses may be playing in driving any observed deficits on inhibitory tasks in poor comprehenders. By uniting the executive function and language approaches to explaining poor comprehenders'

comprehension problems in this thesis, I hope to be able to provide a clearer picture of the aetiological underpinnings of this reading disorder.

Despite the recent increase in research attempting to clarify the causal factors that may play a role in poor comprehension, the consequences of being a poor comprehender in terms of their impact on behavioural and educational outcomes in the school context have been largely neglected as an area of study. Although research has established a relationship between word reading deficits and behavioural problems in the classroom (Carroll, Maughan, Goodman, & Meltzer, 2005; Everatt, Weeks, & Brooks, 2008; Heiervang, Stevenson, Lund, & Hugdahl, 2001; Knivsberg & Andreassen, 2008), behavioural outcomes in children with specific reading comprehension difficulties have not yet been explored. Similarly, while a great deal is known about educational outcomes of children with specific word reading disorders, for example in mathematics (e.g., Miles, 1983; Miles, Haslum, & Wheeler, 2001; Pritchard, Miles, Chinn, & Taggart, 1989; Simmons & Singleton, 2006, 2008), much less is known about how poor comprehension, and the underlying deficits that lead to comprehension weaknesses, impact on educational development in different areas of the curriculum. Cain and Oakhill (2006) reported that poor comprehenders achieved significantly lower scores than skilled comprehenders in the standardised attainment tests (assessing skill in three different curriculum areas; maths, English, science) taken by all children at the end of Year 6, providing early evidence to suggest that poor comprehenders' deficits may be having an impact on their educational achievement beyond the domain of literacy. However, this was a very broad-brush approach to measuring educational attainment in these children, consisting as it did of these three broad curriculum

areas. Moreover, this assessment of educational performance depended on the children's performance on a series of tests, a potentially inaccurate reflection of their actual attainment in these curriculum areas. A more sensitive approach to examining educational outcomes is needed, in which classroom teachers (who are the people best-placed to provide information on a child's educational performance) clarify poor comprehenders' educational strengths and weaknesses across a much wider range of curriculum areas to provide a more nuanced picture of their abilities. Moreover, it must be acknowledged that even within one area of the curriculum (e.g. mathematics) there are multiple components to success, and children can succeed at one of these components whilst struggling with another. A final aim of this thesis therefore, is to carry out a series of studies designed to supplement the paucity of information that exists concerning behavioural outcomes in poor comprehenders, and to provide a more fine-grained analysis of their educational outcomes.

Overview of thesis

This thesis is comprised of two broad sections which correspond to the two overarching aims of the programme of research reported here, namely to clarify both the causes and the consequences of being a poor comprehender. Chapters 2-5 contain experiments that address the first of these aims, in that they attempt to supplement our knowledge regarding the aetiological underpinnings of poor comprehension. Chapters 6 and 7 present research designed to address the second aim which investigates the behavioural and educational outcomes associated with

poor comprehension. Of course, this distinction between the causes and consequences of poor comprehension is purely organisational, my research into the causes of poor comprehension informed my research into consequences and vice-versa, and links are made between chapters throughout. I will now present a brief overview of the thesis, detailing what experiments each chapter will include, and how these experiments will improve our understanding of children who meet the profile of a poor comprehender.

In Chapter 2, an experiment will be presented that follows from the strand of research concerning the presence of suppression deficits in poor comprehenders that was discussed earlier in this chapter. Previous experiments have examined suppression ability using simple, experimental recall tasks that involved single words or sentences. This experiment used a newly-created narrative suppression paradigm to explore participants' ability to suppress no longer relevant information at the level of the mental model. By requiring the participants to update their situation model of the narrative when new information replaces older information, it was possible to determine whether poor comprehenders' suppression deficits extend to the level of the narrative. The use of comprehension questions throughout the narratives also allowed me to explore whether suppression deficits could be having a *direct* impact on the core difficulty of poor comprehenders, that is, in understanding and taking meaning from narratives.

Chapter 3 will report a study which examined predictors of reading comprehension in a large unselected sample of typically developing 7- to 8-year-olds in a bid to answer a series of questions concerning the links between reading comprehension and other theoretically-relevant variables. Children carried out a

series of standardised tests measuring their reading ability, working memory, and verbal and non-verbal ability, which allowed me to explore whether working memory and verbal ability were significant predictors of reading comprehension outcomes over and above reading accuracy. This in turn would confirm that they were viable as factors that could limit comprehension in children whose reading comprehension is not being limited by their reading accuracy, i.e. poor comprehenders. The children also completed two newly-created suppression tasks. These tasks were based on a proactive interference paradigm, with one requiring children to suppress no longer relevant verbal information, and the other requiring them to suppress no longer relevant non-verbal information. The tasks were designed to provide a measure of children's suppression ability within both the verbal and the non-verbal domains, and so to determine whether previously-established links between suppression and comprehension were domain-specific (i.e. exclusive to the verbal domain) or domain-general.

The studies that will be reported in Chapter 4 capitalised upon the two suppression tasks developed in Chapter 3, in combination with verbal and non-verbal standardised tests of working memory, to explore whether poor comprehenders' working memory and suppression deficits were specific to the verbal domain. This question is of fundamental theoretical importance, not only to our understanding of causation in poor comprehension, but also because of the impact the existence of domain-specific working memory deficits would have on current theories of working memory. Chapter 5 will include the final series of studies that focus on clarifying the nature of the cognitive deficits that may underlie poor comprehension. The focus of this chapter will move beyond the cognitive inhibition

discussed in the previous three chapters and onto wider aspects of executive inhibition, in order to determine the nature and extent of inhibitory deficits in poor comprehenders. Administering a variety of different tasks measuring different levels of inhibitory control, in both the verbal and non-verbal domains, enabled me to do this.

In Chapter 6, data will be presented from a study which aimed to explore behavioural and educational outcomes in poor comprehenders, an area in which very little research has been conducted to date. The study involved classroom teachers rating poor comprehenders and controls on a series of theoretically-motivated behaviour rating scales, as well as providing an indication of their educational attainment in a range of curriculum areas. Chapter 7 will discuss a series of experiments which focused in on one specific curriculum area; mathematics. The specific profile of language strengths and weaknesses shown by poor comprehenders discussed earlier in this chapter, in combination with research into mathematical performance in children with other developmental disorders, raised specific predictions about how they would perform in different types of mathematical task. I tested these predictions by administering two standardised tests, each tapping a different aspect of mathematical ability in order to observe whether poor comprehenders displayed a dissociation in their performance on the two tasks. To supplement our understanding of the role that poor comprehenders' language deficits may play in their mathematical outcomes, links between language ability and mathematical performance were also explored in a large unselected sample of typically-developing children.

To summarise, the research presented in this thesis aims to make a significant contribution to the knowledge base concerning children who have specific reading comprehension difficulties; poor comprehenders. A series of experiments will elucidate the complex interplay of causal factors which drive poor comprehension, and will explore the impact being a poor comprehender may have on behavioural and educational outcomes. Results will not only inform our theoretical understanding, but will also have important practical applications in terms of education and intervention for poor comprehenders.

Chapter 2: Examining poor comprehenders' suppression deficits at the level of the mental model.

This chapter reports an experiment that explored whether previously demonstrated suppression deficits in poor comprehenders would extend to the level of the mental model. Poor comprehenders have repeatedly been shown to have difficulties suppressing no longer relevant words in simple experimental recall tasks, but the extent to which these suppression deficits would impact on poor comprehenders' performance at the level of the narrative had hitherto remained unexplored. Participants listened to a series of stories and answered questions about them. In order to successfully answer some of the questions, it was necessary to suppress no longer relevant information presented earlier in the stories. Poor comprehenders made more errors than controls in the presence of interfering information that should have been suppressed, and also showed a processing cost in terms of reaction time. These results suggested that poor comprehenders were less efficient at updating their mental model of the narrative, and confirmed that previous demonstrations of suppression deficits in poor comprehenders extend to the level of the mental model.

In Chapter 1 of this thesis, the established links between working memory and reading comprehension were discussed. If one considers the processes involved in comprehending a text, it is clear to see why working memory is vital for reading comprehension performance. Key among these processes is the need to build up a mental model of the situation described by that text, hold this mental model online in temporary memory, and dynamically update it as new information becomes available, particularly if this new information is incompatible with previous information. Taken together, these processes allow the reader to formulate a

coherent representation of a text while reading it, but they also place significant demands on working memory. Clear parallels can be drawn between the cognitive inhibitory processes needed to successfully suppress irrelevant information in the experimental recall tasks used by De Beni and colleagues (see Chapter 1), and the suppression mechanisms necessary to dynamically update a mental model of a text as new information replaces no longer relevant information. Both require the individual to suppress irrelevant information that is currently activated in working memory, with failure to do so reducing the capacity of working memory to process and maintain incoming novel information.

One question therefore is whether experimental demonstrations of suppression difficulties in poor comprehenders would extend to the level of the mental model. Thus far the vast majority of research into suppression deficits in poor comprehenders has focused on suppression processes operating at the level of the word or sentence. For example, De Beni et al. (1998) found that poor comprehenders showed suppression deficits at the single word level, producing intrusion errors comprising words that should have been efficiently suppressed. Similarly, in Palladino et al.'s (2001) study, the stimuli used to demonstrate suppression deficits in poor comprehenders were exclusively single words. However, these findings at the word level were not extended to the level of the narrative, i.e. the studies failed to examine discourse level suppression processes in poor comprehenders. The experiment reported in this chapter therefore aimed to fill this gap in the research base by examining whether poor comprehenders would show suppression deficits when required to update a mental model of a narrative.

The one study to date that *has* addressed poor comprehenders' suppression abilities at the level of the mental model cannot provide any firm conclusions on this issue, due to the way in which the poor comprehender sample was selected.

Gernsbacher and colleagues (Gernsbacher, Robertson, Palladino, & Werner, 2004) examined suppression at the discourse level in a sample of adults identified as less-skilled comprehenders on the basis of their performance on a multiple-choice assessment of reading comprehension. According to Gernsbacher's Structure Building Framework (see, Gernsbacher, 1997, for review), a framework for describing processes that occur at a cognitive level during discourse comprehension, there are two key mechanisms that support the development of mental representations during narrative comprehension. *Enhancement* acts to increase the activation of relevant information, whilst *suppression* serves to attenuate any information that is irrelevant or interfering. In the experiment, participants read narratives in which a main character was introduced in the first paragraph. Subsequently, either the main character was re-mentioned, or a new character was introduced. According to the Structure Building Framework, re-mentioning a character should lead to enhancement of that character representation, hence rendering it more accessible. By contrast, introducing a new character is argued to lead to suppression of the representation of the main character, thus producing interference and making the representation of the main character less accessible. Gernsbacher et al. found that the poor comprehenders showed much higher costs in terms of their accuracy at verifying the main character's name than the good comprehenders when a new character was introduced to the story, i.e. when interfering information was present that needed to be suppressed. The authors therefore argued that demonstrations of

suppression deficits in adult poor comprehenders at the single word or sentence level (De Beni, et al., 1998; Palladino, et al., 2001) extend to the narrative level.

However, the way in which the good and poor comprehenders were selected in Gernsbacher et al.'s study means that this conclusion must be treated with a certain degree of caution. Participants in the study were all undergraduate students; groups of poor and good comprehenders were selected on the basis of scores on a multiple-choice reading comprehension task, with the top third of scorers comprising the good comprehender group and the bottom third of scorers making up the poor comprehender group. As well as the potentially restricted range of comprehension ability that this method of participant selection afforded, no attempt was made to match the groups on basic word reading skills, or on non-verbal intelligence. It is likely therefore that the groups differed on more than just their reading comprehension ability, meaning comparisons with the poor comprehenders used in the studies of De Beni and colleagues (Carretti, et al., 2005; De Beni & Palladino, 2000; De Beni, et al., 1998; Palladino, et al., 2001) are not necessarily justified. Particularly relevant for this experiment is evidence that suggests impaired phonological short term memory in individuals with poor decoding skills (e.g., Newbury, Bishop, & Monaco, 2005); if the poor comprehenders in Gernsbacher's study were also poorer word readers, then it is likely that their memory deficits were not restricted to those involving an executive control component, but also encompassed simple short term storage problems. The current experiment therefore aimed to explore the question of whether poor comprehenders' deficits in the suppression of irrelevant information from working memory would extend to the

level of the mental model, when they were selected to have *specific* deficits in reading comprehension.

As discussed above, if poor comprehenders have difficulties in suppressing no longer relevant information from working memory, then one would predict that updating their mental model of a text whilst maintaining it in working memory would also be something that they would find difficult. Whilst Gernsbacher et al.'s (2004) study focused only on the suppression demands of introducing a new and competing character into a story, it was reasoned that the introduction of *any* novel information that requires updating of the mental model would be challenging for poor comprehenders. To test this hypothesis, I developed a task in which information that was initially relevant in a story was replaced by more recent information, rendering the initial information no longer relevant. If the initial information was not adequately suppressed from working memory, it could interfere with participants' responses to subsequent questions about the story: Imagine information A is presented first, then replaced by information B, which directly conflicts with information A. If the child is then asked a question about information B, and they have not adequately suppressed information A, this initial conflicting information is likely to slow down their response times to any question about information B, and potentially even interfere with their response accuracy. It was predicted that previous findings of suppression deficits in poor comprehenders in the context of experimental recall tasks would extend to this newly developed story suppression task, resulting in poor comprehenders showing greater processing costs than controls with good reading comprehension in the presence of interfering information that needs to be suppressed.

Experiment 2.1

Method

Participants

To select poor comprehenders, as well as matched controls with good reading comprehension, 121 children aged 7-9 years were screened using the following measures of component reading skills and cognitive ability. Children were drawn from mainstream classrooms in schools in Oxfordshire and Lancashire that served a range of socially diverse catchment areas.

Nonverbal reasoning. The Matrix Reasoning subtest of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) was used to assess participants' nonverbal reasoning ability. This measure comprises a series of progressively more difficult pattern completion items; children are shown a pattern with a piece missing and must choose the correct piece from five possible alternatives.

Decoding. Children's decoding ability was assessed using the Phonemic Decoding subtest of the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999). This test requires children to read a list of non-words of increasing difficulty as quickly as they can, with decoding ability quantified by the number of non-words correctly read by the child in 45 seconds.

Word reading. The Sight Word component of the TOWRE (Torgesen et al., 1999) provided a measure of participants' word reading fluency. Children were presented with a list of progressively more difficult words, and were required to read as many as they could in 45 seconds. Their score on this component was the total number of words correctly read within the allotted time.

Reading comprehension. To assess reading comprehension, the Neale Analysis of Reading Ability-II (NARA-II; Neale, 1997) was administered. In this task, children read aloud passages of connected text, as well as answering a series of literal and inferential comprehension questions on each passage. This measure renders a standard score for both text reading accuracy and reading comprehension.

From the screening process 16 poor comprehenders and 16 controls were identified using the following criteria. All children had English as a first language, and none had any registered special educational needs. To fit a poor comprehender profile, children must have reading comprehension ability that lags significantly behind their decoding competence, that is, they must show specific deficits in their reading comprehension performance in the face of average or above-average non-word reading. To this end, all the poor comprehenders had comprehension standard scores on the NARA-II that were less than 90 ($M = 86.44$, $SD = 2.56$). Furthermore, each poor comprehender's reading comprehension score was at least one standard deviation below their score on the measure of decoding ability provided by the Phonemic Decoding subtest of the TOWRE. Finally, poor comprehenders were selected to have non-verbal ability within the normal range.

The controls, unlike the poor comprehenders, had reading comprehension standard scores on the NARA-II ($M = 104.13$, $SD = 7.46$) that were greater than or equal to their reading accuracy standard scores. The two groups differed significantly in terms of comprehension standard scores with a mean difference of approximately 18 standard score points ($t(30) = 8.97$, $p < 0.001$, $r = .85$), but were well-matched for chronological age, word and non-word reading, NARA-II accuracy, and non-verbal ability (Table 2.1).

Table 2.1. Comparison of poor comprehenders' and controls' mean chronological age and performance on the screening measures.

	Poor Comprehenders	Controls	<i>F</i>	<i>p</i>
Age (months)	98.75	99.69	0.26	.61
Matrix Reasoning (WASI) ¹	53.44	55.93	1.01	.32
Text Reading Accuracy (NARA) ²	98.94	100.94	0.61	.44
Reading Comprehension (NARA) ²	86.43	104.12	80.41	< .001
Word Reading (TOWRE) ²	108.38	111.25	0.88	.66
Phonemic Decoding (TOWRE) ²	110.00	106.06	1.22	.28

Note: ¹T Scores, *M* = 50, *SD* = 10; ²Standard Scores, *M* = 100, *SD* = 15

Materials

Four short stories were created, each of which described happenings in the life of a fictitious character called Lucy. The stories were divided into four sections. For two out of the four sections of each story, both interference and no-interference versions of the section were created. In the interference versions, information that was initially relevant (underlined in the example below) was replaced by more recent information that rendered the initial information irrelevant. This initial information was designed to interfere with the recall of the more recent information if the former was not adequately suppressed.

Today Mrs Finch was going to announce who had which part in the school nativity play. Lucy hoped she would be Mary, as that was the starring role. She had even practised some of Mary's lines just in case. Mrs Finch got out

her list and began to give out the parts. When she came to Lucy's name she said 'Lucy Brown, you will be an angel, perhaps you could have a look at home for some white material for your costume?'

In the no-interference versions of the story sections, the interfering information that was present in the interference version of each section was replaced by neutral information that did not interfere with later information (underlined in the example below), and therefore did not need suppressing from working memory to ensure optimum performance; there was no updating demand.

Today Mrs Finch was going to announce who had which part in the school nativity play. Lucy hoped she would get a part, as she loved acting. She had even practised some of the songs in the play just in case. Mrs Finch got out her list and began to give out the parts. When she came to Lucy's name she said 'Lucy Brown, you will be an angel, perhaps you could have a look at home for some white material for your costume?'

The key difference between the interference and no-interference stories rested on a change at the level of the situation model (i.e. interfering vs. neutral information).

However, in order to minimise any other potential differences between the conditions that these changes might make, interference and no-interference versions of each story section were equated for overall length, as well as semantic and grammatical complexity. The remaining two sections of each of the four stories were designated filler sections, and contained no interfering information; they were included to ensure that children were not aware of the construct being studied.

Two different versions of the task were created, each of which contained four stories with four different sections. The two filler sections of each story were the

same in both task versions. However, in the other two sections, where version A contained a no-interference version of a story section, version B contained an interference version of that same section, and vice versa. The poor comprehenders and controls were counterbalanced between the two versions, so that half of each participant group were randomly assigned to version A and the other half completed version B. The stories were recorded and programmed into an Eprime script, so that they could be played automatically to the children through headphones, thus giving each participant exactly the same auditory experience. For each story section a related test statement was also created and recorded (e.g. *Lucy got the part of Mary in the school nativity play*), with participants required to make a true/false judgment about each statement. The test statement for a particular story section was always the same, regardless of whether the child had heard an interference or a no-interference version of that section.

Procedure

Children were told that they were going to hear some stories about the life of a little girl called Lucy, and were instructed to listen very carefully to these stories as now and again the computer would stop telling them the story and would ask them a question to check they remembered what had happened. Children completed two practice trials, followed by four blocks of four trials each. Each trial commenced with the child hearing one of the short story sections described above. They were then alerted that it was time for the test statement by a series of visually appealing graphics and attention-grabbing sounds. A test statement relating to the section they had just heard was played to the child and they had to indicate whether they thought it was true or false by pressing the appropriately labelled key on the

keyboard. Children were instructed to respond as quickly as they could to the test statement, without sacrificing accuracy. RT and accuracy of response to the test statement was recorded each time.

Results

For all analyses, the p -level for significance was set at .05. The accuracy dependent variable was the mean proportion of correct responses to the test statements, whilst the RT dependent variable reflected each child's mean RT in milliseconds to respond to the test statements. As preliminary analyses confirmed no differences between version A and B of the stories (Accuracy: $F(1, 30) = 0.20, p > .10$; RT: $F(1, 30) = 0.22, p > .10$), data were collapsed across the two versions, allowing subsequent analysis to compare the performance of the poor comprehenders ($N = 16$) with that of the controls ($N = 16$) on a total of eight interference sections, eight no-interference sections, and sixteen filler sections of the stories.

Accuracy Results

Figure 2.1 shows the mean accuracy performance of the two groups of children on the interference and no-interference trials in this task. Cohen's d effect sizes were calculated to examine differences between the two participant groups. These effect sizes provide an indication of the standardised effect size between two means, hence allowing comparison of the performance of the poor comprehenders and the controls in the interference and no-interference conditions. On the basis of the predictions detailed in the introduction section of this chapter, it was expected that the poor comprehenders would show a greater difference between their mean accuracy in the interference versus the no-interference trials (i.e. they should show

more of a decrement in performance in the presence of interfering information), than controls. The effect sizes support this prediction, with poor comprehenders showing a large effect size between their interference and no-interference means ($d = 0.68$); in contrast, the controls showed a minimal difference in accuracy across conditions ($d = 0.06$).

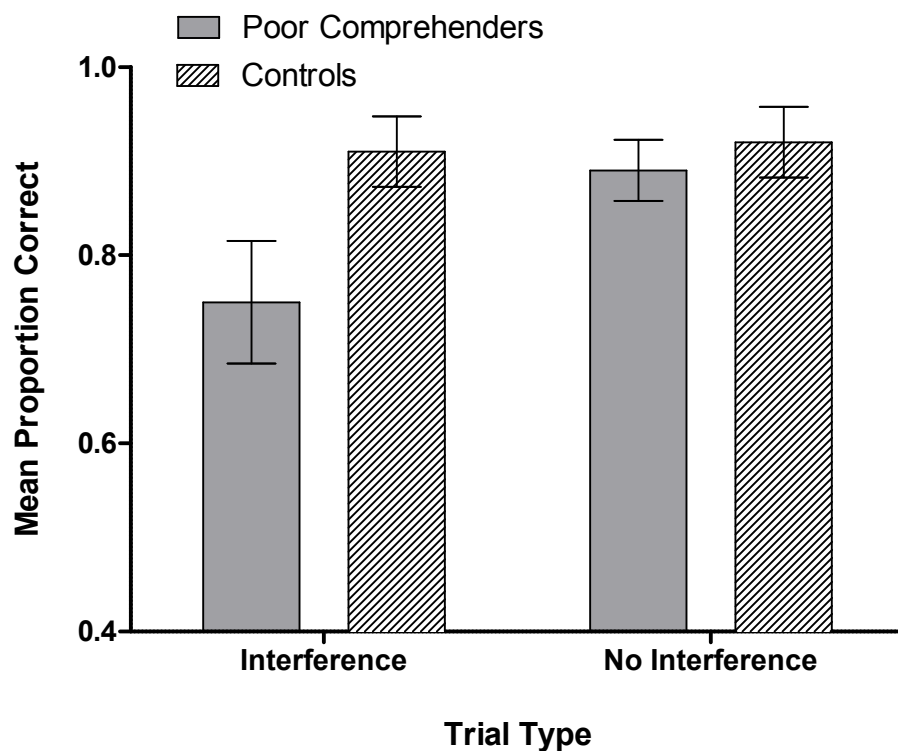


Figure 2.1. Mean proportion of correct responses made in the interference and no-interference trials for poor comprehenders and controls. Error bars show the standard error of the mean.

As can be seen in Figure 2.1, the poor comprehenders ($M = .89$, $SD = .12$) and the controls ($M = .92$, $SD = .15$) performed at a comparable level on the no-interference trials, rendering no significant differences between the two groups, $F(1, 30) = 0.43$, p

>.10. However, in the interference trials, the poor comprehenders ($M = .75, SD = .26$) performed more poorly than the controls ($M = .91, SD = .15$), $F(1, 30) = 4.31, p = .047, \eta_p^2 = .13$; poor comprehenders only perform at a significantly lower level than the controls when interfering information is present that needs to be suppressed.

There were no differences between the poor comprehenders ($M = .86, SD = .10$) and the controls ($M = .85, SD = .15$) in terms of their accuracy performance on the filler trials ($F(1, 30) = 0.03, p > .10$).

RT Results

As shown in Figure 2.2, the RT data showed a similar pattern to the accuracy data.

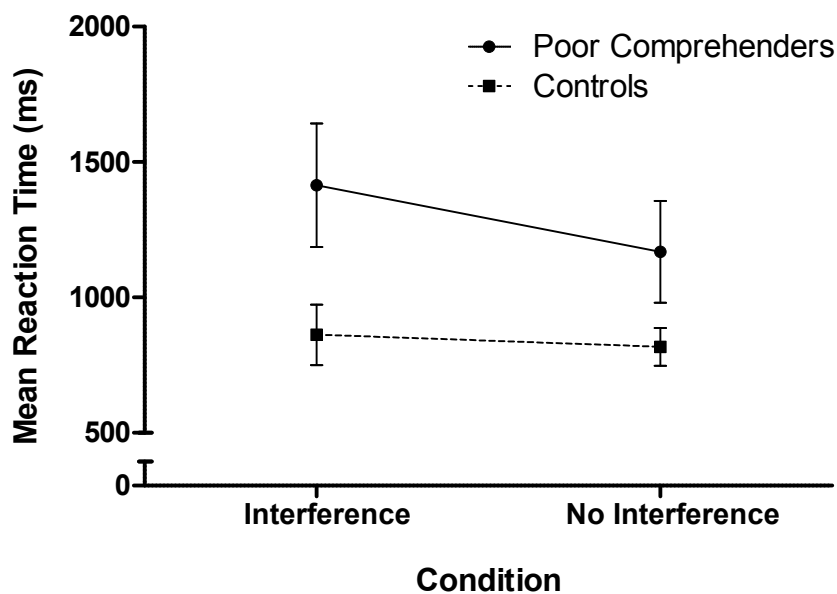


Figure 2.2. Mean RTs on interference and no-interference trials for poor comprehenders and controls. Error bars show the standard error of the mean.

Cohen's d effect sizes were again calculated to compare the performance of the poor comprehenders and the controls in the interference and no-interference conditions.

As with the accuracy data, poor comprehenders showed a greater difference between their interference and no-interference means ($d = 0.29$) than the controls ($d = 0.11$); they showed a greater decrement in performance in the presence of interfering information. There were no significant group differences in RT on the no-interference trials, $F(1, 30) = 3.08$, $p = .09$, although the poor comprehenders did have a tendency for slower RTs than the controls. However, as Figure 2.2 shows, the controls processed interference trials as rapidly as no-interference trials. By contrast, the poor comprehenders showed RT costs in the interference condition relative to the no-interference condition. They were significantly slower than the controls in the interference condition, $F(1, 30) = 4.72$, $p = .038$, $\eta_p^2 = .14$, despite the lack of significant group differences in RT in both the no-interference condition, and the filler condition, $F(1, 30) = 1.49$, $p > .10$ ¹. It is important to note that due to the relatively small number of trials in this experiment, as well as the difference between the two participants groups in terms of their accuracy, it was not feasible to analyse RTs for the correct trials only. Therefore, these RT results must be treated with a degree of caution, as they do not take into account any speed-accuracy trade-offs that participants may have been making. However, the finding that removing RTs for incorrect trials serves to decrease rather than increase mean RTs for both poor comprehenders and controls in all conditions (mean RT all trials = 1115.43; mean RT correct trials only = 1050.50) argues against the idea that speed-accuracy trade-offs are affecting the performance of either group.

¹ Given the small number of observations per participant/condition and the potential for outliers to influence mean RT, analyses were repeated using more conservative non-parametric tests, based on ranks rather than means. Mann-Whitney tests confirmed that the two participant groups differed in RT in the interference condition ($U = 71$, $p = .03$) but not in the no-interference condition ($U = 81$, $p = .08$).

There were no significant differences between the poor comprehenders ($M = 1319.83$, $SD = 560.26$) and controls ($M = 1110.21$, $SD = 397.32$) in terms of their RT on the filler trials ($F(1, 30) = 1.49$, $p > .10$).

Discussion

The aim of this experiment was to explore whether previous demonstrations of poor comprehenders' deficits in the suppression of no longer relevant information from working memory extended to the level of the mental model. To address this question, stories were created that required the children to update their mental model of the situation described by the text, and more specifically to replace initially relevant information with more recent information. Poor comprehenders were selected to have *specific* deficits in reading comprehension (c.f., Gernsbacher, et al., 2004), allowing direct comparisons to be made between this study and previous research into poor comprehenders' suppression deficits using experimental recall tasks (Carretti, et al., 2005; De Beni & Palladino, 2000; De Beni, et al., 1998; Palladino, et al., 2001). Poor comprehenders made more errors than controls in the presence of interfering information that should have been suppressed, and they showed a processing cost in terms of RT. By contrast, there were no group differences on the closely matched no-interference trials, or for the filler trials. These findings show that poor comprehenders' difficulties in suppressing irrelevant information from working memory extend beyond simple experimental recall tasks, and also impact on tasks that are representative of their primary area of difficulty; comprehension.

An important question concerns the locus of the suppression effect as measured by this experiment. It is possible that rather than reflecting suppression

processes that are active and ongoing as stories are being read, the results presented here instead reflect suppression processes that occur at the time of test (backwards context checking; see, Potts, Keenan, & Golding, 1988). Backwards context checking explanations of performance would imply that the locus of suppression failure of the poor comprehenders in this experiment was not during online comprehension, but rather at the point when they were required to check their representation of the text in order to answer a question about it. Thus, while this task shows that poor comprehenders have difficulty in suppressing outdated information, it does not enable us to isolate the locus of the suppression failure. Nevertheless, and in line with previously discussed models of discourse comprehension (Gernsbacher, 1997), I would argue that during the natural process of reading comprehension, suppression processes designed to eliminate no longer relevant information from the online mental model of the narrative must be operating in order for an efficient updating of this mental model to occur, particularly over more lengthy narratives. On this view, it is a failure of these online suppression processes that contributes to poor comprehenders difficulties with understanding what they read.

Evidence consistent with the idea that suppression deficits emerge during the reading process itself comes from a consideration of resonance. This is the process by which concepts that are currently in working memory make contact with other concepts processed earlier and reactivate those earlier concepts through a passive resonance process (see, O'Brien & Myers, 1999). The key determinant of reactivation by resonance is believed to be the degree of semantic and contextual overlap between the activating concept and the previously processed concepts. Following

this view, when each test statement is presented in the interference condition in my experiment, there is considerable conceptual overlap between this statement and the outdated information, leading to reactivation of the outdated information and increased suppression demands. By comparison, in the no-interference condition, the test statement would not resonate strongly with the neutral information presented earlier, leading to comparatively low suppression demands in this condition. It seems likely that resonance processes are contributing to the effects found in this task; they act to increase the suppression demands on the interference trials, hence amplifying the deficits that the poor comprehenders show in this condition. A body of evidence suggests that resonance operates *during* reading (O'Brien & Myers, 1999), lending support to the idea that poor comprehenders' suppression difficulties were occurring during ongoing comprehension of the narrative, rather than at the time of test. Future work investigating the exact locus of poor comprehenders' suppression deficits is warranted, perhaps using online methods such as eye-tracking.

Discussion so far has focussed on how difficulties with suppressing irrelevant information may be associated with poor reading comprehension. An alternative account of the relationship between suppression and comprehension was proposed by McNamara and McDaniel (2004). They argued that differences in knowledge and the activation of knowledge during the course of comprehension underpin readers' ability to deactivate irrelevant meanings. On this view, differences in knowledge account for the relationship between suppression and comprehension. The data reported here, however, are difficult to accommodate within a pure knowledge activation account. While deficits in knowledge are to be expected in poor

comprehenders (though less clear is the extent to which such deficits are a cause, a correlate, or a consequence of poor reading comprehension, see Nation, 2009), it is hard to see how such differences could account for the specific deficits poor comprehenders showed on the interfering trials in this experiment, given that interfering vs. non-interfering stories were well-matched. Clearly however, it seems likely that any putative difficulty with suppression is likely to interact with differences in knowledge in dynamic and complex ways, given the richness and complexity of the reading comprehension process.

Finally, it is also important to note that the conclusions drawn from this experiment, and others in this thesis, are based on a single measure of reading comprehension ability, namely the Neale Analysis of Reading Ability-II (NARA-II; Neale, 1997). In recent years there has been much discussion of the differences between currently available reading comprehension tests with regards to which underlying skills they are most dependent on. For example, Cutting and Scarborough (2006) examined the relative contributions made by reading accuracy and oral language skills to three commonly-used measures of reading comprehension, and found that the relative contributions of these skills to reading comprehension outcome varied considerably from test to test. Keenan, Betjemann and Olson (2008) reported similar findings, and also noted that tests vary in the cognitive skills they measure at different developmental levels. The NARA test contains many inferential questions (Bowyer-Crane & Snowling, 2005) and has a close relationship with listening comprehension (Nation & Snowling, 1997). It might be that my findings do not generalise to children selected using different reading comprehension measures. Researchers need to be aware of the cognitive skills that are tapped by different

comprehension tests so they can select appropriate tests that are consistent with the construct of interest in their study, as well as with previous studies that have examined that construct. This issue will be discussed further in Chapter 8.

In summary, this experiment has shown that previous demonstrations of suppression deficits in poor comprehenders using experimental recall tasks extend to a more realistic story context; poor comprehenders find it difficult to suppress no longer relevant information from the mental model that they construct of a story. This provides a way in which failure to appropriately suppress no longer relevant information could directly impact on the understanding of a story in children with specific reading comprehension difficulties. This experiment has emphasised the link that exists between a child's comprehension ability and their capacity to appropriately regulate the contents of working memory; the next two chapters will explore this idea further and will examine the role that language ability could be playing in mediating this relationship.

Chapter 3: Predicting individual differences in reading comprehension.

This chapter reports an experiment which investigated predictors of reading comprehension outcomes in a large unselected sample of 7- to 8-year-olds. The participants completed standardised measures of reading ability, working memory and verbal and non-verbal ability, as well as two newly-designed measures of verbal and non-verbal suppression. Working memory and verbal ability were found to be significant independent predictors of reading comprehension, even when controlling for reading accuracy and non-verbal ability, thus confirming them as viable factors that could limit comprehension in children whose reading comprehension is not being limited by their reading accuracy; poor comprehenders. The verbal and non-verbal suppression tasks produced the expected effects, with children showing interference effects in the presence of earlier information that needed to be suppressed. Performance on the verbal, but not the non-verbal, suppression task was found to be associated with reading comprehension performance, suggesting the link between the ability to regulate the contents of working memory and reading comprehension may be specific to the verbal domain.

This study sought to examine predictors of reading comprehension in a large sample of typically developing 7- to 8-year-olds, in order to inform our understanding of which factors might be placing a limit on reading comprehension development in poor comprehenders. Ordinarily, a child's ability to decode words is a strong predictor of their reading comprehension ability (see Gough, Hoover, & Peterson, 1996); understandably, because in order to be able to understand words, one must first translate them from text into a speech-based code. In poor comprehenders however, reading comprehension is *not* predicted by their reading

accuracy; they display comprehension ability that is substantially below what would be predicted by their age-appropriate decoding skills. Comprehension deficits in these children cannot therefore be accounted for by deficits in word reading skills; other factors must be placing a limit on comprehension and causing it to dissociate from reading accuracy. Some suggestions as to what these other factors might be were discussed in Chapter 1, with the majority of research thus far focusing either on working memory deficits or on language weaknesses. The first aim of this experiment then, was to examine the power of working memory and verbal ability to predict reading comprehension. If it is the case that these two factors do place a limit on comprehension development independently from word reading, then they would be expected to emerge as unique predictors of comprehension in this whole sample, even when controlling for individual differences in decoding ability. If they do, this would confirm them as potential limiting factors on comprehension in children with specific reading comprehension deficits.

Previous work by Cain, Oakhill and Bryant (2004), which looked at predictors of reading comprehension ability in a large sample of typically-developing children, suggested that working memory was an independent predictor of comprehension ability. They tested the children in their sample at the ages of 8, 9, and 11 years, and found that at each time point working memory predicted unique variance in reading comprehension outcomes, even after controlling for the effects of word reading skills and verbal ability. However, they did not control for individual differences in non-verbal intelligence, a variable that has been shown to be related to reading comprehension (Nation, Clarke, & Snowling, 2002) and whose strong relationship with working memory is still the subject of much debate (see Conway, Kane, & Engle,

2003, for discussion). I intend to address this in the current experiment by including a standardised measure of non-verbal ability. Nonetheless, their finding adds further weight to the hypothesis put forward by De Beni and colleagues (e.g. Carretti, Cornoldi, De Beni, & Palladino, 2004; Carretti, et al., 2005; De Beni & Palladino, 2000; De Beni, et al., 1998; Palladino, et al., 2001), namely that poor comprehenders' comprehension difficulties are driven by working memory problems at the level of the central executive. On this view, the central executive fails to adequately regulate the contents of working memory through the usual inhibition and suppression processes, meaning working memory gets overloaded and does not function optimally in support of comprehension.

The findings of Experiment 2.1 also supported this idea of a link between a child's suppression ability and their comprehension performance, with poor comprehenders seemingly having much more difficulty than controls in suppressing no longer relevant information from working memory. However, as with previous studies that have investigated the links between comprehension and suppression (e.g. Carretti, et al., 2004; Carretti, et al., 2005; De Beni & Palladino, 2000; De Beni, et al., 1998; Palladino, et al., 2001), Experiment 2.1 took place exclusively in the verbal domain. As a result, it is unclear whether the link between suppression ability and comprehension skill is only evidenced when the material to be suppressed is verbal, or whether a domain-general failure to suppress no longer relevant information from working memory is associated with comprehension difficulties. If this latter suggestion is correct, then the ability to suppress both verbal and non-verbal information from working memory should be associated with comprehension outcomes. An additional aim of the experiment reported in this chapter then, was to

address this by examining whether verbal and non-verbal suppression abilities predicted comprehension outcomes in a large sample of typically-developing 7- to 8-year-olds.

To look at verbal and non-verbal suppression abilities, two tasks were developed based on a proactive interference (PI) paradigm. PI refers to the interfering effect of information that has been encoded earlier on the recall of more recent information. If children are poor at suppressing no longer relevant information, they should be particularly vulnerable to the effects of PI. Capitalising upon PI tasks therefore provides an excellent experimental technique for assessing individual differences in verbal and non-verbal suppression abilities, and their relationship with comprehension, within the context of a tightly-controlled, experimental paradigm.

Experiments using the Brown-Peterson paradigm (Brown, 1958; Peterson & Peterson, 1959) demonstrate how earlier information can interfere with the recall of more recent information within the context of a simple experimental recall task. In this paradigm, each trial begins with a list of words that need to be remembered, with this list of words themed around a particular semantic category (e.g., animals). After all the words have been presented, participants are required to perform a distractor task for a period of a few seconds (e.g. verbal shadowing of sets of digits) to prevent rehearsal of the words, before being asked to recall the words that were presented at the start of the trial. The general finding on this task is that participants show minimal forgetting on the first trial of a Brown-Peterson task, but that as subsequent trials using words from the same semantic category take place, the rate of forgetting increases across trials. Furthermore, if the semantic category from

which the words are drawn is then changed, performance increases again to levels comparable with the first trial of the task (e.g., Wickens, Born, & Allen, 1963). This suggests that PI, interference from earlier related trials, is playing a key role in performance in Brown-Peterson tasks, and is integral to the progressive forgetting that is seen in this task.

Given the findings concerning the role of PI in Brown-Peterson tasks, it seems logical to assume that PI would also play a role in determining performance on classic working memory tasks, such as the reading span task. Such tasks also involve a series of trials, and require the participant to successfully inhibit previously encoded information in order to succeed on the current trial (see Lustig, May, & Hasher, 2001). A large body of literature has addressed the question of the role that PI plays in working memory performance (e.g., Conway & Engle, 1994; Dempster, 1981; May, Hasher, & Kane, 1999; Rosen & Engle, 1998; Shah & Miyake, 1996), and has suggested that the ability to resist PI over a series of trials is an important factor in determining working memory span. For example, May et al. (1999) manipulated two working memory span tasks (backward digit span and reading span) so that they varied in the amount of PI they induced. They found that by reducing the opportunity for PI to occur, span scores of the participants improved, suggesting that PI is influencing performance on these working memory tasks.

The tasks that I created to assess individual differences in suppression ability were based on PI tasks used by Tehan and colleagues (Tehan & Hauff, 2000; Tehan & Humphreys, 1995, 1998). These tasks have reliably demonstrated PI effects within a short-term memory timeframe and have been successfully used to explore individual differences in PI in adult populations. In these original tasks, participants heard a

series of words, were required to shadow digits as a distraction task, and were then asked to recall one of the words in response to a semantic category recall cue (e.g. ANIMAL). Critical trials in the task were double block trials: after the first series of words was presented, participants saw an exclamation mark on the screen, and were subsequently presented with another series of words. They were then shown a category recall cue and instructed only to respond with a word from the second block of words, that is, they knew that when they saw an exclamation mark they had to forget the preceding block of words as they would now be incorrect responses. In the interference trials of this task, a word matching the recall cue was present in both the first and the second block of the trial, giving the opportunity for PI to occur if words in the first list were not adequately suppressed. Performance on these trials was compared to performance on no-interference control trials, in which a word matching the recall cue was only present in the second block, hence giving no opportunity for PI from the first block. The verbal task created for this experiment followed a very similar format, but was adapted in a number of ways so that it was suitable for use with children (see methods). Based on research showing that PI occurs in both verbal and non-verbal working memory (Brandon, Jha, Trueswell, Barde, & Thompson-Schill, 2003), a non-verbal version of the task was also created to assess the children's ability to suppress no longer relevant non-verbal information (see methods).

In this experiment, a large sample of typically-developing 7- and 8-year-olds completed both the verbal and the non-verbal PI tasks. This allowed me to assess whether each task was producing the expected PI effects, as well as to determine whether a dissociation exists between verbal and non-verbal suppression

performance. Additionally, the relationship between performance on the verbal and non-verbal PI tasks and standardised measures of reading comprehension and working memory was examined. As discussed above, if it is the case that comprehension failure is associated with domain-general suppression failure, then low comprehension scores should correlate with poor suppression performance across both verbal and non-verbal PI tasks. However, if there is a more specific association between poor comprehension and suppression of irrelevant verbal material, then comprehension should correlate with suppression performance on the verbal, but not the non-verbal, PI task. In line with previous research, it was also predicted that there would be an association between a child's susceptibility to PI and their working memory ability.

To summarise, Experiment 3.1 had three main aims. First, to explore the power of working memory and verbal ability as unique predictors of reading comprehension outcomes in a large sample of typically developing children, when controlling for the effects of age, non-verbal ability and word reading skills. Secondly, to determine whether my newly-designed verbal and non-verbal PI tasks would produce the expected PI effects in this same large sample. Thirdly, to explore the relationship between performance on the verbal and non-verbal PI tasks and outcomes on the reading comprehension and working memory measures.

Experiment 3.1

Method

Participants

Eighty-nine children (38 boys, 51 girls) participated in this experiment.

Children were recruited from primary schools in Oxfordshire and Lancashire. Written

informed consent from the relevant caregiver was obtained for all children prior to participation. Participants all spoke English as a first language and had no registered special educational needs.

Materials and procedure

Reading comprehension. The NARA-II (Neale, 1997) was used to assess reading comprehension. See Experiment 2.1 for description of this test.

Non-verbal ability. The Matrix Reasoning subtest of the WASI (Wechsler, 1999) was used to assess participants' nonverbal reasoning ability. See Experiment 2.1 for description of this test.

Verbal ability. A measure of verbal ability was provided by the Vocabulary subtest of the WASI (Wechsler, 1999). This expressive vocabulary task assessed children's definition knowledge.

Working memory. The backward digit span (BDS) component of the British Ability Scales II (BAS-II; Elliot, Smith, & McCulloch, 1997) was used to assess children's working memory. Children heard increasingly long lists of digits and were required to repeat these back to the experimenter in reverse order.

Verbal PI task. Children were first introduced to two aliens, 'Zark' and 'Zenia', and told that they were going to play a memory game using the words that these aliens had acquired whilst on a visit to Earth. After receiving detailed task instructions, as well as a demonstration of how the task would work, children completed four practice trials designed to familiarise them with task procedure. The task itself consisted of two blocks of 12 trials each, separated by a short break, rendering a total of 24 trials.

Each trial followed either a single or double block structure (see Figure 3.1). The eight single block trials were included to ensure that participants paid attention to the first block in the double block trials. Each began with the word 'ready?' displayed on the screen until the experimenter ascertained that the child's attention was focused on the task. Subsequently children heard four of the stimulus words presented serially through headphones, before seeing a question mark symbol on the screen. They were then required to shadow two sets of three digits (e.g. 364, 742) that were presented verbally by the experimenter, before being asked to recall one of the four words in response to a category cue (e.g. can you remember the word that was a type of fruit?). The sixteen double block trials followed the same series of events, but after the first four words had been presented a cross appeared on the screen and another four words were presented before the verbal shadowing and recall question took place. Children were instructed that when they saw the cross symbol on the screen they had to forget the four words they had just heard because they were not going to be tested on those, and that instead they should only focus on remembering the four words that came after the cross.

Of the 16 double block trials, eight were 'interference' trials and eight were 'no-interference' trials; comparison of performance in these two trial types provided a measure of PI in this task. In the interference trials, a word that matched the category cue (e.g., a type of pet) was present in both the first block (the foil word, e.g., cat) and the second block (the target word, e.g., dog). By contrast, in the no-interference trials a word that belonged to the cued category was present only in the second block. This no-interference condition therefore acted as a control for the interference trials, as there was no opportunity for PI to influence performance.

Twenty four semantic categories (e.g., type of pet, fruit, flower) were selected, with each category being used on one trial. In the eight interference trials, both a target and a foil were selected to match the category cue. Targets and foils were matched on the basis of word frequency per million words ($t(7) = .068, p > .10$) taken from the Children's Printed Word Database (Masterson, Dixon, & Stuart, 2002). The target/foil was embedded within three filler words to create each four word block (see Figure 3.1). Fillers were selected from a word pool that consisted of concrete nouns of no more than two syllables. Care was taken to ensure that there was no overlap between category membership of target/foil items and filler items.

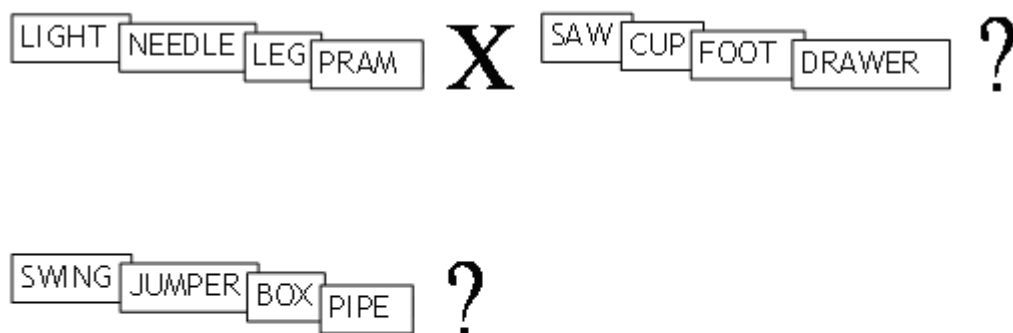


Figure 3.1. Examples of the trial structure of double (top) and single (bottom) trials in the verbal PI task. The category recall cue in the double block example would be 'a part of the body'; a word that corresponds to this cue is present in both the first and second blocks, making this an example of an interference trial. The category recall cue in the single block example would be 'an item of clothing', requiring the child to recall the word 'jumper'.

The target word in both interference and no-interference trials always appeared in either position two or three in a block of four words. Position was counterbalanced between conditions to ensure that primacy or recency effects did not contribute to any observed discrepant performance in the two critical conditions. Additionally, the foil word in each interference trial was always allotted the same position within the first block as the target assumed in the second block. In the eight single block trials, the target word appeared twice in each of the four possible positions.

Responses to the category cue recall question were coded into one of four response categories. Answers were scored as correct if the child produced the target word. List intrusion errors occurred when the child produced the foil word from the first block in an interference trial. A response was scored as an extra-list intrusion error if it was a word that matched the category cue but that was not presented in the trial. Finally, if the child did not produce a response this was scored as an omission.

Non-verbal PI task. While the verbal PI task required children to verbally recall a word from each trial, the non-verbal PI task took the form of a recognition test. Faces were selected as the task stimuli on the basis of previous demonstrations of PI in adults, using face stimuli (Brandon, et al., 2003). The aim was to eliminate any necessity for verbal processing and to maximise the likelihood that children were using visuospatial, as opposed to verbal, working memory.

Children were introduced to two aliens, 'Zark' and 'Zenja', and told that they were going to play a memory game with the faces of some of the new human friends these aliens had made while visiting Earth. Comprehensive task instructions, as well

as concrete demonstrations of how the task would operate, were given. These were followed by six practice trials on the computer. The task itself consisted of 30 trials, randomly separated into four blocks or 'levels' (the first two blocks comprised eight trials per block, the second two blocks both contained seven trials). Visually presented motivational words and pictures appeared on the screen at the end of each block to engage the child in the task and thereby maintain their attentional focus.

As with the verbal PI task, each trial followed either a single or double block structure (Figure 3.2). Ten single block trials were included to ensure that participants paid attention to the first block in the double block trials, a prerequisite for any PI effects to be manifested. Each of these trials began with the word 'ready?' displayed on the screen until the experimenter ascertained that the child's attention was focused on the task. Subsequently children saw three faces presented sequentially on the screen, each for a duration of 1000ms. Pilot testing on children of the same age as the experiment participants (N = 8) established that this trial structure was maximally effective for avoiding floor or ceiling effects in response accuracy. A question mark was then displayed to make the children aware that they would next be shown the test face. On viewing the test face, participants had to decide whether it was one of the three faces from the most recent block they had seen, and respond to the question by pressing keys labelled 'yes' and 'no'. The 20 double block trials followed the same structure, but after the first three faces had been presented a cross appeared on the screen, and another block of three faces was shown before the recognition test took place. It was emphasised to the children that when they saw the cross appear, they had to forget the three faces that came

before it and just focus on remembering the three that came after the cross, as the recognition test would *only* be on the most recent block.

Of the 20 double block trials, 10 were interference trials and 10 were no-interference trials. In the interference condition, the test face was present in the first block which children had been instructed to forget. Thus, yes responses on these trials provide evidence of PI of the to-be-forgotten material. In the no-interference trials, the target was never present in the first block, leaving no opportunity for PI to occur in this control condition. In half of both the no-interference trials and the single block trials, no target face was included in the trial, meaning that the correct response to the recognition question would be negative on these occasions.

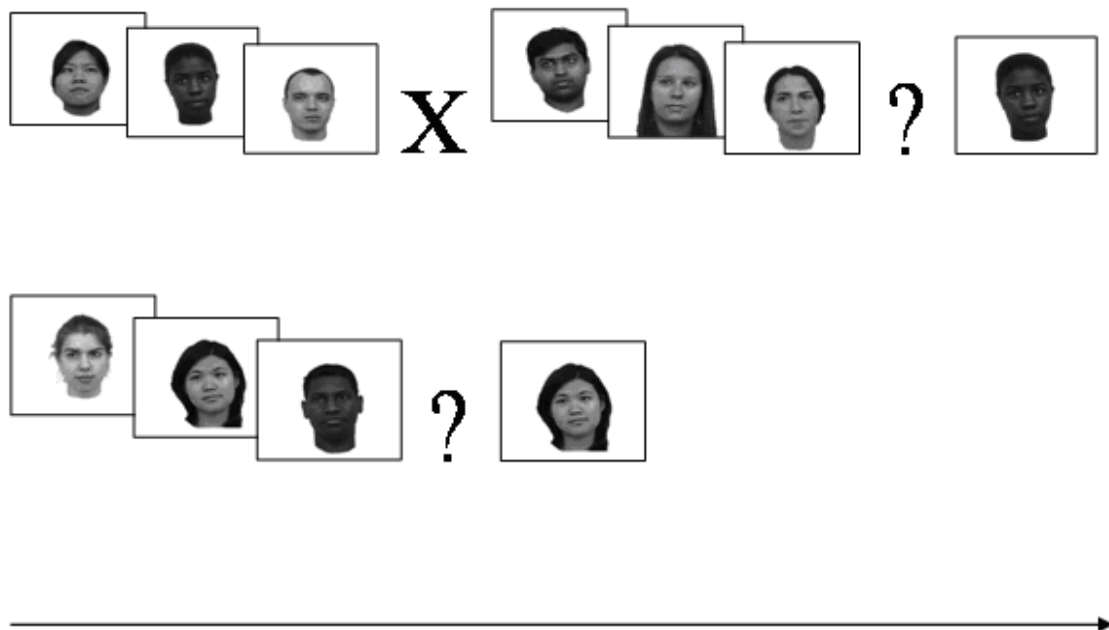


Figure 3.2. Examples of the trial structure of double (top) and single (bottom) trials in the non-verbal PI task. The double block trial is an example of an interference trial as the test face is present in the first, to-be-forgotten block.

Face stimuli were taken from the Face-Place Face Database (Tarr, 2007). Each stimulus comprised a colour photograph of the face of a young male or female posing with a neutral expression. Faces were randomly assigned, three to a block, to create the requisite number of single and double block trials. The position of the target face in the interference trials and no-interference trials (where a target was included) was counterbalanced between conditions in order to ensure that primacy or recency effects did not contribute to any observed discrepant performance in the two critical conditions.

Results

Relationship between comprehension and standardised tests

Table 3.1 shows the mean performance of the whole sample on each of the standardised measures; the sample of typically developing children scored at or near the standardised test mean on all of the measures.

Table 3.1. Mean performance of whole sample on standardised measures.

	<i>M</i>	<i>SD</i>
NARA-II accuracy*	101.61	10.44
NARA-II comprehension*	98.02	11.41
WASI matrices**	51.98	10.02
WASI vocabulary**	51.16	10.25
Backward Digit Span**	50.97	7.49

* Standard Scores; M = 100, SD = 15, ** T scores; M = 50, SD = 10

Pearson's correlation coefficients were used to examine the relationship between reading comprehension and reading accuracy (as measured by the NARA-II), verbal ability (as measured by WASI vocabulary), non-verbal ability (as measured by WASI matrices), and working memory (as measured by BDS). Table 3.2 shows the results of these correlations.

Table 3.2. Correlations between the standardised measures.

	1.	2.	3.	4.	5.
1. Working memory	1.00				
2. Non-verbal ability	.34*	1.00			
3. Verbal ability	.31*	.40**	1.00		
4. Reading accuracy	.34*	.28*	.56**	1.00	
5. Reading comprehension	.45**	.44**	.61**	.69**	1.00

* = $p < .01$, ** = $p < .001$

Reading comprehension showed strong and significant correlations with each of these other variables, particularly with reading accuracy and verbal ability, suggesting that there exists a relationship between reading comprehension and each of the variables of interest.

A hierarchical regression analysis was therefore carried out to examine the relative contribution of these variables of interest to reading comprehension outcomes. Table 3.3 shows the results of this analysis.

Table 3.3. Hierarchical regression predicting reading comprehension standard score.

	R Square	R Square Change	F	p	Final β
<i>Step 1</i>					
Age					.01
Non-verbal ability	.20	.20	10.24	<.001	.16*
<i>Step 2</i>					
Reading Accuracy	.54	.34	32.31	<.001	.45**
<i>Step 3</i>					
Verbal ability	.58	.04	27.93	<.001	.24*
<i>Step 4</i>					
Working memory	.60	.02	24.11	<.001	.16*

Note: * p<.05, ** p<.001

When entered as control variables at Step 1, age and non-verbal ability together accounted for approximately 20% of the variance in reading comprehension score. Adding reading accuracy score at Step 2 accounted for an additional 34% of the variance in performance on the reading comprehension task. Verbal ability and working memory explained an additional 4% and 2% of the variance in reading comprehension respectively, and were significant independent predictors of reading comprehension performance in the final model, confirming that they explain unique variance in reading comprehension over and above that accounted for by individual differences in reading and non-verbal ability.

Verbal PI task performance

Two of the 89 participants failed to complete the verbal PI task, due to scheduling restrictions at their school. Data were therefore analysed from a total of 87 participants. Children produced the correct response to the category cue question on approximately half the trials ($M = .50$, $SD = .14$). The absence of any floor or ceiling effects in response accuracy suggests that the task was suitably pitched to allow analysis of errors, as well as to reveal differences between individual participants. The proportion of correct responses on the single block trials was very similar to that obtained overall ($M = .51$, $SD = .23$), suggesting that children were paying attention to the first block in each trial, a pre-requisite for any PI effects to influence target recall.

The critical comparison in terms of establishing PI effects was that between performance on the interference trials and no-interference trials. Children showed a significantly higher proportion of correct responses on the no-interference trials ($M = .61$, $SD = .19$) than on the interference trials ($M = .39$, $SD = .18$), $t(86) = 8.48$, $p < 0.001$, $r = .51$ (see Figure 3.3). It could be argued that this difference was driven by the interference trials somehow being harder than the no-interference trials, but the finding that children actually made more extra-list (where they produced a word that has not been presented; $t(86) = 2.42$, $p = .02$, $r = .17$) and omission (where they produced no response; $t(86) = 4.60$, $p < .001$, $r = .27$) errors in the no-interference condition than in the interference condition suggests that this is not the case. What is driving the inferior performance in the interference condition is a shift in the relative proportion of the four different response types. As Figure 3.3 shows, in the interference trials children made a high proportion of list intrusion errors ($M = .35$,

$SD = .16$), where items from the first block were incorrectly produced over targets from the second block. Consequently, there was a shift downwards in the proportion of responses in the three other categories; correct, extra-list intrusions, and omissions.

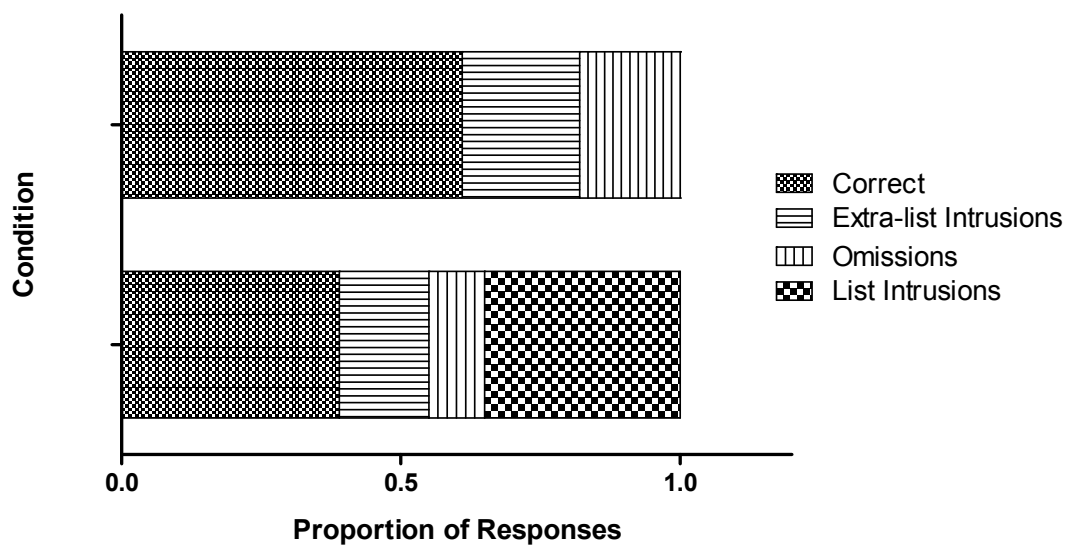


Figure 3.3. Mean proportion of each response type made on the interference and no-interference trials in the verbal PI task.

Non-verbal PI task performance

Three of the children failed to complete the non-verbal PI task, one due to computer malfunction, and two due to scheduling restrictions at their school. Five participants were excluded from analysis due to below chance performance on the single block trials, whilst a further five perseverated with the same response in each trial of the task, thus invalidating their data. Data were therefore analysed for a total of 76 participants. Because the task utilised a two-alternative forced choice procedure, it was important to establish that children were performing above a

chance level on the single block trials in order to confirm that they were paying attention to the first block in each trial (a prerequisite of any PI effects being demonstrated). Children performed well above chance on these trials, with their mean proportion of correct responses ($M = .69$, $SD = .12$) being significantly higher than .50, $t(75) = 14.03$, $p < 0.001$.

The critical comparison to establish PI effects was to compare performance in the interference trials with that in the no-interference control trials. If to-be-forgotten information was intruding from the first block in the interference trials, then we would expect children to show inferior accuracy scores on these trials when compared with the no-interference trials (in which the target face was never present in the first block, hence leaving no opportunity for PI effects). This was indeed found to be the case, with children performing significantly better on the no-interference ($M = .76$, $SD = .11$) than the interference ($M = .70$, $SD = .20$) trials, $t(75) = 2.45$, $p = .017$, $r = .18$.

Because in the interference trials a 'no' response was required every time, whereas in the no-interference trials a 'no' response was only required half the time, it could be the case that the poorer performance in the interference condition arose due to participants showing a general 'yes' response bias. To ascertain whether this was the case, the frequency of 'yes' and 'no' responses in the single block control trials, in which the target face was present in half of the trials and absent in the other half, was examined. On average, children produced 57% ($\pm 13\%$) 'no' responses in these trials, suggesting that if anything there was a slight bias towards the production of negative responses and therefore that a response bias towards

pressing 'yes' in the recognition test cannot explain the poorer performance in the interference trials.

Relationship between verbal and non-verbal PI and reading comprehension

Comprehension performance on the NARA correlated significantly with performance in the verbal PI interference condition ($r = .40, p < .001$); as comprehension performance increased, response accuracy in the presence of interfering verbal information also increased. By contrast, there was no significant correlation between comprehension performance on the NARA and performance in the non-verbal PI interference condition ($r = .11, p > .10$); there was no significant relationship between comprehension and response accuracy in the presence of interfering non-verbal information.

Although comprehension performance correlated strongly with performance in the interference condition of the verbal PI task, there was also a significant correlation with performance in the verbal PI no-interference condition ($r = .36, p = .001$). To establish that there was a *specific* relationship between comprehension and performance in the interference condition of the PI task beyond the relationship between comprehension and general performance on this verbal memory task, a hierarchical regression analysis was carried out. In line with the finding of a strong correlation between comprehension and performance in the verbal PI interference condition, the regression analysis revealed that performance in the verbal PI interference condition was a significant independent predictor of comprehension performance, even after controlling for performance in the verbal PI no-interference condition (see Table 3.4).

Table 3.4. Hierarchical regression predicting reading comprehension standard score.

	R Square	R Square Change	F	p	Final β
<i>Step 1</i>					
Age	.01	.01	1.12	.29	-.006
<i>Step 2</i>					
No-interference	.08	.07	4.04	.02	.22*
<i>Step 3</i>					
Interference	.20	.12	8.00	< .001	.36**

Note: * $p < .05$, ** $p < .001$

When entered as a control variable at Step 1, age accounted for only 1% of the variance in reading comprehension performance. Performance on the no-interference trials of the verbal PI task was added at Step 2, and accounted for an additional 7% of the variance in comprehension performance. Adding performance on the interference trials of the verbal PI task as a predictor in Step 3 of the model accounted for an additional 12% of the variance in comprehension performance; performance in the interference trials was a significant independent predictor of comprehension outcome, even after controlling for performance on the no-interference trials, suggesting a specific link between the ability to suppress no longer relevant verbal information from working memory and comprehension.

Relationship between verbal and non-verbal PI and working memory

There was a significant correlation between working memory, as measured by BDS, and performance on the interference trials of the verbal PI task, $r = .21$, $p = .04$, but not with performance on the no-interference trials of this task, $r = .10$, $p >$

.10., suggesting a specific relationship between working memory and performance in the interference condition of the PI task beyond the relationship between working memory and general performance on this verbal memory task. Again this implies a specific relationship between the ability to suppress no longer relevant verbal information from working memory and outcomes on standardised measures of working memory. BDS did not correlate with either interference ($r = -.02, p > .10$) or no-interference ($r = .03, p > .10$) trials on the non-verbal PI task.

Discussion

The first aim of this experiment was to examine the capacity of the standardised measures to predict variance in reading comprehension, and more specifically, to determine whether working memory and verbal ability were significant predictors of reading comprehension outcomes over and above decoding ability and non-verbal ability. As expected, word reading ability was a powerful predictor of reading comprehension ability, accounting for more than a third of the variance in reading comprehension scores even after age and non-verbal ability had been taken into account. Results showed however, that both working memory and verbal ability explained unique variance in reading comprehension outcome, even when controlling for children's word reading ability. This confirmed the findings of Cain et al. (2004) even with the additional control for non-verbal ability which was included in the regression model in this experiment, and suggested that working memory capacity and verbal ability are viable candidates for factors that could be limiting comprehension in poor comprehenders, that is, children whose comprehension deficits are not associated with word reading deficits.

The second aim of this experiment was to determine whether the newly-designed verbal and non-verbal PI tasks produced PI effects in a large group of typically developing children. Both tasks produced the intended effects, with performance declining in the presence of earlier interfering information that needed to be efficiently suppressed, relative to a control condition in which there were no suppression demands. This suggests that these tasks have been successfully adapted from the original adult-oriented task to assess PI in children. The finding of an absence of floor or ceiling effects on performance in both of the tasks supports their utility for exploring individual differences in verbal and non-verbal suppression ability within the age range studied. In the following Chapter therefore, I will go on to use these tasks to address important research questions regarding verbal and non-verbal suppression abilities in poor comprehenders. Methodological constraints of these tasks will also be discussed and addressed.

The final aim of the experiment was to explore the relationship of the verbal and non-verbal PI tasks with other variables of interest, namely reading comprehension and working memory. Performance on the no-interference trials of the verbal PI task was found to be significantly related to comprehension performance, suggesting a relationship between performance on this verbal memory task in general and comprehension outcomes. However, regression analyses revealed that performance on the interference trials of the verbal PI task predicted variance in reading comprehension over and above the variance predicted by general task performance (i.e. performance in the no-interference trials). This suggests that the demands that are specific to the interference condition relative to the no-interference condition (i.e. the requirement to efficiently suppress no longer

relevant material) are uniquely related to comprehension outcome, and so supports the idea proposed in Chapter 2 that verbal suppression ability plays an important role in comprehension ability. By contrast, there was no significant relationship between performance in the interference condition of the non-verbal PI task and reading comprehension. This pattern of associations suggests that comprehension difficulties might not be related to a domain-general failure to suppress no longer relevant information, but rather that this link between comprehension and suppression is exclusive to the verbal domain.

The relationship between performance on the two PI tasks and the BDS working memory task followed a very similar pattern. There was a significant association between performance on the interference trials of the verbal PI task and working memory score, but not between performance on the no-interference trials of this task and working memory score. This suggests, as with the relationship with reading comprehension, that the suppression demands of the interference trials share a specific relationship with working memory. This fits with the previous research concerning links between PI control and working memory span (e.g., Conway & Engle, 1994; Dempster, 1981; May, et al., 1999; Rosen & Engle, 1998; Shah & Miyake, 1996), and supports the conclusions drawn from that research, namely that the ability to resist PI plays a role in determining an individual's working memory span. No relationship was found between performance on the interference trials of the non-verbal PI task and working memory performance (on the verbally-based BDS task), suggesting that as with comprehension, the link between working memory and suppression ability is exclusive to the verbal domain. Reasons as to why this might be will be discussed in detail in the following chapter.

In summary, this examination of predictors of reading comprehension in an unselected sample of 7- to 8-year-olds has revealed that both working memory and verbal ability predict unique variance in reading comprehension outcomes over and above reading accuracy, confirming them as important candidates for factors that could be limiting comprehension in poor comprehenders. Furthermore, exploration of the links between a child's ability to suppress irrelevant information from working memory and their comprehension skills revealed a dissociation between verbal and non-verbal suppression, with only verbal suppression skills showing a significant relationship with reading comprehension. This raises important questions concerning the domain-specificity, or otherwise, of previously-established working memory and suppression deficits in poor comprehenders, with far-reaching implications for aetiological theories of poor comprehension. The series of experiments reported in the subsequent chapter will attempt to address these questions.

Chapter 4: Suppressing irrelevant information from working memory: Evidence for domain-specific deficits in poor comprehenders.

This chapter reports a series of experiments that explored whether poor comprehenders' working memory and suppression deficits are specific to the verbal domain, a question raised both by previous literature (Nation et al., 1999) and the findings reported in the previous chapter of this thesis. Experiment 4.1 examined the memory profiles of poor comprehenders and demonstrated a memory deficit specific to working memory, and the verbal domain within working memory. Experiment 4.2 compared the same poor comprehenders and controls on both verbal and non-verbal versions of a proactive interference task designed to assess their ability to suppress no longer relevant information from working memory. The poor comprehenders showed domain-specific suppression deficits, demonstrating impairments relative to the controls only in the verbal version of the task. Experiment 4.3 replicated these findings after the response modes of the verbal and non-verbal tasks were equated, confirming the domain specificity of this sample of poor comprehenders' suppression deficits. The implications of these findings for our theoretical understanding of poor comprehension, and of working memory, are discussed at the end of this chapter.

The results of Experiment 2.1 confirmed previous findings of suppression deficits in poor comprehenders, suggesting that they have problems with appropriately regulating the contents of working memory (cognitive inhibition). According to De Beni and colleagues (Carretti, et al., 2005; De Beni & Palladino, 2000; De Beni, et al., 1998; Palladino, et al., 2001), difficulties in regulating the contents of working memory mean that working memory gets overloaded because irrelevant information is not adequately suppressed, causing the working memory

system to function at sub-optimal capacity. This impacts on comprehension because fewer resources are available for the processing and maintenance of incoming information, thereby limiting the individual's ability to form a coherent representation of the text while reading it and dynamically update that representation when required. Important to this account is that difficulties with cognitive inhibition are attributed to attentional problems at the level of the central executive (e.g., De Beni & Palladino, 2000). As explained in Chapter 1, the central executive is the domain-general attentional control component of Baddeley's (2007) multicomponent working memory, which he argued regulated and controlled the contents of the two domain-specific slave systems.

If correct, the hypothesis outlined above leads to the prediction that poor comprehenders should show working memory and suppression deficits in both the verbal and the non-verbal domain because any deficit at the level of the domain-general central executive should impact on both verbal and visuospatial working memory. The findings of Experiment 3.1 concerning the specific link between comprehension and *verbal* suppression ability suggest that such a prediction may be questionable. Findings from a study by Nation and colleagues (Nation, et al., 1999) support the findings from Experiment 3.1. They examined poor comprehenders' working memory abilities using both a verbal and a visuospatial span task, and found that poor comprehender showed deficits relative to skilled comprehenders only on the verbal working memory task. In accordance with this, evidence from a recent meta-analysis (Carretti, et al., 2009) that examined the contribution of verbal and visuospatial short term and working memory to reading comprehension revealed

that verbal working memory tasks are most effective at discriminating between poor and good comprehenders.

An alternative perspective that takes into account these early indications of potential domain-specificity in working memory and suppression deficits is the proposal that poor comprehenders have general difficulties with the processing and representation of verbal information as a result of their underlying language weaknesses (see Chapter 1 for review). On this view, these verbal deficits detrimentally impact performance on any tasks that require verbal processing, with the magnitude of the impact increasing as a function of the processing demands of the task. The findings of Experiment 2.1 sit comfortably within this account, as the task used was firmly rooted in the verbal domain. Furthermore, the poor comprehenders performed slightly less well than the controls in the no interference trials on the task used in Experiment 2.1, with group differences only becoming significant when processing demands were high, that is, when there was a need to suppress a strong competing response.

There is a clear need to further explore the domain-specificity, or otherwise, of poor comprehenders' memory deficits, to allow us to differentiate between the two aetiological theories of poor comprehension discussed above. First, replication is needed of Nation et al.'s (1999) finding that poor comprehenders' performance on working memory span tasks is only impaired in the verbal domain. The verbal and visuospatial working memory tasks used in their experiment were unstandardised measures, and the range and variability of the scores was small, particularly for the visuospatial task. Although Carretti et al.'s meta-analysis seems to provide evidence to support the idea that poor comprehenders' core memory deficit is in verbal

working memory, few studies included in the meta-analysis used visuospatial working memory tasks. In fact if one excludes those studies which used the counting span task, a measure which arguably taps verbal working memory as well as visuospatial working memory (see Kane, et al., 2004), only two studies remain in the analysis (Cornoldi, De Beni, & Pazzaglia, 1996; Swanson & Berninger, 1995).

Additional empirical research that systematically explores poor comprehenders' visuospatial working memory abilities is needed. In Experiment 4.1 therefore, I investigated whether the dissociation between verbal and nonverbal working memory ability reported by Nation et al. (1999) replicates when the same children are compared on standardised and co-normed measures of verbal and visuospatial span.

The results of Experiment 3.1 raised the possibility of a dissociation between verbal and non-verbal suppression ability, and suggested a strong link between verbal suppression ability (but not non-verbal suppression ability) and comprehension outcomes in the large sample of children included in that study. It seems likely then that poor comprehenders have suppression deficits that are specific to the verbal domain, in line with the more general finding of differences in verbal but not visuospatial span (Nation et al., 1999). Previous work with poor comprehenders (e.g. Carretti, et al., 2004; Carretti, et al., 2005; De Beni & Palladino, 2000; De Beni, et al., 1998; Palladino, et al., 2001), including my own reported in Chapter 2, has shown that these children have deficits in suppressing irrelevant information from working memory, but all these studies have taken place in the verbal domain, and have primarily used verbal stimuli such as words and sentences. Carretti et al. (2005) attempted to reduce reliance on verbal skills in their updating

task by using a visual task comprising familiar, nameable pictures. However, it was still the case that the items to be maintained (and suppressed when irrelevant, or no longer relevant) were words. This meant that although the language processing demands of this task were reduced compared to previous studies, it was still clearly rooted in the verbal domain. Thus, the extent to which deficits in the suppression of irrelevant information from working memory are specific to the verbal domain remains unexplored. Experiments 4.2 and 4.3 therefore assessed the hypothesis that poor comprehenders' impairments on suppression tasks are restricted to the verbal domain.

Experiment 4.1

The investigation began by assessing the memory skills of poor comprehenders and controls using standardised tasks. It was anticipated that poor comprehenders would show normal short-term memory (as assessed by forward digit span) but impaired working memory, in line with previous investigations (Cain, 2006; Nation, et al., 1999; Oakhill, et al., 1988; Yuill, et al., 1989). Within the working memory domain, previous research using non-standardised memory measures found that poor comprehenders' deficits were specific to the verbal domain (Nation et al., 1999). To assess this claim more thoroughly, verbal and visuospatial span were compared using two tests that have been co-normed and recently standardised in the UK. It was predicted that poor comprehenders would show deficits relative to control children on standardised measures of verbal, but not visuospatial, working memory.

Method

Participants

Fourteen of the poor comprehenders and 14 of the controls who participated in Experiment 2.1 participated in this experiment (see Chapter 2 for detailed description of selection criteria for each participant group). Table 4.1 shows their performance on the standardised tests of reading and non-verbal ability that were used to select and match the groups.

Table 4.1. Comparison of poor comprehenders' and controls' mean chronological age and performance on the screening measures.

	Poor Comprehenders	Controls	<i>F</i>	<i>p</i>
Matrix Reasoning (WASI) ¹	52.50	56.21	1.83	.188
Text Reading Accuracy (NARA) ²	99.36	100.29	0.112	.741
Reading Comprehension (NARA) ²	86.57	103.57	65.84	< 0.001
Word Reading (TOWRE) ²	108.29	110	0.28	.603
Phonemic Decoding (TOWRE) ²	111.14	104.64	3.00	.095

Note: ¹T Scores, *M* = 50, *SD* = 10; ²Standard Scores, *M* = 100, *SD* = 15

Materials and Procedure

Short-term memory. The forward digit span (FDS) component of the British Ability Scales II (BAS-II; Elliot, et al., 1997) was used to assess children's phonological short-term memory. Children heard increasingly long lists of digits and were required to repeat these back to the experimenter in the correct order.

Working memory. Working memory was assessed using two co-normed subtests from the Automated Working Memory Assessment (AWMA; Alloway, 2007), one measuring verbal working memory (listening recall) and the other measuring visuospatial working memory (spatial recall). In the verbal working memory task, children heard sets of sentences (ranging from one sentence to six sentences in total) and were required to judge the veracity of each sentence after they had heard it. After all the sentences in the set had been heard, the children had to recall the final word of each of the sentences in the same order that they were presented. Children attempted a maximum of six sets of sentences at each set size, and the task was discontinued when they produced three or more incorrect recall responses at any one set size. In the visuospatial working memory task, the children were presented with two shapes at a time, and each time had to judge whether they were the same or mirror images of each other. At the same time they had to remember the location of a red dot which was presented alongside each pair of shapes and subsequently point to where each dot appeared in the same order as they were presented. Again there was a range of set sizes, from one to seven sets of shapes, with six trials for each set size. The discontinue rule was the same; children stopped the task when they made three or more incorrect responses at any one set size.

Results and Discussion

For all analyses, the p -level for significance was set at .05. As predicted, no significant differences were found between the groups on the FDS measure of short-term memory, $F(1, 26) = 1.62, p > .10$ (poor comprehenders, $M = 46.64, SD = 6.35$; controls, $M = 49.43, SD = 5.18$). Turning to the AWMA results, a 2×2 mixed-design ANOVA with group (poor comprehenders vs. controls) as a between-subjects factor

and working memory measure (verbal vs. visuospatial) as a within-subject factor was conducted on the data. The main effects of working memory measure ($F(1, 26) = 1.47, p > .10$) and group ($F(1, 26) = 3.63, p = .07$) were not significant, nor was the interaction between group and task ($F(1, 26) = 1.28, p > .10$). However, as it can be seen in Figure 4.1, and as demonstrated by univariate ANOVAs, poor comprehenders ($M = 92.00, SD = 11.36$) performed significantly less well than the controls ($M = 102.36, SD = 11.83$) on the verbal working memory measure producing a mean difference of 10.36 standard score points, $F(1, 26) = 5.58, p = .026, \eta_p^2 = .18$. This is despite there being no significant group differences in the standard scores obtained on the visuospatial working memory measure, $F(1, 26) = 0.82, p > .10$. It is likely then that the lack of a significant group \times working memory measure interaction in the mixed-design ANOVA arose because of a combination of the relatively small sample sizes involved, and a small, non-significant trend for superior performance by the controls in the visuospatial working memory task. Cohen's d effect sizes, calculated to examine differences between the two participant groups on the verbal and visuospatial working memory tasks, supported this assumption. On the verbal working memory task there was a large effect size for the difference between the mean scores obtained by poor comprehenders and controls ($d = 0.89$). By contrast, a much smaller effect size was found on the visuospatial working memory task for the difference between the mean scores obtained by poor comprehenders and controls ($d = 0.34$).

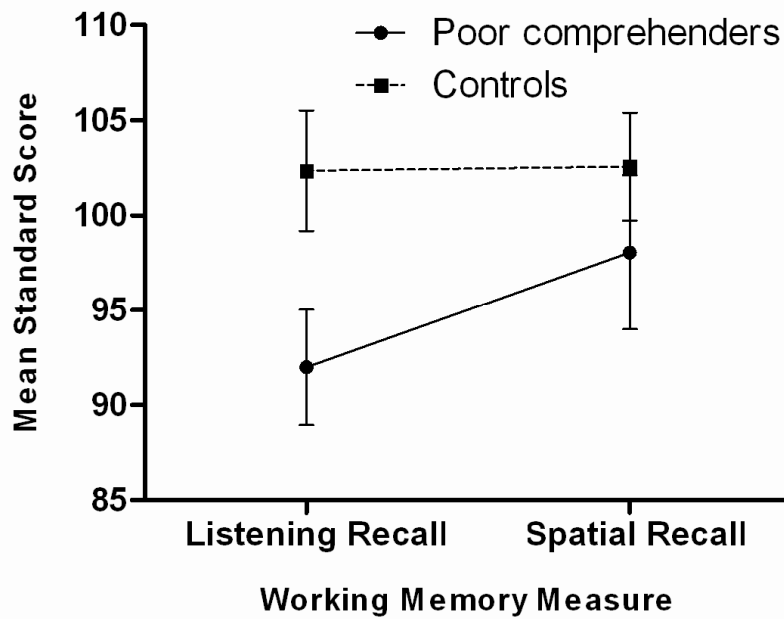


Figure 4.1. Mean standard score of poor comprehenders and controls on verbal and visuospatial working memory subtests of the AWMA. Error bars show the standard error of the mean.

These data confirm previous findings that poor comprehenders show impaired working memory, despite achieving normal levels of phonological short-term memory as assessed by forward digit span; they also demonstrate that poor comprehenders' deficits on working memory tasks are specific to the verbal domain: Poor comprehenders performed significantly less well than the controls on a verbal working memory task, but not on a co-normed visuospatial working memory task, replicating Nation et al.'s (1999) findings but using recently standardised and co-normed memory measures.

Experiment 4.2

Experiment 4.1 used span measures and confirmed that memory deficits in poor comprehenders are specific both to working memory, and to the verbal domain

within working memory. Following this, in Experiment 4.2 the proactive interference paradigm developed in the previous chapter was used to explore suppression in both the verbal and non-verbal domains. As discussed in Chapter 3, proactive interference refers to the interfering effect of previously encoded information on the recall of more recent information. If poor comprehenders are less good at suppressing no longer relevant information from working memory, they should be more susceptible to the effects of proactive interference at recall. By using both a verbal and non-verbal version of the proactive interference task, it was possible to address the question of whether poor comprehenders' suppression deficits are specific to the verbal domain, or whether they reflect a domain general deficit in regulating the contents of working memory. It was predicted that in line with their specific verbal working memory deficits, as well as the demonstration of specific links between comprehension and verbal suppression ability documented in the previous chapter, poor comprehenders would show suppression deficits that are specific to the verbal domain.

Method

Participants

The same poor comprehenders (N = 14) and controls (N = 14) that participated in Experiment 4.1 also participated in this experiment.

Materials and Procedure

Both the verbal and the non-verbal PI tasks were exactly the same as those used in Experiment 3.1 (see Chapter 3 for detailed description of the materials and procedures involved in these tasks).

Results

Verbal PI task

Participants produced the correct response to the category cue question on approximately half the trials ($M = .49, SD = .13$). The absence of any floor or ceiling effects in response accuracy suggests that the task was suitably pitched to allow analysis of errors, as well as to reveal individual differences between participants. There were no significant group differences between the poor comprehenders ($M = 4.43, SD = 1.65$) and the controls ($M = 5.29, SD = 1.54$) on the no-interference control trials, $F(1, 26) = 2.02, p > .10$. However, poor comprehenders ($M = 2.50, SD = 1.29$) performed significantly less well than controls ($M = 3.79, SD = 1.05$) on the interference trials, $F(1, 26) = 8.39, p < .01, \eta_p^2 = .24$. It was not the case that the poor comprehenders were worse in general on these interference trials, as there were no group differences in the number of extralist errors (where a word that has not been presented is produced) or omissions (where no response is produced; both $ps > .10$, see Figure 4.2). The inferior performance of the poor comprehenders on the interference trials was therefore carried by their greater number of list intrusion errors ($M = 3.29, SD = 1.49$), relative to controls ($M = 2.07, SD = 1.07$), producing a mean difference of 1.21, $F(1, 26) = 6.13, p < .05, \eta_p^2 = .19$ (Figure 4.3).

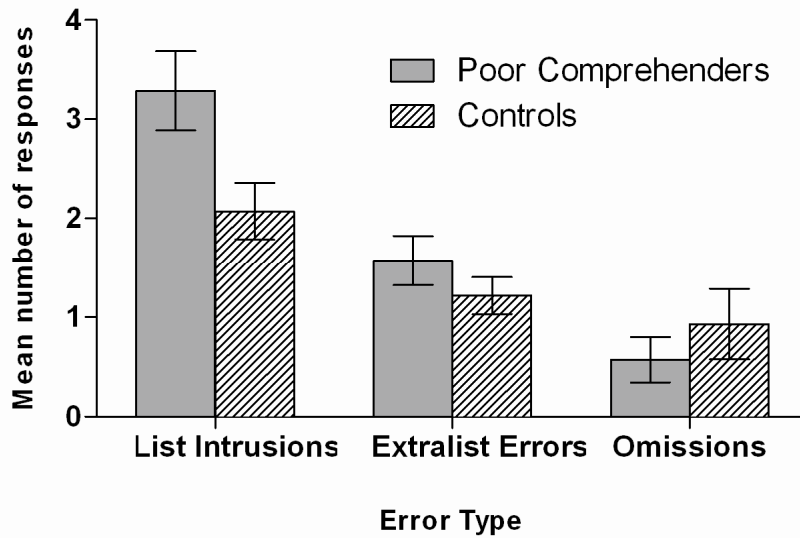


Figure 4.2. Mean number of responses (out of a possible eight) classified as list intrusion errors, extralist intrusion errors or omissions in the interference condition of the verbal PI task for poor comprehenders and controls. Error bars show the standard error of the mean.

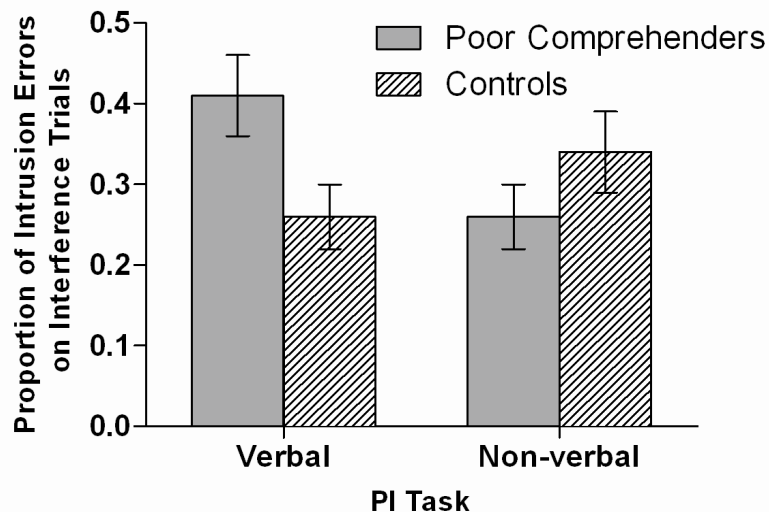


Figure 4.3. Mean proportion of intrusion errors made in the interference trials on the verbal and non-verbal PI tasks for poor comprehenders and controls. Error bars show the standard error of the mean.

Non-verbal PI task

Because the non-verbal task utilised a two-alternative forced choice procedure, it was important to establish that children were performing above chance level to avoid any floor effects masking group differences. Children performed well above chance on the task, with their total proportion of correct responses ($M = .72$, $SD = .08$) being significantly higher than 0.5, $t(26) = 14.82$, $p < 0.001$, but not approaching ceiling. Poor comprehenders ($M = 7.71$, $SD = 0.83$) did not differ from controls ($M = 7.77$, $SD = 0.93$) in terms of their accuracy on the no-interference trials, $F(1, 25) = 0.03$, $p > .10$, suggesting that both groups were equally good at discriminating and remembering the faces.² Furthermore, there was no evidence for any group differences on the interference trials either, $F(1, 25) = 1.39$, $p > .10$; unlike in the verbal PI task, poor comprehenders did not make more intrusion errors than the controls (Figure 4.3). In order to confirm this group by task interaction effect, data were entered into a 2 x 2 mixed-design ANOVA with group (poor comprehenders vs. controls) as a between-subjects factor and proportion of intrusion errors in each task (verbal vs. non-verbal) as a within-subject factor. The main effects of group ($F(1, 25) = 0.74$, $p > .10$) and task ($F(1, 25) = 0.61$, $p > .10$) were not significant. However, the interaction between group and task, shown graphically in Figure 4.3, was statistically significant, $F(1, 25) = 4.79$, $p = .038$, $\eta_p^2 = .16$.

² Due to computer malfunction, one control participant failed to complete the non-verbal PI task. Analyses are therefore conducted on the data of 13 of the 14 the control participants.

Discussion

This experiment explored the ability of children with specific reading comprehension problems to suppress no longer relevant information from working memory. By using both verbal and non-verbal suppression tasks, I hoped to clarify whether previous demonstrations of suppression deficits in these poor comprehenders reflected a domain general problem in regulating the contents of working memory, or whether they were specific to the verbal domain in which poor comprehenders' reading and language weaknesses lie. The findings are clear in showing that poor comprehenders made significantly more intrusion errors than the controls on the verbal proactive interference task, suggesting relative weaknesses in the suppression of irrelevant verbal information from working memory, and replicating previous findings (e.g., de Beni & Palladino, 2000). Importantly though, Experiment 4.2 has shown for the first time that poor comprehenders' suppression deficits are specific to the verbal domain; there was no evidence of group differences on the non-verbal proactive interference task.

It could be argued that because the measure of non-verbal PI was a recognition task, whereas the verbal version took the form of a recall task, these differences in response mode may have affected the pattern of results that was found. This seems unlikely given that Petrusic and Dillon (1972) found that participants showed significant levels of PI, as well as equivalent rates of PI buildup over trials, in a Brown-Peterson task regardless of whether memory was tested using a recognition or a recall measure. This suggests that the response mode used to assess memory in PI tasks does not affect individuals' vulnerability to PI.

Nevertheless, an additional experiment was carried out to see whether the findings

from Experiment 4.2 replicate when the response modes of the verbal and non-verbal PI tasks are equated.

Experiment 4.3

Converting the non-verbal PI task into a recall task would not be possible. However, a recognition version of the verbal PI task was viable, allowing me to compare a verbal recognition task directly with a non-verbal recognition task, and so isolate the variable of task modality (verbal vs. non-verbal) from that of task response mode (recall vs. recognition). Following Petrusic and Dillon (1972), it was predicted that the method of testing memory in the PI task would have little effect on the development of PI. It was therefore expected that poor comprehenders and controls would produce the same pattern of results seen in Experiment 4.2, namely that poor comprehenders would show a greater number of intrusion errors on the verbal PI task than controls because they are less able to suppress irrelevant verbal information. This would contrast with the lack of group difference in the number of intrusion errors produced on the non-verbal recognition PI task.

Method

Participants

The same poor comprehenders (N = 14) and controls (N = 14) that participated in Experiment 4.2 also participated in this experiment, with this second testing session taking place approximately six months after they completed Experiment 4.2.

Materials and procedure

Participants completed a recognition version of the verbal PI task described in Experiment 4.2. The stimuli presented were exactly the same as those in Experiment 4.2, with the only change to the task being in the response mode required. Whereas in the original recall version of the task children were asked a recall question at the end of each trial (e.g. can you remember the word that was a type of pet?), in this recognition version they were asked a recognition question (e.g. was the type of pet you heard a cat?). The recognition question still cued the participants with a semantic category, but rather than requiring them to recall a word from that trial that matched the category, they simply had to decide whether the word presented in the question was the exemplar of the category that was presented in the most recent block of four words. Pilot testing showed that children found this recognition version of the verbal PI task easier than the recall version, so the digit shadowing component of each trial was increased in difficulty (children were required to shadow two sets of five digits, rather than two sets of three digits), in order to avoid any ceiling effects on performance variability.

In the interference condition, the test word was present in the first block which children had been instructed to forget. Thus, 'yes' responses on these trials provided evidence of proactive interference of the to-be-forgotten material. In the no-interference trials, the target was never present in the first block, leaving no opportunity for proactive interference to occur in this control condition. In half of both the no-interference trials and the single block trials, the target word was not

included in the trial, meaning that the correct response to the recognition question was negative on these occasions.

Results

As with the non-verbal PI task reported in Experiment 4.2, this recognition version of the verbal PI task used a two-alternative forced choice procedure, meaning that it was important to establish that children were performing above chance level to avoid any group differences being masked by floor effects. Participants' mean proportion of correct responses ($M = .70$, $SD = .10$) was significantly higher than a chance level of .50, $t(27) = 10.95$, $p < .001$. The fact that this mean proportion of correct responses was also significantly below a ceiling level of 1.0, $t(27) = 15.90$, $p < .001$, suggests that the task was appropriately pitched to detect performance differences between the groups.

The poor comprehenders ($M = .75$, $SD = .13$) performed at a very similar level to the controls ($M = .78$, $SD = .14$) on the no-interference trials, $F(1, 26) = 0.28$, $p > .10$. However, as with the recall version of this verbal PI task, the children with comprehension deficits ($M = .50$, $SD = .23$) showed a decrement in performance relative to the controls ($M = .67$, $SD = .20$) on the interference trials, with this difference approaching significance, $F(1, 26) = 3.97$, $p = .057$, $\eta_p^2 = .13$; the poor comprehenders again showed evidence of a greater vulnerability to intrusion of no longer relevant verbal information. As Figure 4.4 shows, the results in this recognition verbal PI task show a very similar pattern to those produced in the original recall verbal PI task, with the poor comprehenders showing a greater number of intrusion errors than the controls in both cases. These can be contrasted

with the results from the non-verbal PI task, also shown in Figure 4.4, in which group differences are slight, and in the opposite direction with poor comprehenders making slightly fewer non-verbal intrusion errors than controls.

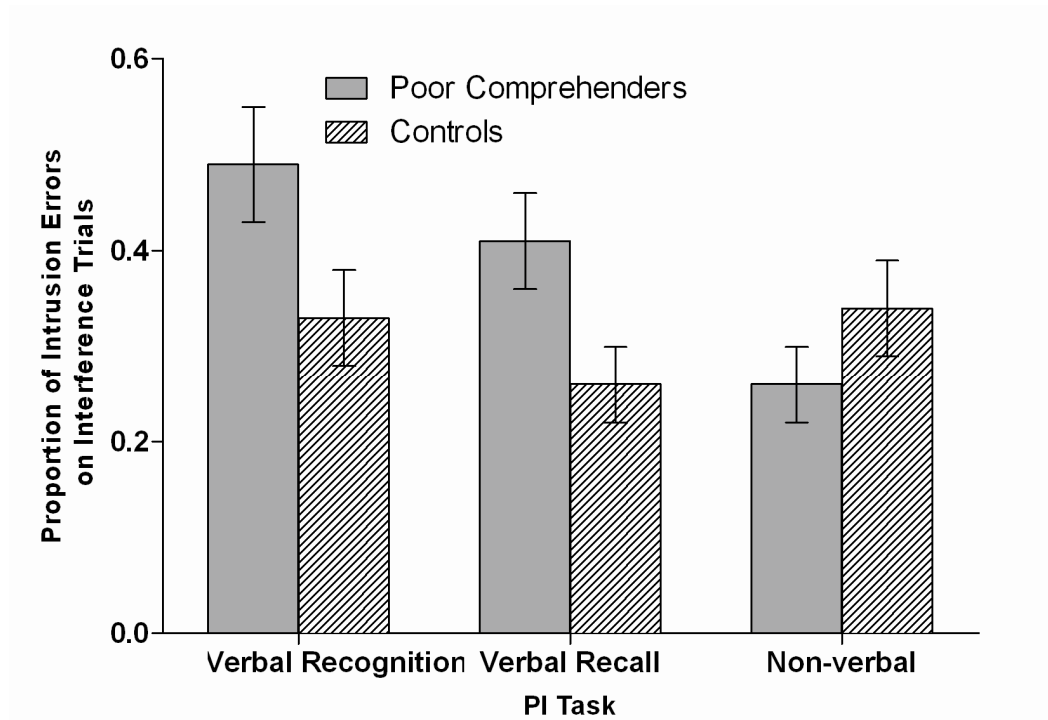


Figure 4.4. Mean proportion of intrusion errors made in the interference trials on the recognition (data from Experiment 4.2) and recall (data from Experiment 4.3) versions of the verbal PI task, as well as on the non-verbal PI task (data from Experiment 4.2). Error bars show the standard error of mean.

To directly compare intrusion errors on the verbal and non-verbal recognition tasks, data from Experiment 4.2 (non-verbal recognition task) and Experiment 4.3 (verbal recognition task) were entered into a 2 x 2 mixed-design ANOVA with group (poor comprehenders vs. controls) as a between-subjects factor and proportion of

intrusion errors in each task (verbal vs. non-verbal) as a within-subject factor. There was a significant main effect of task; participants produced more intrusion errors in the verbal task ($M = .42$, $SD = .22$) than in the non-verbal task ($M = .30$, $SD = .16$), rendering a mean difference of $.12$, $F(1, 25) = 6.03$, $p = .021$, $\eta_p^2 = .19$. The main effect of group was not significant, $F(1, 25) = 0.41$, $p > .10$. Importantly however, the interaction between group and task was significant, $F(1, 25) = 5.26$, $p = .03$, $\eta_p^2 = .17$, with poor comprehenders making more intrusion errors than the controls in both verbal PI tasks but making fewer intrusion errors than the controls in the non-verbal PI task, as shown in Figure 4.4.

Discussion

Experiment 4.3 explored whether the effects that were attributed to task modality (i.e. verbal vs. non-verbal) in Experiment 4.2 could be accounted for by the differential response modes of these tasks; the verbal task originally followed a recall format, whereas the non-verbal task used recognition. To address this question, the response modes of the two tasks were equated by creating a recognition version of the verbal PI task, so that two tasks of different modalities (verbal vs. non-verbal) but with the same response mode (recognition) could be compared. The results of Experiment 4.3 reinforced those of Experiment 4.2. This shows that it was not the response mode of the task, but rather its modality, that was the key factor in the pattern of findings produced in Experiment 4.2. Poor comprehenders were more vulnerable than controls to interference of no longer relevant verbal material that should have been suppressed from working memory; in both the recognition and the recall versions of the verbal PI task, poor comprehenders made more intrusion errors than controls. This was not the case in the non-verbal PI task, with poor

comprehenders not differing significantly from the controls in the number of intrusion errors made. As a result, when performance on the verbal recognition task was compared directly to that on the non-verbal recognition task, the interaction between group and task was significant, confirming a domain-specific deficit in poor comprehenders.

General Discussion

The findings of Experiments 4.2 and 4.3 show that poor comprehenders' suppression deficits are specific to the verbal domain. This is consistent with the span data reported in Experiment 4.1 showing that poor comprehenders have deficits in verbal span but not visuospatial span. Taken together, these findings argue against the idea that poor comprehenders' comprehension difficulties are underpinned by working memory deficits at the level of the central executive and consequent inadequacies in the regulation and control of both verbal and visuospatial domain-specific slave systems.

The specific pattern of memory deficits observed in this sample of poor comprehenders argues against Baddeley's multicomponent model (Baddeley, 2007) being an adequate model of working memory. Replicating previous experiments, the poor comprehenders showed no deficits in verbal short term memory, demonstrating intact phonological loop function. Thus, their deficits in verbal working memory suggest a problem at the level of the central executive. However, Baddeley's model posits a domain general central executive, resulting in the prediction that if poor comprehenders have verbal working memory deficits that cannot be accounted for by deficits in the phonological loop, then they should also

have deficits in visuospatial working memory. This prediction does not fit with the finding of impaired verbal working memory, in the face of both spared visuospatial working memory and verbal short term memory.

It is possible that individual differences in source monitoring ability, that is, the ability to appropriately attribute the source of remembered information (see Johnson, Hashtroudi, & Lindsay, 1993, for review of this concept), may have played a role in the PI tasks used in these experiments. External source monitoring refers to the ability to differentiate between different perceptually derived (as opposed to self-generated) memories (e.g. did person A tell me that or did person B tell me?). With reference to the PI tasks then, if an individual is poor at source monitoring they may experience confusion regarding the source (first block vs. second block) of the target stimuli, hence producing the observed interference effects. In order to accurately attribute an event to its correct source, it has been argued that one needs to successfully bind together diverse sources that contextualise the memory at encoding (see Mammarella & Fairfield, 2008). Returning to Baddeley's working memory model, the most recently-added component of this model, the episodic buffer, has been associated with the integration and binding functions that are necessary for accurate source monitoring. Could it be the case then that poor comprehenders have deficits in the function of the episodic buffer that drove their performance deficits on the PI tasks? Again the finding of domain-specific deficits for poor comprehenders in the PI tasks argues against this as a feasible explanation. The episodic buffer is a multimodal interface that binds information from both verbal and visuospatial domains, and that is under central executive control. Thus a deficit in this component of working memory, whether or not it results from a higher-level

central executive deficit, should impact on both verbal and non-verbal source monitoring, and hence should have resulted in deficits on both verbal and non-verbal tasks.

A model of working memory that would fit better with the data would be one that allows for a division of the central executive into separate pools of resources devoted to verbal working memory and visuospatial working memory. Shah and Miyake (1996) made the case for a verbal-visuospatial dissociation within working memory *beyond* the level of the visuospatial sketchpad and phonological loop, that is, a separability of the resources that contribute to the processing aspects of working memory, as well as the established separation of the storage aspects. If it is the case that there is a functional distinction between verbal and visuospatial working memory at the level of the central executive, then it might be possible for a selective verbal central executive deficit to underlie the specific verbal suppression deficits demonstrated by the poor comprehenders in Experiments 4.2 and 4.3. If we give credence to the contribution that may have been made by source monitoring deficits to poor comprehenders' poorer performance on the verbal PI task, then it is feasible to argue that a division of working memory resources that goes beyond the slave systems could also account for domain-specific weaknesses in source monitoring, which could in turn compound the group differences on the verbal PI task.

An alternative proposition is that children with specific reading comprehension difficulties show deficits on verbal working memory and suppression tasks as a consequence of general underlying difficulties in the processing and representation of verbal information. If we attribute to poor comprehenders general

language processing weaknesses, then it seems logical that we would find deficits on a task that requires verbal processing but not on one that requires non-verbal processing. Furthermore, the higher the verbal processing demands, the greater the difficulties that the poor comprehenders should have relative to the controls. In the interference condition of the verbal PI task, processing demands are high because there is a strong competing response that has to be appropriately suppressed, whereas in the no-interference condition there are no such competing responses. This could explain why group differences reached significance in the interference trials but not in the no-interference trials. A similar argument can be made regarding the results from Experiment 4.1. On the verbal short-term memory task (forward digit span), in which the processing demands are minimal, there were no differences between poor comprehenders and controls. However, on the verbal working memory task when the processing demands are high, the poor comprehenders showed deficits relative to the controls. It would be interesting to further explore this hypothesis by systematically manipulating the processing demands of a verbal memory task and examining the effect this has on the magnitude of the group differences. My prediction would be that the relative superiority of the controls on the verbal memory task would covary with the processing demands of the task. Comparing performance across a variety of storage and updating memory measures should help elucidate the complex interplay between language, memory, and reading comprehension.

A related argument concerns the causal direction of the relationship between reading comprehension and verbal suppression ability. Thus far explanations have focused on the idea that weaknesses in the suppression of verbal information from

working memory lead to difficulties in reading comprehension. However, it remains a possibility that children who have difficulties with comprehension avoid reading and that this leads to the observed deficits in efficiently suppressing irrelevant verbal information. On this view, a lack of reading experience in the poor comprehender group could explain the observed group differences in both comprehension and suppression ability, an argument supported by research into the role of experience in language comprehension ability in adults (MacDonald & Christiansen, 2002; Wells, Christiansen, Race, Acheson, & MacDonald, 2009). The need for longitudinal studies to clarify causality is clear. It should be possible to examine suppression ability, potentially by using simplified versions of the PI tasks used in this chapter, before children actually begin to read, hence giving us the opportunity to determine whether early deficits in verbal suppression predict later comprehension outcomes. Controlling for the effects of language abilities on comprehension outcomes within the context of such a longitudinal design could also offer a valuable way of teasing apart the competing explanations for verbal-only suppression and memory deficits that were discussed above. If poor comprehenders' verbal suppression ability predicts unique variance in reading comprehension outcomes after controlling for their underlying verbal abilities, it would suggest that they may have a problem within the memory system and that their difficulties do not result entirely from underlying language deficits. Training studies would offer another way of addressing this issue by allowing us to determine whether training in either verbal working memory or underlying oral language abilities impacts on comprehension ability (see Chapter 8 for detailed discussion).

In summary, the studies presented in this chapter have converged to demonstrate that poor comprehenders' working memory and suppression deficits are exclusive to the verbal domain. Competing explanations for these domain-specific findings were discussed, with the conclusion being that longitudinal or training studies are necessary to distinguish between these explanations. This issue will be discussed further in Chapter 8 of this thesis. In the following chapter, the focus of investigation will be broadened beyond cognitive inhibition to address wider aspects of executive inhibitory control in poor comprehenders. However, experiments in both the verbal and the non-verbal domains will allow me to continue to address the domain-specific nature of any observed deficits.

Chapter 5: Broader deficits in executive inhibition in poor comprehenders

This chapter presents two experiments designed to go beyond previous examination of cognitive inhibition in poor comprehenders to explore broader aspects of executive inhibitory control. In Experiment 5.1, poor comprehenders and controls completed tasks designed to measure one aspect of executive inhibition, interference control; these tasks took place in both the verbal and the non-verbal domain. Poor comprehenders showed an unexpected pattern of inhibitory deficits in the non-verbal interference control task and normal performance in the verbal interference control task, with the absence of verbal interference control deficits attributed to the confounding role that semantic processing plays in the task. Experiment 5.2 aimed to resolve ambiguities regarding what construct the non-verbal interference control task was measuring by administering another measure of non-verbal interference control and a behavioural inhibition task. Poor comprehenders showed impairments relative to controls on both of these tasks, converging to suggest the presence of wide-ranging deficits in executive inhibition which span both the verbal and the non-verbal domain; this contrasted with my previous finding of verbal-only deficits for these children on cognitive inhibition tasks. Explanations for these findings will be discussed, including the possibility of domain-general executive function deficits in a subgroup of the poor comprehenders, and the idea that verbal deficits may impact on performance on executive tasks.

The findings of Experiments 4.2 and 4.3 are consistent with the idea that poor comprehenders have inhibitory deficits. However, the finding that these deficits were specific to the verbal domain suggests that the story may not be as simple as poor comprehenders simply having general deficits in inhibition.

Moreover, Nigg (2000) made clear in his taxonomy of inhibition, that the type of inhibition studied in Experiments 4.2, and 4.3 (cognitive inhibition) is merely one of several kinds of inhibitory control. He specified four different types of inhibitory processes in the class of executive inhibitory control, including cognitive inhibition, shown in Table 5.1.

Table 5.1. Taxonomy of executive inhibition (adapted from Nigg, 2000).

Inhibition Process	Cognitive View (measurement paradigms)	Neural View
1. Interference control (prevent interference due to resource or stimulus competition)	Stroop; flanker tasks, dual task interference; priming tasks	Anterior cingulate → dorsolateral prefrontal/premotor cortex → basal ganglia
2. Cognitive inhibition (suppress nonpertinent ideation to protect working memory/attention)	Directed ignoring; ratings of intrusive thoughts; negative priming	Anterior cingulate → prefrontal → association cortex
3. Behavioural inhibition (suppress prepotent [automatic/prepared/cued response])	Stop task; go/no-go; suppress attentional orienting	Lateral and orbital prefrontal → premotor
4. Oculomotor (effortfully suppress reflexive saccade)	Antisaccade and oculomotor tasks	Frontal eye fields/ orbitofrontal cortex

As well as the deficits at the level of cognitive inhibition demonstrated in Experiments 4.2, and 4.3, preliminary evidence suggests that poor comprehenders may have deficits in behavioural inhibition as well. Nation, Marshall, and Altmann (2003) reported that the poor comprehenders in their study showed marginally significant deficits relative to controls in the Opposite Worlds subtest of the Test of

Everyday Attention for Children (TEA-Ch; Manly, Robertson, Anderson, & Nimmo-Smith, 1999), a task that requires children to inhibit a prepotent response, i.e. behavioural inhibition. Furthermore, while the mean scaled score obtained by the skilled comprehenders on this task was actually slightly above average, the poor comprehenders' mean score was very much in the low average range and was almost one standard deviation below that of the skilled comprehenders, confirming deficits for poor comprehenders on this behavioural inhibition task. However, poor comprehenders' interference control abilities have not yet been explored, so we do not know whether their deficits at the level of cognitive inhibition would also extend to the level of interference control.

Nigg argued that little is known about the links between interference control and cognitive inhibition, and whether these two types of inhibitory control activate the same or different underlying processes. More recently, there has been some attempt to address this question, but the issue remains controversial. Friedman and Miyake (2004) used latent-variable analysis to clarify the relationship between interference control (resistance to distractor interference), cognitive inhibition (resistance to proactive interference) and behavioural inhibition (prepotent response inhibition). Confirmatory factor analysis revealed a strong relationship between interference control and behavioural inhibition; however, neither of these inhibitory processes was related to cognitive inhibition. This lack of a link between cognitive inhibition and interference control suggests that different processes may underlie these two types of inhibitory control, but no subsequent studies have yet been conducted to confirm these findings. Furthermore, Bissett, Nee, and Jonides (2009) argued that the way in which Friedman and Miyake modelled resistance to proactive

interference (as the 'residual variance not captured by pure recall') was not a valid measure of participants' actual ability to resist proactive interference, hence rendering any examination of the links with interference control invalid. As a result of these inconclusive outcomes, we do not know whether, if a child shows deficits in cognitive inhibition, they will show deficits in interference control as well.

Experiment 5.1 therefore aimed to explore whether demonstrations of inhibitory deficits in poor comprehenders at the level of cognitive inhibition extended to the level of interference control. The most widely utilised measure of interference control is the Stroop task (see Macleod, 1991, for review) in which participants see a colour word such as RED written in a different colour ink, such as green, and are required to name the colour of ink whilst ignoring the colour word itself. This requires interference control because it is necessary to suppress the irrelevant dimension of the stimulus (in this case, the colour word itself) to prevent interference. The classic Stroop finding is that participants are slower to name the ink colour of an incongruent colour word than they are to name the ink colour of a neutral stimulus (e.g. XXXX), a condition where there is no interfering dimension that needs to be suppressed.

As discussed above, although poor comprehenders showed deficits at the level of cognitive inhibition (see Experiments 4.2 and 4.3), these deficits were only manifested when the tasks used took place in the verbal domain. Chapter 4 discussed potential explanations for why poor comprehenders might display verbal-only deficits. Potentially, the most feasible explanation is that poor comprehenders have general underlying difficulties in the processing and representation of verbal information, and that these difficulties impact on any task that requires these verbal

processes; thus, the greater the verbal processing demands of a task, the greater the difficulties experienced by poor comprehenders should be. If this explanation is correct, poor comprehenders should show deficits in the Stroop task, because like the verbal PI tasks that were used in Chapters 3 and 4, this task also requires the representation and processing of verbal material. As incongruent trials are more demanding than neutral trials, poor comprehenders should show processing costs in the incongruent condition and as a consequence they should show larger interference effects than control children.

However, another factor that must be taken into account when making predictions about the performance of the poor comprehenders on the verbal Stroop is the role of semantic processing in this task. Using a traditional colour Stroop task, Adams and Jarrold (2009) found that children with autism showed less interference than typically developing children. They argued that as children with autism are poor at taking semantic meaning from words (associated with their poor reading comprehension), this leads them to experience less interference from the colour words than control children and hence show a smaller interference effect. Evidence to support this argument came from performance on a Stroop-like task which did not require the children to extract semantic meaning from words, but instead required them to name pictures. In this 'chimeric animal task', the children saw a creature with the head of one animal and the body of another, and were required to name the head of the creature and ignore the body, or vice-versa. In this condition, the children with autism showed a similar level of interference to control children. This led Adams and Jarrold to argue that the reduced interference effect shown by the children with autism in the classic Stroop task does not reflect good inhibitory

skills, but rather less automatic processing of the semantic content of the colour words; an impairment in taking meaning from the words. To return to our poor comprehenders then, a group who also have marked deficits in taking meaning from what they read, on the basis of Adams and Jarrold's arguments it could be predicted that they too should show a reduced colour Stroop effect relative to control children.

Experiment 5.1 also explored whether any deficits in poor comprehenders at the level of interference control are specific to the verbal domain, as they were at the level of cognitive inhibition (Experiments 4.2 and 4.3). To do this, I developed a non-verbal Stroop-like task that required the children to suppress an irrelevant non-verbal dimension of a stimulus. Briefly, children saw an arrow on the screen and had to respond to the direction of the arrow whilst ignoring its actual location on the screen. A measure of non-verbal interference control could be taken by comparing performance on incongruent trials (e.g. a right-pointing arrow on the left of the screen), in which the location of the arrow generated interference, with neutral trials (e.g. a right-pointing arrow in the middle of the screen), in which the location of the arrow did not generate interference. It was predicted that in line with their lack of non-verbal deficits at the level of cognitive inhibition, poor comprehenders would also show normal performance in non-verbal interference control.

Experiment 5.1

Method

Participants

The experiments reported in this chapter and in Chapter 6 constituted a new phase of testing. To increase the power of these experiments, I carried out some

additional screening to identify a larger group of poor comprehenders and controls than used in previous experiments. This screening followed exactly the same procedure as that described in Experiment 2.1, and selection of poor comprehenders and controls was based on identical criteria. I screened 208 8- to 9-year-olds at the end of Year 4, and identified an additional 24 poor comprehenders, and 24 controls. Table 5.2 shows the performance of the two groups on each of the screening measures.

Table 5.2. Comparison of poor comprehenders' and controls' performance on the screening measures.

	Poor Comprehenders	Controls	<i>F</i>	<i>p</i>
Age (months)	108	109	0.36	> .10
Matrix Reasoning (WASI) ¹	51.75	52.29	0.06	> .10
Text Reading Accuracy (NARA) ²	100.17	102.25	0.83	> .10
Reading Comprehension (NARA) ²	85.04	106.21	133.61	< .001
Word Reading (TOWRE) ²	110.67	109.75	0.16	> .10
Phonemic Decoding (TOWRE) ²	111.33	109.83	0.22	> .10

Note: ¹T Scores, *M* = 50, *SD* = 10; ²Standard Scores, *M* = 100, *SD* = 15

Of these, 42 (21 poor comprehenders and 21 controls) were available to take part in this experiment which took place when these children were beginning Year 5.

I also approached the poor comprehenders and controls recruited to be part of previous experiments reported in this thesis (who were also beginning Year 5 at

this time), and re-tested them on the NARA-II and the TOWRE to determine whether they still displayed the previously established reading profile of a poor comprehender or control (see Experiment 2.1). Of these original groups I was able to retain 11 controls (whose NARA-II comprehension scores were still higher than their NARA-II accuracy scores) and 10 poor comprehenders (whose NARA-II comprehension scores were at least one SD below their decoding scores on the TOWRE) for inclusion in the sample. For more discussion of the change in the reading abilities of these original poor comprehenders and controls over time, see Chapter 8.

A combination of screening for new poor comprehenders and controls, and targeted screening of my original samples, rendered a total of 63 participants (31 poor comprehenders and 32 controls). Due to scheduling restrictions in the school one participant failed to complete the verbal task, meaning that data was analysed for 31 poor comprehenders and 31 controls. Additionally, two participants failed to complete the non-verbal task, meaning that data was analysed for 31 poor comprehenders and 30 controls.

Materials and procedure

Children completed both Stroop tasks within the same testing session. Each child completed the tasks in the same order, with the verbal Stroop task administered first, followed by the non-verbal Stroop task.

Verbal Stroop task. Before commencing the task, children were given full instructions and concrete demonstrations of how it would work. They also completed a series of practice trials, designed to familiarise them with experimental procedure. The task consisted of four blocks, each of which was made up of 24 trials, rendering a total of 96 trials. Each block was separated by a short break and a display

screen which provided encouragement to the child to motivate them to continue the task. Each trial followed the same structure: a fixation cross was presented in the centre of the screen for a duration that varied randomly between 1500 and 2500 ms. The purpose of randomly changing the duration was to ensure that children did not get into a fixed rhythm of responding, which would act to reduce any RT differences between trials. The fixation cross was replaced by the target stimulus (either a colour word or a row of coloured stars), and the children were required to respond as quickly as they could to the colour of the ink in which the stimulus was presented. They responded to the colour of the ink by pressing the corresponding marked key on the mouse buttons. The stimulus stayed on the screen until the child had made a response.

Of the 96 trials, 32 were congruent trials, 32 were incongruent trials and 32 were neutral trials. In the congruent trials, children saw a colour word written in the same colour ink as was indicated by the word, i.e. the word 'red' written in red ink. In the incongruent trials, children saw a colour word that was written in an ink colour that differed to that indicated by the colour word itself, i.e. the word 'red' written in blue ink. In the neutral trials, children simply saw a row of stars and had to indicate their colour. The same four colours (red, green, pink and blue) were used throughout the experiment. Children responded to each of these ink colours by pressing an assigned button, with red and green assigned to one button, and pink and blue to the other. In the neutral and congruent trials therefore, each of the four possible stimuli that could be created from using four colours was repeated eight times throughout the experiment, rendering 32 congruent and 32 neutral trials in total. In the incongruent trials the maximum possible number of permutations that could be

created using the four colours, in which the ink colour was different to the colour word itself, and in which the two different colours were not assigned to the same button, was eight. As a consequence, each of these eight incongruent trials was repeated four times throughout the experiment, rendering 32 incongruent trials in total. Presentation of the trials was randomised within each block of the experiment. RT and accuracy to each trial was measured by the E-Prime software in which the experiment was programmed.

Non-verbal Stroop task. Children were given full instructions and concrete demonstrations of how task trials would work before they started this non-verbal Stroop task. They also completed a series of practice trials, designed to familiarise them with experimental procedure. As with the verbal Stroop task there were four blocks of 24 items, making a total of 96 trials. Each block was separated by a short break and a display screen which provided encouragement to the child to motivate them to continue with the experiment. Each trial followed the same structure, beginning with the presentation of a fixation cross in the centre of the screen for between 1500-2500 ms. The duration of this fixation cross varied randomly between these two points from trial to trial, as discussed in the previous section. The fixation cross was then replaced by the target stimulus (an arrow), and the children were required to respond as quickly as they could and indicate whether the arrow was pointing right or left by pressing marked keys on the computer keyboard. The stimulus stayed on screen until the child had made a response.

The 96 trials that made up the task were of three different types; congruent, incongruent and neutral, with 32 of each of these trial types presented. In the congruent trials, the direction in which the arrow was pointing was the same as its

location on the screen, i.e. an arrow pointing right would be presented on the right side of the screen. In the incongruent trials, the direction in which the arrow was pointing was the opposite to the side of the screen on which it was presented, i.e. an arrow pointing right would be presented on the left side of the screen. In the neutral trials, the arrow was presented at the top of the screen, thus requiring an equivalent attentional shift from the central fixation point but not introducing the direction vs. location conflict that is apparent in the incongruent trials. Children responded to the direction in which the arrow was pointing by pressing one of two labelled buttons on the keyboard. The right-pointing arrow label was located towards the right side of the keyboard and children were required to press this button if the arrow pointed right. The left-pointing arrow label was located towards the left side of the keyboard and children were required to press this button if the arrow pointed left.

The two arrow stimuli used were identical, the only difference being that one pointed left, and the other right. For each of the three trial types then, there were two possible permutations (e.g. for the incongruent trials, they could either comprise a right-pointing arrow on the left of the screen, or a left-pointing arrow on the right of the screen), meaning that each of these permutations was repeated 16 times throughout the experiment, producing the total of 96 trials. Presentation of the trials was randomised within each of the four blocks that made up the experiment. RT and accuracy to each trial was measured by the E-Prime software in which the experiment was programmed.

Results

Accuracy

Table 5.3 shows the proportion of correct responses obtained by the poor comprehenders and controls in each condition of the verbal and non-verbal Stroop tasks.

Table 5.3. Mean proportion of correct responses by group and condition.

	Poor Comprehenders		Controls	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<i>Verbal</i>				
Congruent	.96	.04	.97	.05
Neutral	.95	.06	.94	.07
Incongruent	.96	.04	.95	.05
<i>Non-verbal</i>				
Congruent	.98	.03	.99	.02
Neutral	.96	.06	.98	.03
Incongruent	.91	.10	.94	.08

In the verbal task, performance levels were very high and there was no evidence of an interference effect on accuracy for either group of participants; neither group showed lower accuracy in the incongruent condition compared to the neutral condition. To confirm this, accuracy data were entered into a 2 x 2 repeated measures ANOVA, with condition (incongruent vs. neutral) as a within-subject factor

and group (poor comprehenders vs. controls) as a between-subjects factor. The main effect of condition ($F(1, 60) = 2.21, p > .10$) was not significant, and there was no significant interaction with group ($F(1, 60) = 0.28, p > .10$). The main effect of group was also not significant ($F(1, 60) = 0.94, p > .10$).

Accuracy data for the non-verbal Stroop task were also entered into a 2 x 2 repeated measures ANOVA, with condition (incongruent vs. neutral) as a within-subject factor and group (poor comprehenders vs. controls) as a between-subjects factor. There was a significant main effect of condition ($F(1, 59) = 21.21, p < .001, \eta_p^2 = .26$), but no interaction with group ($F(1, 59) = 0.01, p > .10$); both the poor comprehenders ($t(30) = 3.63, p = .001, r = .29$) and controls ($t(29) = 2.95, p = .006, r = .30$) attained lower mean accuracy scores in the incongruent condition compared to the neutral condition, suggesting there was an interference effect on accuracy for both groups of participants. The main effect of group was not significant ($F(1, 59) = 1.98, p > .10$).

RTs

Table 5.4 shows the mean RTs for the poor comprehenders and controls in each condition of the verbal and non-verbal Stroop tasks. Mean RTs were calculated based on the correct trials only.

Table 5.4. Mean RTs by group and condition (correct trials only).

	Poor Comprehenders		Controls	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<i>Verbal</i>				
Congruent	1005	106	982	113
Neutral	1050	138	1004	114
Incongruent	1100	121	1074	144
<i>Non-verbal</i>				
Congruent	714	159	678	146
Neutral	737	151	717	169
Incongruent	824	162	751	135

RT data for the verbal Stroop task were entered into a 2 x 2 repeated measures ANOVA, with condition (incongruent vs. neutral) as a within-subject factor and group (poor comprehenders vs. controls) as a between-subjects factor. There was a significant main effect of condition ($F(1, 60) = 19.30, p < .001, \eta_p^2 = .24$), but no significant interaction with group ($F(1, 60) = 0.60, p > .10$); both poor comprehenders ($t(30) = 2.33, p = .03, r = .19$) and controls ($t(30) = 4.11, p < .001, r = .26$) produced quicker response times in the neutral than the incongruent trials, indicating that the task was producing the expected interference effects. There was no main effect of group ($F(1, 60) = 1.24, p > .10$). RT data for the non-verbal Stroop task were also entered into a 2 x 2 repeated measures ANOVA, with condition (incongruent vs. neutral) as a within-subject factor and group (poor comprehenders

vs. controls) as a between-subjects factor. There was a significant main effect of condition ($F(1, 59) = 41.35, p < .001, \eta_p^2 = .41$), with participants considerably slowed in the incongruent condition compared to the neutral condition. The main effect of group was not significant ($F(1, 59) = 1.47, p > .10$), but there was a significant interaction between group and condition ($F(1, 59) = 7.73, p = .007, \eta_p^2 = .12$). Planned t-tests revealed that this interaction arose because there were no differences between the groups in terms of their RTs to neutral trials ($t(59) = 0.50, p > .10$), but the poor comprehenders were verging on being significantly slower in the incongruent trials ($t(59) = 1.91, p = .06, r = .24$), indicating that they were experiencing more interference in the face of interfering information than the controls.

To directly compare the amount of interference experienced by the two groups on the verbal and non-verbal tasks, an interference score was calculated for each child, reflecting the difference between RT in the neutral control condition of each task, and RT in the incongruent version of the task. This rendered a verbal and a non-verbal interference score for each participant. These were then entered into a 2 x 2 repeated measures ANOVA with task (verbal vs. non-verbal) as a within-subject factor, and participant group (poor comprehenders vs. controls) as a between-subjects factor. Neither the main effect of task ($F(1, 59) = 0.001, p > .10$) nor group ($F(1, 59) = 0.91, p > .10$) were significant. However, there was a significant interaction between task and group ($F(1, 59) = 4.60, p = .04, \eta_p^2 = .07$), shown in Figure 5.1. Planned t-tests revealed that poor comprehenders showed higher interference than the controls in the non-verbal task ($t(1, 59) = 2.48, p = .02, r = .30$) but not in the verbal task ($t(1, 60) = 0.83, p > .10$).

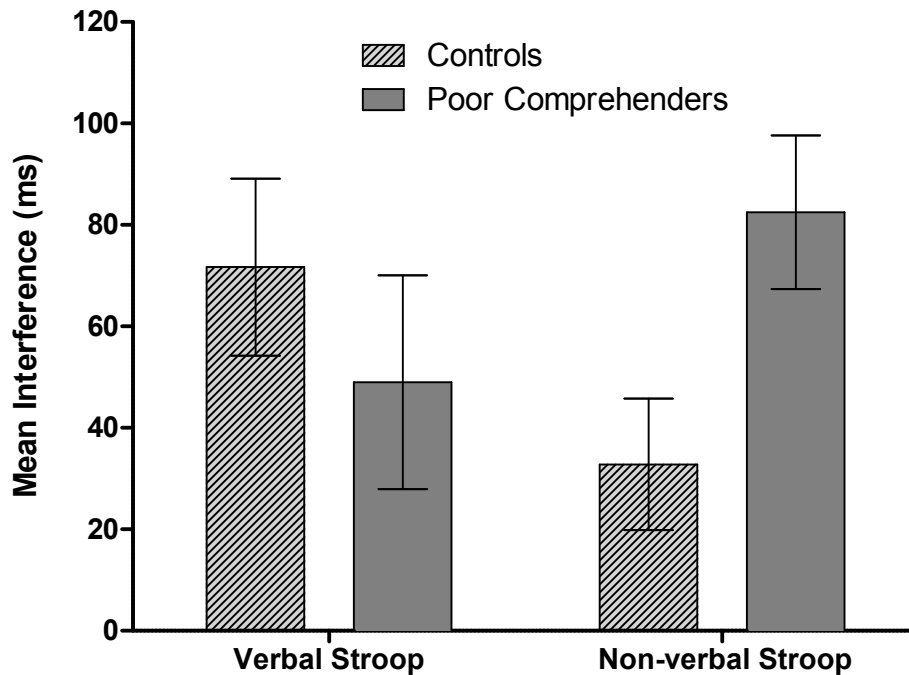


Figure 5.1. Mean interference effect on RT by condition and group.

Before discussing these findings, it is worth noting a potential complexity in the nonverbal condition. Observation of the participants as they completed the non-verbal task suggested that trials in which they had to switch attentional set (i.e. responding to an incongruent trial after a congruent trial, or vice versa) might be harder for them than trials in which they stayed within the same attentional set (i.e. responding to an incongruent trial after another incongruent trial, or a congruent trial after a congruent trial). This would suggest that the task carried behavioural inhibition demands as well as the predicted interference control demands. To explore this in the data, switch costs were calculated for both accuracy and RT. Switch costs when switching to incongruent trials were calculated as the difference between the accuracy/RT in incongruent trials that followed incongruent trials and the accuracy/RT in incongruent trials that followed congruent trials. Switch costs

when switching to congruent trials were calculated as the difference between the accuracy/RT in congruent trials that followed congruent trials and the accuracy/RT in congruent trials that followed incongruent trials. Table 5.5 shows the switch costs for both the incongruent and congruent trials, as well as results from one sample t-tests, run to establish whether the switch costs are significantly greater than zero (i.e. no switch cost at all).

Table 5.5. Switch costs on accuracy and RT to congruent and incongruent trials.

	<i>M</i>	<i>SD</i>	<i>t</i>	<i>p</i>
<i>Switch to incongruent</i>				
Accuracy	.10	.12	6.13	< .001
RT	17.03	125.50	1.06	> .10
<i>Switch to congruent</i>				
Accuracy	.01	.05	1.82	.07
RT	125.56	112.01	8.76	< .001

There is an interesting pattern of switch costs, with a differential effect on accuracy and RT depending on what type of trial is being switched to. When switching to incongruent trials, there were significant switch costs on accuracy but not on RT, presumably because the participants were making quick but erroneous responses. By contrast, when switching to congruent trials, there were significant switch costs on RT, but only very small switch costs on accuracy. These results point to a speed-accuracy trade-off working in opposite directions for the congruent and incongruent

trials. Overall, there is strong evidence that having to switch attentional sets leads to a cost in terms of accuracy or RT for the participants.

In terms of differences between the groups; when switching to incongruent trials, where switch costs have their impact on accuracy, the poor comprehenders ($M = .12, SD = .14$) show a tendency for greater switch costs than the controls ($M = .08, SD = .09$), although this difference did not reach significance ($F(1, 59) = 1.85, p > .10, r = .16$). When switching to congruent trials, where switch costs have their impact on RT, the poor comprehenders ($M = 143, SD = 134$) again show a tendency for greater switch costs than the controls ($M = 107, SD = 81$), with this difference also not reaching significance ($F(1, 59) = 1.61, p > .10, r = .16$).

Discussion

Experiment 5.1 explored poor comprehenders' interference control in verbal and non-verbal domains, in order to establish whether their deficits at the level of cognitive inhibition extend to the level of interference control. The results contrast markedly with those found in cognitive inhibition, discussed in Experiments 4.2 and 4.3, in which poor comprehenders showed deficits on the verbal cognitive inhibition task but not on the non-verbal one. In the interference control tasks used in this experiment, poor comprehenders differed from the controls on the non-verbal task, but not on the verbal task.

The finding that poor comprehenders showed neither deficits nor strengths on the verbal Stroop task may have arisen because of a combination of the opposing predictions outlined earlier. Adams and Jarrold (2009) argued that children who are poor at reading for meaning will show less automatic processing of the semantic contents of written words, and therefore will show less interference in colour

Stroop. This logic generated the prediction that poor comprehenders would show less interference on the verbal Stroop task than the controls. By contrast, on the basis of some of the previous findings reported in this thesis suggesting that poor comprehenders have difficulties on any task which requires complex verbal representation and processing (like the incongruent condition of the verbal Stroop task), the prediction would be that poor comprehenders would show more interference than the controls. It is possible then that both of these predicted effects impacted on poor comprehenders, cancelling out any effect in either direction and rendering the lack of significant group differences.

The finding that poor comprehenders showed significantly more interference on the non-verbal Stroop task was in stark contrast to the prediction that they would not differ from controls, just as they did not differ in the non-verbal cognitive inhibition task presented in Experiment 4.2. It suggests that they have deficits in non-verbal interference control. However, although Stroop-like tasks like the non-verbal task used in this experiment have traditionally been regarded as measuring interference control (see Nigg, 2000), the finding that participants showed costs (either in terms of accuracy or RT) on trials where there was a switch in the attentional/motor set required implies that behavioural inhibition is also a factor that influences performance in this task. Poor comprehenders showed a tendency for greater switch costs than controls, indicating that they may have behavioural inhibition problems. However, this tendency did not reach significance, suggesting that the behavioural inhibition demands of the task are not a complete explanation of poor comprehenders' deficits on the task. It may be the case that both interference control and behavioural inhibition are necessary for success in this task,

and potentially that poor comprehenders have deficits in both these inhibitory domains, which combine to produce the deficits observed on the non-verbal Stroop task.

To explore this further, Experiment 5.2 compared the two groups on another measure of non-verbal interference control, without a behavioural inhibition component to it, as well as a direct measure of behavioural inhibition. The aim of the experiment was to tease apart these two inhibition constructs and to clarify the nature and extent of poor comprehenders' inhibitory deficits.

Experiment 5.2

To address this, two measures from the TEA-Ch (Manly, et al., 1999) were selected, one considered to tap non-verbal interference control, and one which measured behavioural inhibition. The Sky Search subtest of the TEA-Ch was used to assess children's non-verbal interference control. In this task, children are required to circle pairs of identical spaceships on a sheet, whilst ignoring similar-looking non-identical pairs. Although labelled as a selective attention measure in the TEA-Ch, it is clear to see that this task is equivalent to a measure of interference control; in line with this, the TEA-Ch manual describes it as measuring 'the efficiency with which information can be filtered to detect relevant information and reject or inhibit irrelevant or distracting information', a description almost identical to Nee's (2008) definition of interference control as 'the ability to select relevant information whilst filtering out irrelevant distracting information'. If poor comprehenders' do have weaknesses in non-verbal interference control, then we would expect them to show deficits relative to the controls on this task.

The Opposite Worlds subtest of the TEA-Ch (as used by Nation et al., 2003) was selected to examine the children's behavioural inhibition skills. Children perform two different types of trial; on the Same World trials they follow a path made of the digits 1 and 2 and simply have to name each digit along that path. On the Opposite World trials, children must follow the path but say a 1 when they see a 2 and vice-versa. These trials require the inhibition of a prepotent verbal response, and fit into Nigg's (2000) behavioural inhibition category. They are also very similar to other tasks that have been used to assess behavioural inhibition, such as go/no-go tasks which also require inhibition of a dominant, prepotent response. As discussed previously, Nation et al. (2003) found that poor comprehenders showed marginally significant deficits on this Opposite Worlds task relative to controls, indicating potential behavioural inhibition deficits. If poor comprehenders' inhibitory deficits do extend to the level of behavioural inhibition, then we would expect to replicate this finding.

Finally, the Score! Subtest of the TEA-Ch was used to assess sustained attention. Children are required to count a series of scoring sounds which are interspersed with silent pauses, thus requiring them to self-maintain an actively attentive stance to what is an intrinsically uninteresting task. Obtaining a measure of the children's sustained attention will provide a fuller picture of their attentional capacity, as well as to rule out the possibility that differences in the ability to pay attention consistently had systematically influenced results in previous experiments.

Method

Participants

The same 63 participants (31 poor comprehenders and 32 controls) who took part in Experiment 5.1 also took part in this experiment.

Measures

Three subtests of the TEA-Ch (Manly, et al., 1999) were used to assess interference control, behavioural inhibition, and sustained attention. Each test was administered according to the instructions provided within the TEA-Ch manual.

Interference control. The Sky Search subtest of the TEA-Ch was used to assess the participants' interference control abilities. This test required them to search for matching pairs of spaceships (i.e. pairs in which the two spaceships were identical to each other) in an array of spaceship pairs presented on an A3 sheet. When they found a matching pair they were instructed to put a circle around it. The children were told to find all the matching pairs of spaceships as quickly as they could, and were instructed to tick a box at the bottom of the sheet when they thought they had found them all. The test also involved a motor control condition, designed to control for the effect of a child's motor speed on their performance on the original Sky Search task. This comprised a piece of card that was identical to the original in all respects, except that all non-matching pairs of spaceships had been removed. Again, children had to circle all the pairs of spaceships where the two spaceships were identical, and tick the box at the bottom of the sheet when they thought they had found them all. The number of targets circled by a child, as well as the time taken, was recorded for both the original and the motor control Sky Search conditions. This enabled a time-per-target score to be computed for each condition by dividing the

total time taken by the number of targets successfully found. To limit the confounding effect of motor speed, it was then necessary to minus the time-per-target score in the motor condition from the time-per-target score in the original condition. This rendered an overall Sky Search score; a more accurate reflection of the efficiency of interference control.

Sustained attention. This was measured using the Score! subtest of the TEA-Ch. In this task children were required to listen to a series of scoring sounds separated by silent pauses, and to count how many of these scoring sounds they heard in each trial. Children completed 10 trials, with the number of scoring sounds in each trial varying from 9 to 15. For each correct count they were allocated a point, giving a maximum possible score of 10 on this task. One child failed to complete the Score! task due to scheduling problems at their school, meaning that data was obtained on this task for 31 controls, and 31 poor comprehenders.

Behavioural inhibition. This was assessed using the Opposite Worlds subtest of the TEA-Ch. This task comprised two conditions. In the Same World condition, children were required to follow a path made of the digits 1 and 2, naming them as they proceed along the path. In the Opposite World condition they had to do the same task, but were required to say 'one' when they saw a 2 and 'two' when they saw a 1. The time taken to respond to all the digits in each condition was recorded. The difference between the time taken to complete the Same World and the Opposite World conditions was calculated, hence providing a measure of the extent to which having to suppress a prepotent response (i.e. the behavioural inhibition demand) impacts on performance.

Procedure

Children completed all of the above measures under the supervision and guidance of a trained experimenter within a single testing session. Testing took place in participating schools, in a quiet area near to the child's classroom.

Results

The raw scores produced on each of the three subtests of the TEA-Ch were converted to age-scaled scores ($M = 10$, $SD = 3$) using the normative tables provided in the TEA-Ch manual. Each child had four scores representing their performance on the Sky Search task, the Score! task, the Same World condition of the Opposite Worlds task, and the Opposite World condition of the Opposite Worlds task respectively. Data were entered into a 4 x 2 mixed-design ANOVA, with TEA-Ch task (Sky Search vs. Score! vs. Same World vs. Opposite World) as a within-subject factor and group (poor comprehenders vs. controls) as a between-subjects factor. Mauchly's test revealed that sphericity could not be assumed, therefore the Greenhouse-Geisser correction was applied where appropriate. There was a significant main effect of TEA-Ch task, $F(1.87, 112.58) = 7.43$, $p = .001$, $\eta_p^2 = .11$, with children attaining the highest mean age-scaled scores on the Score! task ($M = 9.77$, $SD = 2.95$), then on the Same World task ($M = 9.67$, $SD = 2.34$), the Opposite World task ($M = 9.03$, $SD = 2.09$), and the lowest on the Sky Search task ($M = 8.27$, $SD = 1.85$). The main effect of group was not significant, $F(1, 60) = 0.21$, $p > .10$. However, there was a significant interaction between group and TEA-Ch task, $F(1.87, 112.58) = 3.83$, $p = .03$, $\eta_p^2 = .06$, shown in Figure 5.2.

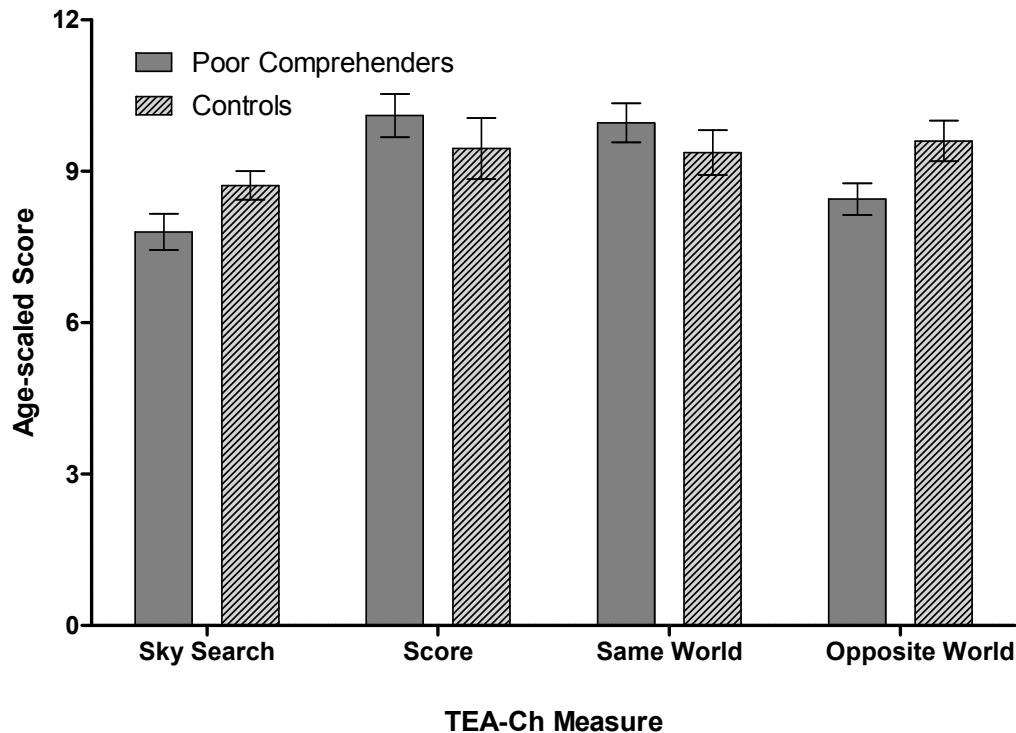


Figure 5.2. Mean age-scaled scores on each of the four TEA-Ch measure for poor comprehenders and controls. Error bars show the standard error of the mean.

Planned comparisons revealed that this interaction arose due to a specific pattern of strengths and weaknesses shown by the poor comprehenders. There were no significant differences between the groups on either the Score task ($t(60) = 0.85, p > .10$) or the Same World condition of the Opposite Worlds task ($t(61) = 1.00, p > .10$), although as Figure 5.2 shows, poor comprehenders attained slightly higher mean age-scaled scores than controls on both these tasks. By contrast, poor comprehenders performed at a significantly lower level than the controls on both the Sky Search task ($t(61) = 2.00, p = .05, r = .25$) and the Opposite World condition of the Opposite Worlds task ($t(61) = 2.23, p = .03, r = .27$).

The finding that poor comprehenders showed a deficit relative to controls on the Opposite World condition but not in the Same World condition implies that they have a specific problem when inhibition of a prepotent response is required. To confirm that this was the case, the mean difference in seconds between the two conditions was calculated for each child, and compared for the two participant groups. The poor comprehenders showed a significantly larger difference score ($M = 9.45$ secs., $SD = 2.75$ s.) than the controls ($M = 5.88$ secs., $SD = 2.81$ s.), $t(61) = 5.10$, $p < .001$, $r = .54$, suggesting that they showed a much greater decrement in performance when the behavioural inhibition demands of the task were increased.

Poor comprehenders showed deficits relative to controls on both the Sky Search and Opposite World tasks suggesting that they are relatively poorer at both these tasks. However, because the tasks are standardised measures, as well as comparing poor comprehenders to controls on this subscale, it was also possible to examine the performance of this group relative to the test norms to explore the severity of their deficits and how pervasive the deficits were within the group. On the Sky Search task, 11 of the 31 poor comprehenders attained scaled scores that were one standard deviation or more below the test mean, indicative of a significant deficit on this task. Furthermore, 23 of the 31 poor comprehenders attained scores that were below average, i.e. lower than the test mean. On the Opposite World task, nine out of the 31 poor comprehenders attained scaled scores that were one standard deviation or more below the test mean, while 22 out of the 31 poor comprehenders attained scores below the test mean. Of the 22 poor comprehenders who were below average on the Opposite Worlds task, 18 were also below average

on the Sky Search task, suggesting that on the whole it was the same children who were doing poorly at both of these executive inhibitory tasks.

Discussion

Experiment 5.2 compared performance on tasks reflecting non-verbal interference control (Sky Search) and behavioural inhibition (Opposite Worlds) in order to further clarify the nature and extent of poor comprehenders' inhibitory deficits. Poor comprehenders showed deficits relative to the controls in the interference control task, confirming that they do have weaknesses in non-verbal interference control. The Sky Search task included a control condition that took account of the child's general motor speed, meaning that the poor comprehenders' deficits on this task could not be accounted for by group differences in motor speed. The poor comprehenders also showed deficits in the Opposite World condition of the Opposite Worlds task, confirming the findings of Nation et al. (2003), and suggesting impairments in their ability to inhibit a prepotent verbal response. This is despite being unimpaired in the Same World condition of this task, which followed the same procedure as the Opposite World condition, with the only difference being that inhibition of a prepotent response was not required. Although at a group level poor comprehenders were impaired relative to controls on both the interference control and behavioural inhibition tasks, examination of the performance of each poor comprehender relative to the test mean revealed that not all showed impairments on this task. Approximately two thirds of the poor comprehender sample showed below-average performance on each of the tasks, with this subgroup showing below-average performance on both tasks in the vast majority of cases. This suggests that a majority, but not the whole group, of poor comprehenders have

deficits on tasks measuring executive inhibition; explanations for these findings will be presented in the general discussion section of this chapter.

Administering a measure of sustained attention (Score!) to the participants allowed me to establish whether there were any group differences in the ability to sustain task-focused attention. The poor comprehenders showed no deficits, and in fact they obtained slightly higher age-scaled scores than the control children. This suggests that it is unlikely that performance on previous tasks was influenced by group differences in the capacity to sustain task-focused attention.

General Discussion

The results from Experiments 5.1 and 5.2 point to general weaknesses in executive inhibition for a majority of poor comprehenders, with deficits observed for this participant group in both interference control and behavioural inhibition. The only executive inhibition task that poor comprehenders did not show deficits in was the verbal Stroop task presented in Experiment 5.1, and I argued that this arose because of task-specific semantic factors acting in the opposite direction to any inhibitory effects. The finding that inhibitory deficits were evidenced by poor comprehenders on both verbal and non-verbal tasks does not fit with my previous findings of specific verbal deficits in these children. Two potential explanations for the findings are discussed below. The first is that poor comprehenders have deficits in executive inhibition which led to their poor performance on the behavioural inhibition and interference control tasks, with these deficits reflective of wider executive deficits. The second is that verbal ability mediates performance on executive tasks, and that poor comprehenders' verbal weaknesses drove their apparent inhibitory deficits. To turn to the first explanation, executive function refers

to a host of higher order cognitive skills that enable goal-directed behaviour, including working memory, attentional control, planning, organising, self-monitoring, cognitive flexibility, and inhibition. The executive inhibition processes defined by Nigg (2000) would fall under the rubric of executive function. Although not traditionally viewed as a disorder of executive function, in recent years, links between specific reading comprehension failure and problems with executive function have been established (Cutting, Materek, Cole, Levine, & Mahone, 2009; Sesma, Mahone, Levine, Eason, & Cutting, 2009).

Some skills, such as working memory (Cain, 2006; Carretti, et al., 2009; Daneman & Merikle, 1996; Nation, et al., 1999; Palladino, et al., 2001; Stothard & Hulme, 1992; Swanson & Berninger, 1995; Yuill, et al., 1989) and comprehension monitoring (Cain, et al., 2004; Ehrlich, et al., 1999; Oakhill, et al., 2005) and their relation to comprehension had previously been studied in isolation, but had not been linked explicitly with the concept of executive function. Cutting et al. (2009) remedied this by exploring the links between executive function and comprehension using a neuropsychological framework. They examined the performance of children with specific reading comprehension deficits on tasks designed to measure executive function, including the Tower of London task (see Shallice, 1982) and the Elithorn Perceptual Maze Test (see Elithorn, 1955). They found that the poor comprehenders in the study showed marked deficits in performance on these tasks relative to control children, and even relative to children with specific word reading deficits. Hence they argued for a specific link between executive function and reading comprehension skills. It could be therefore that at least a subgroup of the poor comprehenders who took part in Experiments 5.1 and 5.2 have generalised deficits

in executive inhibition, which are reflective of broader deficits in executive function, and which led to the group differences on the executive inhibition tasks. If this is correct, then the differences between the verbal-only deficits discussed in Chapter 4 and the more general deficits reported in the current chapter may have arisen due to differences in the composition of the samples of poor comprehenders used in the two sets of experiments. It could be that only a very small proportion of the poor comprehender sample used in Experiments 4.1, 4.2, and 4.3 had executive deficits at the root of their reading comprehension, while a greater proportion did in the sample used in this chapter, thus leading to the group differences on the non-verbal executive inhibition tasks.

Another alternative is that poor comprehenders do not have genuine deficits in executive inhibition, but that their performance on the executive inhibition tasks (and by extension, other executive function tasks) is mediated by verbal factors. On this view, it is verbal weaknesses that are leading to the apparent behavioural inhibition and interference control weaknesses. There has been considerable discussion concerning the role of language in executive function (see Muller, Jacques, Brocki, & Zelazo, 2009, for review), with the conclusion being that language plays an important role in the development of executive function. Barkley (1997) argues that internal, self-directed language (self talk) supports executive functioning by allowing reflection, description and self-questioning during tasks, as well as facilitating the formulation of rules and plans. It also provides a means for individuals to control and monitor their behaviour whilst engaged in an ongoing task. It could therefore be the case that verbal weaknesses, and consequent deficits in internal, self-directed language, in poor comprehenders are contributing to their difficulties in

successfully managing the executive inhibition components of the non-verbal Stroop task, the Sky Search task, and the Opposite Worlds task. In terms of my previous finding of a lack of deficits for poor comprehenders in the non-verbal task that was used to assess cognitive inhibition (see Experiment 4.2), it may be that the use of faces as the non-verbal stimuli in this task rendered it less amenable to verbal strategy control, and hence resulted in the lack of group differences. Indeed, previous research using faces in a non-verbal proactive interference task has demonstrated a complete lack of a relationship between the amount of verbal labelling done by subjects and their ability to resist proactive interference (Brandon, et al., 2003), suggesting that verbal strategising in such tasks is not effective. It would be useful for future studies to run non-verbal proactive interference tasks that utilise non-face stimuli; the challenge will be to find a stimulus set that is not readily verbalisable but that is not so complex and abstract that floor effects will limit individual differences in performance.

The findings of Experiments 5.1 and 5.2 also raise interesting questions regarding our understanding of the structure and nature of the executive inhibition construct and the relations between its different components. As discussed in the introduction section of this chapter, the relationship between the different components of executive inhibition is underspecified. The experiments reported in this chapter suggested that at a group level poor comprehenders were impaired on measures of both behavioural inhibition and interference control. Furthermore, the findings of Experiment 5.2 indicated that in the majority of cases, those poor comprehenders with below average behavioural inhibition performance were also the ones who displayed below average performance on interference control tasks.

This supports Friedman and Miyake's (2004) finding of a relationship between these two different components of executive inhibition, and the idea of a common executive inhibitory construct underlying these processes. However, as discussed above, one explanation for poor comprehenders' deficits on both the interference control and the behavioural inhibition tasks is that their language weaknesses mean that they do not benefit as much as the controls from the support that language typically brings to performance on these executive tasks. Hence rather than a common construct (executive inhibition) underlying the two tasks in question and accounting for the common deficits in poor comprehenders, poor comprehenders' common deficits on the tasks *could* be accounted for by the influence of an external variable (in this case, language ability) that impacts on performance on both tasks. This need not preclude the idea of a common construct underlying behavioural inhibition and interference control, but it does raise a cautionary note regarding the attribution of such a construct on the basis of shared variance between tasks.

The second question concerns the overlap between executive inhibition and various components of attention. As became clear in this chapter, tasks designed to measure these two constructs were completely interchangeable, a finding very much in keeping with previous work that has highlighted how tasks used by one researcher to measure executive function are often used by others to measure aspects of attention (Morris, 1996). As discussed earlier in this chapter, the definition of what the selective attention task on the TEA-Ch measured was conceptually identical to the definition offered by Nee (2008) of what interference control is. Both definitions emphasised the selection of relevant information and the rejection of irrelevant information. In line with this, Smith and Jonides (1999) view attention and inhibition

together as one type of executive process (“focusing attention on relevant information and processes and inhibiting irrelevant ones”). One approach to understanding the relationship between the constructs of selective attention and interference control then, may be to view them as complementary aspects of a single process, meaning that any task that measures one of these aspects is necessarily going to measure the other. Evidently, more clarity is needed within the field regarding the nature of the constructs of attention and inhibition, the overlap between them, and the consistency of the terminology used to describe them.

In summary, Experiments 5.1 and 5.2 have built upon experiments presented in the previous chapters by exploring broader aspects of executive inhibition in poor comprehenders. The picture that has emerged is of wide-ranging executive inhibitory deficits in a majority of poor comprehenders that span both the verbal and the non-verbal domain. Two different explanations for these findings were offered, and it is not necessarily the case that these explanations are mutually exclusive; it may be that different explanatory factors apply to different poor comprehenders, or even that both of the explanatory factors discussed above are contributing to poor comprehension in some children. Further discussion of this issue will be included in Chapter 8.

Chapter 6: Poor comprehenders in the classroom: Teacher ratings of cognitive, behavioural, and educational outcomes.

This chapter reports data from a questionnaire study that sought to examine behavioural and educational outcomes in poor comprehenders, a hitherto neglected area of research. Teachers were asked to provide ratings for poor comprehenders and controls on a series of measures of behaviour and academic performance. An extremely high response rate of 98% ensured that results obtained were not biased, and that the study was not underpowered. Poor comprehenders were rated as showing both behavioural and educational deficits relative to control children, but deficits in both areas were not universal. In terms of behaviour, they were rated by their teachers as showing a greater frequency of problem behaviours associated with working memory deficits and inattention but did not show behavioural problems relative to controls in other areas, such as hyperactivity and peer relations. On the measure of educational performance, poor comprehenders were rated as inferior to the controls only in those curriculum areas in which success was contingent on complex verbal ability skills. The pattern of behavioural and educational strengths and weaknesses was consistent with previous work concerning the fundamental cognitive and language deficits that may be driving poor reading comprehension.

Previous chapters in this thesis have presented evidence, garnered from standardised tests and experimental paradigms, which has come together to inform our understanding of some of the potential cognitive deficits that may contribute towards a child displaying a 'poor comprehender' profile. This chapter switches focus in two ways. Firstly, I will move from discussing the causes of poor comprehension to investigating the behavioural and educational outcomes that are associated with this

particular profile of reading ability. Secondly, I will supplement data collected so far from experimental tasks and measures that assess the child directly, with questionnaire data provided by teachers who are arguably best placed to rate educational attainment and behaviour in the classroom, given that they see each child on a daily basis.

While the volume of research investigating aetiological factors in children with specific reading comprehension deficits has been steadily increasing over the last few years, the impact of being a poor comprehender on behaviour and school achievement remains unknown. This can be contrasted with other types of developmental disorder, in which the impact of the disorder on behavioural and academic outcomes has been investigated in detail. For example, the behavioural, attentional, and cognitive characteristics of children with low working memory have been specified, despite this being a relatively recently identified group of children (Alloway, Gathercole, Kirkwood, & Elliott, 2009a; Gathercole, Alloway, et al., 2008). A significant amount of research has also been conducted into behavioural outcomes in children with the opposite profile of reading deficit to poor comprehenders, developmental dyslexia (Everatt, et al., 2008; Heiervang, et al., 2001; Knivsberg & Andreassen, 2008). For example, Heiervang et al. (2001) administered questionnaires designed to assess behaviour problems to teachers and parents of dyslexic 10- to 12-year-olds, and found that dyslexic children were rated as displaying significantly more problem behaviours across a range of domains (including internalising behaviours, externalising behaviours, and attention problems) than a group of control children. Moreover, the level of these problem behaviours was not associated with differences in socioeconomic status or preschool

language problems, suggesting that they were specifically associated with their reading difficulties. Results from a large-scale study by Carroll, Maughan, Goodman, and Meltzer (2005) support the idea of a link between specific word reading difficulties and problem behaviours. They found that on the four 'problem' subscales of the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997), which assess emotional symptoms, hyperactivity, conduct problems and peer problems respectively, children identified as having specific literacy problems (indexed by word reading and spelling scores substantially below their intellectual ability) showed higher scores, indicating a greater frequency of these problem behaviours.

Although this evidence supports the idea of a relationship between word reading deficits and behavioural and attentional problems, it does not inform us about the links between comprehension ability and behaviour. One study that *has* examined the link between comprehension and behaviour (J. W. Adams, Snowling, Hennessy, & Kind, 1999) assessed children's reading comprehension skills using the Suffolk Reading Scale (SRS; Hagley, 1987), and obtained teacher ratings of their behaviour using the SDQ (Goodman, 1997). They found a significant negative correlation between the degree of problem behaviours attributed to a child and their reading attainment on the SRS, supporting the idea of a relationship between comprehension deficits and behavioural problems. However, the SRS as a measure of reading comprehension is very dependent on word decoding skills (Nation & Snowling, 1997), relying as it does on children reading sentences prior to completing them. As a result, it is impossible to tell whether the relationship found by Adams et al. reflects a unique relationship between comprehension and behavioural outcomes, or whether it is merely replicating the link between word reading skills

and behaviour (as indexed by SDQ scores) that was demonstrated by Carroll et al. (2005).

Studying the behavioural and attentional outcomes of poor comprehenders will enable me to fill a gap in the evidence base regarding the consequences of being a poor comprehender, and to isolate and clarify the relationship between comprehension ability and behavioural and cognitive outcomes in the classroom. This study will address three main outcome areas, using three different rating scales; the SDQ, the Conners' Teacher Rating Scale Revised (CTRS-R (S); Conners, 1997) and the Working Memory Rating Scale (WMRS; Alloway, Gathercole, & Kirkwood, 2008). The first of these was selected to enable me to address the question described above concerning the specificity of the link between reading comprehension and problem behaviour ratings on the SDQ, while the latter two were selected due to their theoretical relevance on the basis of my previous experimental work with poor comprehenders. Each of these measures, and predictions regarding poor comprehenders' outcomes on them, is now discussed in turn.

The SDQ, as used by Adams et al. (1999), was selected to provide information on the children's behaviours, emotions and relationships in the school environment. It comprises four subscales assessing problem behaviours and one subscale assessing prosocial behaviour. As discussed above, previous research has found that poor word readers are rated more highly by their teachers on each of the four 'problem' subscales that make up the SDQ (Carroll et al., 2005). The same result was found in children with poor reading comprehension (Adams et al., 1999), but the use of a comprehension assessment that is known to be highly dependent on decoding ability meant that the relationship between SDQ ratings and comprehension could not be

isolated. By comparing poor comprehenders with controls matched on their decoding skills in this study, it should be possible to isolate the link between comprehension and behaviour, as assessed by the SDQ, whilst avoiding the confounding effects of differences in reading accuracy.

The short form of the Conners' Teacher Rating Scale Revised (CTRS-R (S); Conners, 1997) assesses problem behaviours typically associated with attentional deficits. As reported in Chapter 5, poor comprehenders showed some evidence of deficits on measures purported to assess different aspects of attentional control, although this was by no means absolute. Using the CTRS-R (S) should ascertain whether any potential attention deficits are manifested in the form of inattentive behaviours in the classroom. The CTRS-R (S) has subscales reflecting both hyperactivity and inattention. Previous research with children with low working memory (Alloway, et al., 2009a) has found that they show a particularly high frequency of problem behaviours related to inattention rather than hyperactivity, leading the authors to argue that the inattentive dimension of ADHD is strongly related to working memory deficits. Given that poor comprehenders have working memory difficulties (Experiment 4.1), it may be the case that they too display this particular profile of inattentive behaviour without hyperactivity. However, as discussed in Chapter 4, evidence was found to suggest that poor comprehenders' working memory deficits are exclusive to the verbal domain. It may therefore be the case that any apparent working memory deficits are due to underlying language deficits rather than specific working memory problems. If this is true, then we would perhaps not expect to see marked deficits in poor comprehenders on the inattentive subscale of CTRS-R (S). What the data reported in Chapter 4 also suggested however,

is that there may be some poor comprehenders who do have domain general working memory deficits; potentially then, some children in the poor comprehender group in this study might show deficits on the inattention subscale of the CTRS-R (S), leading to group differences on this measure.

The third rating scale used was the Working Memory Rating Scale (WMRS; Alloway, et al., 2008), with this scale selected to identify classroom behaviours that may be a manifestation of working memory deficits. As discussed above, there is evidence to suggest that poor comprehenders have working memory deficits. Given the strongly established links between working memory performance on the AWMA, and teacher ratings of working memory-related behaviours on the WMRS (Alloway, et al., 2008), a clear prediction is that poor comprehenders will be rated as having deficits on the WMRS, relative to controls. As noted above however, it may be that poor comprehenders' impairments on verbal memory tasks are a reflection of underlying language deficits. If this is the case, we would perhaps not expect them to display a high frequency of behaviours in the classroom associated with working memory difficulties. Alternatively, if some poor comprehenders show domain-general working memory difficulties (indicating a more specific problem with working memory) this may manifest itself in the form of problem behaviours associated with working memory difficulties in the classroom, resulting in group differences on the WMRS.

Finally, teachers also completed a questionnaire asking about the children's academic outcomes across the curriculum. By the age of 9 or 10 years (the age of the children in this study), most children have moved from the stage of 'learning to read' to that of 'reading to learn'. They must use their reading comprehension skills to

acquire knowledge in many different areas of the curriculum. If children have comprehension difficulties, this might affect their educational outcomes not just in the narrow domain of literacy, but also in other curriculum areas in which successful learning outcomes depend on good comprehension. Indeed, Cain and Oakhill (2006) provided preliminary evidence to support this idea. At the end of Year 6 (when they are approximately 11 years old) all children take standardised maths, science and English test to assess their abilities in these subjects. Cain and Oakhill found that poor comprehenders performed less well than the controls in each of the three attainment tests, suggesting that poor comprehension is associated with educational difficulties beyond the domain of literacy. However, as mentioned in Chapter 1, this was a very broad-brush approach to measuring educational attainment in these children, and was based on test performance, which is not necessarily an accurate reflection of their actual attainment in these curriculum areas. In this study therefore I elected to use a more sensitive approach to examining educational outcomes. Teachers were asked to rate the abilities of the poor comprehenders and controls in eleven different curriculum areas and hence to clarify poor comprehenders' educational strengths and weaknesses across a much wider range of curriculum areas to provide a more nuanced picture of their abilities. As discussed throughout the earlier chapters of this thesis, poor comprehenders have deficits in their ability to represent and process verbal material. Any curriculum area then that has complex verbal demands should present problems for poor comprehenders. It was predicted therefore that poor comprehenders would be impaired relative to controls on those curriculum areas which are high in their verbal ability demands, or very dependent on comprehension skills for knowledge acquisition (e.g. Reading Comprehension,

Writing Composition). By contrast, it was predicted that poor comprehenders would not show impairments in those curriculum areas which are less dependent on complex verbal skills (e.g. Art, PE).

In summary then, the aim of this study was to explore poor comprehenders' behavioural and cognitive characteristics, as rated by their class teachers using a variety of theoretically-relevant rating scales, as well as to examine the relationships between these teacher ratings and standardised measures of working memory and comprehension ability. Additionally, the study aimed to obtain measures of poor comprehenders' academic performance across multiple different areas of the curriculum.

Experiment 6.1

Method

Participants

The same 63 participants (31 poor comprehenders, 32 controls) who participated in Experiments 5.1 and 5.2 also participated in this study. Their classroom teachers were asked to complete the questionnaires described below for each child in their class who was participating in this study. They were rewarded with vouchers for their assistance to encourage a high response rate. Fourteen classroom teachers completed questionnaires, each rating a mean of 4.6 children.

Measures and procedure

Teachers were asked to complete a series of questionnaires with each questionnaire selected to assess a different aspect of the children's behavioural or cognitive functioning.

Behaviour. The SDQ (Goodman, 1997) provided information on the children's behaviours, emotions and relationships. The SDQ comprises 25 items, each of which describes a particular behavioural or psychological characteristic (e.g. 'often lies or cheats'; 'many fears, easily scared'). Teachers were asked to rate how true each of these descriptions were of the child in question on a three point-scale; 'Not true', 'Somewhat true', 'Certainly true'. The 25 items that make up the SDQ are divided into five sub-scales; hyperactivity scale, emotional symptoms scale, conduct problems scale, peer problems scale, and prosocial scale. Total scores for each child on each of these sub-scales were calculated by summing their scores on the individual items that comprise the scale.

Attention. The CTRS-R (S) (Conners, 1997) assessed the frequency of behaviours associated with attention deficits shown by each participant. The CTRS-R (S) comprises 28 items, each of which takes the form of a short description of a problematic behaviour associated with attention deficits (e.g. 'distractibility or attention span a problem'). The teachers were asked to rate the frequency with which these behaviours occurred for a particular child, using a scale that ran from 0 ('never, seldom'), through 1 ('occasionally') and 2 ('often, quite a bit'), to 3 ('very often, very frequent'). The 28 items of the CTRS-R (S) are divided into four sub-scales, reflecting oppositional behaviour (5 items), hyperactivity (6 items), cognitive problems/inattention (5 items), and an ADHD index (12 items). The total score for each child on each of these sub-scales was calculated and converted to a standardised *T*-Score using norms provided by the CTRS-R (S).

Working memory. The WMRS (Alloway, et al., 2008) was used to assess the number of problem behaviours associated with working memory deficits shown by

each participant. The WMRS comprises 20 short descriptions of such problem behaviours (e.g. 'needs regular reminders of each step in a written task'), with teachers required to rate how typical these behaviours are for the child in question. Ratings were made on a four-point scale from 0 ('not typical at all'), through 1 ('occasionally') and 2 ('fairly typical'), to 3 ('very typical'). The total score for each child was calculated by adding together the ratings for each item, and was then converted to a standardised *T* score ($M = 50$, $SD = 10$) using normative tables provided in the WMRS manual.

Educational performance. Teachers were asked to rate each child's performance in a range of different curriculum areas relative to the performance of same-aged peers. The scale used ran from 'Excellent', through 'Good', 'Average' and 'Low-average', to 'Poor'. Scores were allocated to each point on the scale, running from 1 for 'Excellent' through to 5 for 'Poor'. Thus each child had a numerical score for each subject, with lower scores reflecting superior performance.

Standardised measures. NARA-II comprehension scores were available for each of the participants (see Experiment 5.1 for group means). Participants also completed the listening recall and spatial recall tasks from the AWMA (see Experiment 4.1 for description of these tasks). Scores on these standardised measures allowed associations between reading comprehension and working memory and ratings on relevant rating scales to be examined.

Results

Standardised working memory measures

Table 6.1 shows the performance of the two groups on each of the standardised measures of working memory.

Table 6.1. Comparison of poor comprehenders' and controls' performance on the standardised working memory measures.

	Poor Comprehenders		Controls		<i>F</i>	<i>p</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Verbal Working Memory (AWMA)	90.16	10.38	102.50	11.51	19.91	< .001
Spatial Working Memory (AWMA)	99.81	13.55	105.28	12.62	2.75	> .10

Note: Standard Scores, *M* = 100, *SD* = 15

The results confirm findings reported in Experiment 4.1, showing that poor comprehenders attain significantly lower mean verbal working memory scores than controls, but that there are no significant group differences in spatial working memory.

Questionnaires

Questionnaires were returned for 62 of the 63 participants, a response rate of 98%. This meant that responses could be analysed for 30 poor comprehenders and 32 controls. For one participant, their teacher failed to complete the WMRS, leaving 30 poor comprehenders and 31 controls in the WMRS analysis.

Behaviour. The SDQ is primarily a checklist for behavioural difficulties and as a consequence the data obtained on each subscale of this measure was not normally distributed. As a result, Mann-Whitney tests were used to compare the ratings given to the poor comprehenders and controls, shown in Table 6.2. With the Bonferroni

correction for multiple comparisons applied, the p value for significance was set at .01.

Table 6.2. Mean ratings on the SDQ by group and subscale with U value for group comparisons.

	Poor Comprehenders		Controls		U	p
	M	SD	M	SD		
Hyperactivity	3.20	2.94	2.78	2.93	431.50	>.10
Emotional Problems	1.53	1.89	0.91	1.42	399.50	>.10
Conduct Problems	1.27	1.99	0.72	1.55	377.00	.09
Peer Problems	1.10	1.73	0.91	1.71	441.00	>.10
Prosocial	7.43	2.80	8.25	1.98	414.00	>.10

Although the poor comprehenders had slightly higher mean ratings on the four disorder scales, indicative of behavioural impairments relative to the controls, and lower ratings on the prosocial scale, none of the group differences were significant.

Attention. Table 6.3 shows the mean standard scores for the two participant groups on each of the CTRS-R (S) subscales. The data for each of the four subscales of the CTRS-R (S) were not normally distributed, meaning that parametric tests could not be used to compare the performance of the poor comprehenders and controls. Mann-Whitney tests to compare the groups on each of the four subscales of the CTRS-R (S) were conducted (see Table 6.3). The Bonferroni correction for multiple comparisons was applied, rendering a p value for significance of < .013.

Table 6.3. Mean ratings on the CTRS-R (S) by group and subscale with *U* value for group comparisons.

	Poor Comprehenders		Controls		<i>U</i>	<i>p</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Oppositional behaviour	52.77	11.72	50.28	9.03	406.00	>.10
Hyperactivity	50.47	10.86	49.00	11.57	407.00	>.10
Cognitive problems/ Inattention	51.5	10.13	45.28	4.84	284.50	.005
ADHD	52.97	13.28	50.50	11.50	446.50	>.10

Poor comprehenders were rated significantly higher than the controls on the Cognitive Problems/Inattention subscale, indicating a greater frequency of behaviours associated with this particular classification of attention deficit. By contrast, there were no significant differences between the two participant groups in terms of Hyperactivity, Oppositional Behaviour, or ADHD subscales. This pointed to a deficit that was specific to the behaviours assessed by the Cognitive Problems/Inattention subscale in poor comprehenders. As well as comparing poor comprehenders directly to controls on this subscale, it was also possible to examine the performance of these groups relative to the test norms. Fifteen of the poor comprehender sample had *t* scores of 50 or above on this subscale, indicating above-average levels of problem behaviours associated with cognitive problems and inattention. Of these 15, seven achieved *t* scores that were higher than 60, meaning that they displayed levels of problem behaviour in this domain that were more than

one standard deviation above the standardisation mean. By contrast, seven controls had t scores that were over 50 on this subscale, of which only one had a t score that was over 60.

An examination of the items that comprised the Cognitive Problems/ Inattention subscale of the CTRS-R (S) revealed that some of the items that make up this subscale seemed to be measuring educational attainment (e.g. 'poor in arithmetic') rather than factors specific to attention. It could be the case therefore that differences between the two groups in academic outcomes are driving the group differences on this subscale, rather than differences in inattention *per se*. To determine whether specific items within the Cognitive Problems/ Inattention subscale were driving the group differences on this subscale, an items analysis was carried out to compare the groups on each of the five items that make up the subscale. Again, because the data for each item did not meet the assumptions of normality necessary for parametric tests, non-parametric Mann-Whitney tests were carried out on the data. With the Bonferroni correction for multiple comparisons applied, the p value for significance was set at .01. Table 6.4 shows the results of these tests. The poor comprehenders had a significantly higher mean rating on four of the five items than the controls indicating deficits in both attention and educational attainment; not surprisingly, 'Poor in spelling' was the only item that showed no significant group differences.

Table 6.4. Mean ratings on the Cognitive Problems/ Inattention subscale of the CTRS-R (S) by group and item with U value for group comparisons.

	Poor Comprehenders		Controls		<i>U</i>	<i>p</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Forgets things he/she has already learnt	0.83	0.91	0.25	0.51	299.50	.003
Lacks interest in schoolwork	0.63	0.96	0.16	0.57	333.50	.006
Not reading up to par	0.50	0.73	0.06	0.25	316.00	.001
Poor in arithmetic	0.50	0.78	0.16	0.57	351.00	.01
Poor in spelling	0.67	0.88	0.44	0.76	406.00	.23

Spearman's correlation coefficients were used to examine the relationships between scores on the CTRS-R (S) subscales and scores on the AWMA and NARA. The table shown in Appendix A shows the correlation coefficients from this analysis. In terms of correlations with reading comprehension, ratings on the Cognitive Problems/ Inattention subscale of the CTRS-R (S) showed a significant negative correlation with reading comprehension standard scores, suggesting that children who perform less well at comprehension show more problem behaviours associated with inattention. By contrast, ratings on the three other scales of the CTRS-R (S) did not correlate significantly with comprehension. The same was true for correlations with non-verbal working memory; ratings on the Cognitive Problems/ Inattention subscale, but not on the other three subscales, showed significant negative correlations with non-verbal working memory performance, suggesting that children

who have less good non-verbal working memory show a greater frequency of problem behaviours associated with inattention. None of the subscales of the CTRS-R (S) correlated with verbal working memory performance.

Working memory. The poor comprehenders ($M = 48.30$, $SD = 9.30$) were rated higher than the controls ($M = 43.94$, $SD = 5.89$) on the WMRS, indicating a greater frequency of behaviours associated with working memory difficulties. Levene's test revealed that equal variances of the two group means could not be assumed ($F(1, 59) = 8.85$, $p = .004$), therefore the non-parametric Mann-Whitney test was used to establish whether the difference between the two group means was significant. This confirmed that teacher ratings of the poor comprehenders on the WMRS were significantly higher than those of the controls, $U = 326.50$, $p = .04$. As with the Cognitive Problems/Inattention subscale of the CTRS-R (S), it was possible to examine the deficits of poor comprehenders relative to the standardised norms of the rating scale, as well as simply relative to the controls. Ten of the poor comprehender sample had t scores of 50 or above on this subscale, indicating above-average levels of problem behaviours associated with working memory deficits. Of these 10, four achieved t scores that were higher than 60, meaning that they displayed levels of problem behaviour in this domain that were more than one standard deviation above the standardised test mean. By contrast, only three controls had t scores that were over 50 on this subscale, of which two had a t score that was over 60.

Spearman's correlation coefficients were used to examine the relationship between WMRS ratings and standardised working memory (as assessed by the AWMA) and reading comprehension. There was a significant negative correlation

between WMRS rating and non-verbal working memory score ($r_s = -.30, p = .02$), and between WMRS rating and reading comprehension ($r_s = -.37, p = .003$). By contrast the correlation between WMRS rating and verbal working memory was small and non-significant ($r_s = -.08, p > .10$) (cf., Alloway, Gathercole, Kirkwood, & Elliott, 2009b).

Educational performance. Table 6.5 shows the ratings from the educational performance questionnaire. Higher scores indicate poorer ratings.

Table 6.5. *Mean ratings on the educational performance questionnaire by group and item with U value for group comparisons.*

	Poor Comprehenders		Controls		<i>U</i>	<i>p</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Reading Accuracy	2.43	0.94	1.75	0.57	280.00	.002
Reading Understanding	2.60	0.93	1.75	0.57	237.00	<.001
Spelling	2.77	0.90	2.25	0.92	334.50	.03
Composition	3.03	0.85	2.16	0.72	226.00	<.001
Handwriting	2.97	1.13	2.47	1.24	357.50	.08
Speaking	2.43	0.85	1.63	0.79	242.00	<.001
Listening	2.66	1.06	2.13	0.83	327.00	.02
Maths	2.77	0.85	1.94	0.91	223.00	<.001
Music	2.80	0.71	2.28	0.73	313.50	.01
PE	2.43	1.00	2.25	0.72	436.50	.51
Art	2.57	0.57	2.34	0.70	399.50	.21

Once again, Mann-Whitney tests compared the two groups and the appropriate Bonferroni correction for multiple comparisons lead to the p value for significance being set at .005. Poor comprehenders were rated as performing more poorly in terms of reading accuracy, reading understanding, writing composition, speaking and mathematics skills. There were no significant group differences in spelling, listening, music, handwriting, art, and PE skills.

Discussion

The aim of Study 6.1 was to look at the behavioural, cognitive and educational outcomes associated with being a poor comprehender, as assessed by teacher ratings on a series of theoretically relevant rating scales. The first area considered was behaviour, as assessed by the SDQ. Previous research (e.g. Carroll, et al., 2005; Heiervang, et al., 2001) has demonstrated that children with specific word reading deficits show a higher frequency of behavioural problems than control children in a wide range of behavioural domains, but it was unclear as to whether the same would be true for children with specific comprehension deficits. The poor comprehenders received comparable ratings to control children across all five subscales of the SDQ, suggesting there is no specific relationship between reading comprehension deficits and general behavioural problems. This suggests that Adams et al.'s (1999) finding of a relationship between comprehension ability and problem behaviour ratings on the SDQ was driven, or at least contributed to, by concomitant word reading deficits.

However, when outcomes on rating scales selected specifically to measure problem behaviours associated with the cognitive deficits that have previously been demonstrated in poor comprehenders were examined, a different picture emerged.

The CTRS-R (S) was used to measure problem behaviours associated with attentional deficits. The poor comprehenders showed no significant deficits relative to the controls on the hyperactivity, oppositional behaviour, or ADHD subscales of this measure. However, their teachers did rate them as showing a significantly higher frequency of behaviours associated with cognitive problems/ inattention. Items analysis of this subscale demonstrated that it was not the case that the cognitive problems items (e.g. not reading up to par) were exclusively carrying the group differences. In keeping with the finding of specific deficits for the poor comprehenders on the cognitive problems/ inattention subscale, across the whole sample ratings on this subscale showed a strong and significant association with reading comprehension; this was not the case for ratings on the other three subscales. Taken together, these findings suggest that there is a specific relationship between inattentive, but not hyperactive, behaviour and reading comprehension deficits.

Although these findings have demonstrated an association between inattentive behaviour and comprehension deficits, we face the fundamental problem of any cross-sectional research design, in that this association does not necessarily inform us about the direction of the relationship. It could be the case that inattentive behaviour leads to comprehension difficulties because the child fails to appropriately direct the necessary attentional resources that are required for successful comprehension. Alternatively, it could be that early comprehension difficulties lead the child to display inattentive behaviour in the classroom, simply because if they are not understanding much in the context of a reading or listening task the task is not going to be particularly engaging, and hence they cease to pay attention. A final

possibility is that a third factor is influencing the development of both variables. One viable third factor, as discussed in the introduction section of this chapter, is that poor comprehenders' working memory deficits are leading to the inattentive behaviours that have been highlighted in this study (Alloway et al., 2009). Poor comprehenders' working memory deficits were also predicted to lead to enhanced ratings of problem behaviours associated with working memory deficits on the WMRS. This prediction was borne out by the findings; teachers rated poor comprehenders as having a significantly greater frequency of working memory-related problem behaviours than controls.

The strong negative correlations found between non-verbal working memory performance and both problem behaviour ratings on the WMRS and on the Cognitive Problems/Inattention subscale of the CTRS-R (S) support the idea that poor comprehenders' working memory deficits may be associated with the problem behaviours noted by teachers on these rating scales. However, the finding that verbal working memory was not associated with these problem behaviours suggests that, as hypothesised in the introduction, it may be a subgroup of poor comprehenders with domain-general working memory (i.e. those poor comprehenders who have low non-verbal working memory as well as low verbal working memory) deficits that are carrying the group differences in teacher ratings. The idea is that verbal working memory deficits in some poor comprehenders are caused by general language weaknesses, rather than a specific working memory problem; these poor comprehenders would not show non-verbal working memory problems, and should also not show deficits on the WMRS or the Cognitive Problems/Inattention subscale of the CTRS-R (S). In other poor comprehenders,

domain-general working memory problems at the level of the central executive lead to difficulties on both verbal and non-verbal working memory tasks, as well as impacting on problem behaviours connected with these 'genuine' working memory deficits. Because deficits in verbal working memory in poor comprehenders can be driven by general language weaknesses as well as by genuine working memory problems, it is unlikely that verbal working memory would co-vary with the behaviour problems associated with working memory deficits, hence the specific association with non-verbal working memory. This can be contrasted with the findings of Alloway et al. (2009b) who reported a significant correlation between WMRS scores and scores on the both verbal and non-verbal working memory measures in a sample of children with a range of working memory abilities. This is potentially because compared to poor comprehenders, verbal working memory performance in these children is being limited to a greater extent by working memory capacity, and to a lesser extent by language ability.

Support for the idea that a subgroup of poor comprehenders with domain-general working memory impairments may be principally carrying the group differences on the WMRS and the Cognitive Problems/Inattention subscale of the CTRS-R (S) comes from two sources. Firstly, as discussed in the results section, not all poor comprehenders show deficits on these two rating scales, with many being rated as showing fewer problem behaviours on each scale than the standardised mean. Secondly, having verbal and visuospatial working memory measures for each of the participants means that they can be broadly classified as having domain-specific verbal working memory deficits (below-average verbal working memory; above-average visuospatial working memory), domain-general working memory deficits

(below-average verbal working memory; below-average visuospatial working memory), or neither. This in turn allows us to determine the type of working memory deficit, if any, that predominates in the poor comprehenders who are rated as having above-average levels of problem behaviours on the scales in question. For example, on the WMRS four poor comprehenders had *T* scores that were greater than 60 (more than one standard deviation above the standardised test mean), three of which had domain-general working memory deficits. None of these four had domain-specific verbal working memory deficits. Ten poor comprehenders had *T* scores that were greater than 50 (the standardised test mean), seven of which had domain-general working memory deficits. Again, none of these ten had domain-specific verbal working memory deficits. This provides an early indication that poor comprehenders with domain-general working memory deficits (who potentially have 'genuine' working memory deficits) are much more likely than poor comprehenders with verbal-only working memory deficits (whose apparent working memory deficits may be driven by underlying language problems) to be rated as showing problem behaviours in the classroom that are associated with working memory deficits. This in turn supports the hypothesis discussed above (and in Chapter 5), that there exists a subgroup of poor comprehenders who have working memory problems at the level of the central executive (perhaps reflective of wider executive deficits) which lead to difficulties on both verbal and non-verbal working memory tasks, as well as impacting on problem behaviours connected with these 'genuine' working memory deficits. This idea, and the implications for research and practice, will be discussed further in Chapter 8.

The final area that I investigated in this study was poor comprehenders' educational outcomes. I explored the prediction that being a poor comprehender would have a selective impact on those areas of the curriculum in which there exist complex verbal demands, or in which comprehension would be particularly important for knowledge acquisition. The pattern of results fully supported this prediction, with poor comprehenders showing deficits relative to controls in their reading abilities, composition skills, speaking ability and mathematical performance, whilst being rated as having no significant impairments in spelling, listening ability, music, handwriting, art and creative work, and PE. It seems likely that their spared spelling skills arise from their spared phonological processing and awareness skills (Catts, et al., 2006; Nation, et al., 2004), with many studies demonstrating strong links between phonological ability and spelling development (e.g., Lundberg, Olofsson, & Wall, 1980). In terms of their spared listening ability, although at first this may seem at odds with the prediction that poor comprehenders would be impaired in any area that requires complex language skills, it is a distinct possibility that teachers interpreted listening ability as how well a child sits quietly and listens when required, rather than how much they understand what they are listening to. Future studies using this questionnaire should aim to clarify this item for the teachers, in order to ensure its validity.

One widely recognised issue of conducting a questionnaire study like the one presented here, in which a person is asked to rate an individual in terms of multiple different characteristics, is that of 'Halo effects'. Halo effects refer to how a characteristic shown by an individual can influence ratings of their other characteristics; this influencing characteristic can either be positive or negative. For

example, Abikoff, Courtney, Pelham, and Koplewicz (1993) found that when a child showed evidence of behaviours associated with oppositional defiant disorder, this served to inflate teacher ratings of other negative behaviours, such as hyperactivity. The finding of a very distinct pattern of deficits in the poor comprehenders (e.g. deficits in inattentive, but not hyperactive or oppositional behaviour as rated on the CTRS-R (S)) argues against the idea that Halo effects are having a pervasive effect on teacher ratings in this study.

To summarise, poor comprehenders were rated as showing both behavioural and educational deficits relative to control children, but deficits in both areas were by no means universal. The pattern of behavioural and educational strengths and weaknesses was consistent with previous work concerning the fundamental cognitive and language deficits associated with poor reading comprehension, and it seems likely that subgroups of poor comprehenders with different core cognitive deficits will have different behavioural and educational outcomes.

Chapter 7: An exploration of the mathematical profiles of poor comprehenders.

This chapter reports three experiments that addressed links between language ability and mathematical performance. Experiment 7.1 compared poor comprehenders and controls on two standardised measures of mathematical ability, one measuring procedural arithmetic prowess, and the other tapping higher-level mathematical reasoning. Although there were no group differences in performance on the arithmetic measure, the poor comprehenders showed significantly lower scores than the controls on the mathematical reasoning task. The poor comprehenders exhibited impaired verbal ability relative to controls, with these differences in verbal ability associated with the group differences found on the test of mathematical reasoning. Experiment 7.2 attempted to rule out the possibility that differences in the working memory demands of the two mathematical measures were responsible for the pattern of performance shown by the poor comprehenders in Experiment 7.1. The finding that increasing the working memory demands of the arithmetic measure (by converting it from written to mental arithmetic) did not induce a significant deficit in the poor comprehender group argues against the idea that group differences in working memory played a pivotal role in the findings of Experiment 7.1. Finally, Experiment 7.3 confirmed the important role played by verbal ability in determining mathematical reasoning performance in a large unselected sample of 7- to 8-year-olds.

In Chapter 6 it was reported that teachers rated poor comprehenders as performing significantly less well than controls in the curriculum area of mathematics. Previous research has consistently demonstrated an association between reading and mathematics ability in typically developing children (Geary, 1993; Hecht, Torgesen, Wagner, & Rashotte, 2001; Muth, 1984). Moreover, deficits

in reading and mathematics skills tend to covary, and there exists a substantial comorbidity between the developmental disorders of dyslexia and dyscalculia (Geary & Hoard, 2001; Knopik, Alarcon, & DeFries, 1997; Rourke, 1993). However, the vast majority of research into the relationship between mathematics and reading has focused on the links between word reading skills and mathematics, or on mathematical difficulties in children who are poor word readers. As a result, while we know a good deal about the typical mathematical profiles of children with a dyslexic profile of specific word reading deficits (see Simmons & Singleton, 2008, for review), how children with specific comprehension difficulties perform in mathematics tasks remains unclear. In this study therefore, I sought to elucidate the nature of the impact that being a poor comprehender may have on a child's mathematical performance, and to determine whether teacher ratings of poor comprehenders' mathematical performance are an accurate reflection of their true mathematical abilities.

It is possible to predict how poor comprehenders will perform on tests of mathematical ability based on what has already been established regarding their cognitive profiles. Recent studies exploring the language profiles of children with specific reading comprehension difficulties have suggested that they have problems in processing and understanding oral language. As discussed in Chapter 1, children with specific reading comprehension difficulties (poor comprehenders) show a distinct profile of language competencies, with impairments in non-phonological oral language skills in the face of spared phonological processing abilities. For example, Nation, Clarke, Marshall, and Durand (2004) compared poor comprehenders with age- and decoding ability-matched controls on an extensive battery of oral language

measures, including tasks tapping the linguistic domains of phonology, semantics and morphosyntax, as well as a range of other broader language skills which required children to draw on a combination of the aforementioned three domains. The poor comprehenders showed wide-ranging deficits relative to the controls on all of the language measures, with the exception of those assessing phonological processing. The authors concluded that poor comprehenders' deficits in oral language act as a limiting factor on their reading comprehension development, while their competence in the domain of word reading arises from their spared phonological skills. These findings have been widely replicated (see Chapter 1 for review), confirming impaired non-phonological language skills, despite spared phonological language skills, in poor comprehenders. Having established a typical language profile for a poor comprehender, it is now possible to predict what effects this may have on their mathematical performance.

Studies of typically developing children have suggested strong links between an individual's phonological processing skills and their arithmetic ability (Bull & Johnston, 1997; Hecht, et al., 2001; Rasmussen & Bisanz, 2005; Savage, Carless, & Ferraro, 2007). For example, Hecht et al. (2001) used data from a large-scale, longitudinal study to investigate whether phonological processing skills predicted development of mathematical computation ability between the ages of 7 and 11 years. Performance on each of three different measures of phonological processing (phonological memory, rate of access to phonological information in long term memory, phonological awareness) independently explained significant amounts of variance in general computational skill growth over the four years of the study. The authors make a compelling theoretical argument for why phonological processing

ability predicts arithmetic performance, citing the importance of phonological codes in arithmetic tasks as the operative factor. They suggest that phonological codes will be important when children are using counting strategies to solve arithmetic problems, not only to retrieve the verbal codes for number words in order to represent the problem verbally, but also to maintain these codes in phonological short term memory. Furthermore, when children progress from solely using counting strategies to retrieving arithmetic facts from long term memory, they must use a phonological representation of the problem (e.g., "4 x 4 =") to retrieve a phonologically-represented answer. Taken together, this suggests a key role for phonological processing in arithmetical computation tasks, and provides an explanation for why robust links have been found between children's phonological skills and their arithmetic performance.

If it is the case that phonological processing ability is associated with arithmetical development, children who have phonological deficits should show consequent impairments in performance on arithmetic measures. The phonological representations hypothesis of dyslexia suggests that individuals with the disorder have a core deficit in phonological processing, and converging evidence from many sources lends support to this theory (see Vellutino, Fletcher, Snowling, & Scanlon, 2004, for review). As well as having a detrimental effect on the word reading skills of dyslexic individuals, this phonological deficit seems to have a profound impact on their performance in certain areas of mathematics, with number fact recall the most consistently reported weakness in dyslexic individuals (Miles, 1983; Pritchard, et al., 1989; Simmons & Singleton, 2006). It is clear to see how problems with number fact recall would lead to problems with arithmetic; incorrect recall of a number fact is

going to lead to an incorrect arithmetical solution, whilst inefficient, cumbersome recall is likely to reduce available processing resources for the operation and thereby increase the chances of an inaccurate response. This was corroborated by a study carried out by Miles, Haslum, and Wheeler (2001), who examined the mathematical competencies of 269 dyslexic ten-year-olds. The dyslexic children showed overall deficits in performance relative to controls on a broad-ranging measure of mathematical ability, despite the two groups showing equivalent general intellectual ability. Items analysis revealed that group differences were carried by a subset of the items that the dyslexics seemed to find particularly hard compared to the controls. The majority of these items involved arithmetic, a finding which fits with the idea that dyslexic children's phonological deficits impact on their number fact recall, which in turn hampers their arithmetic ability. This therefore adds weight to the idea that children who experience difficulties with phonological processing will experience difficulties with arithmetical computation.

Given that poor comprehenders have unimpaired phonological processing abilities (e.g., Catts et al., 2006), it was predicted that they would show no deficits relative to controls in the domain of arithmetical computation, with their spared phonological skills leading to normal procedural mathematical skills. The Numerical Operations component of the Wechsler Individual Achievement Test-II (WIAT-II; Wechsler, 2005) involves a series of written arithmetic problems that get progressively more difficult. Children begin with simple addition and subtraction problems and continue the task until they respond incorrectly to six items consecutively. Due to their phonological impairments, it would seem likely that children with dyslexia would perform poorly on this arithmetic task. By contrast, it

was predicted that the unimpaired phonological skills of poor comprehenders would enable them to perform at a comparable level to controls on the Numerical Operations measure.

So far, I have focused on the procedural aspects of arithmetic and mathematics. Clearly however, there are other component skills that contribute to individual differences in mathematical competence (e.g., Dowker, 1998; Jordan & Hanich, 2000; Jordan, Huttenlocher, & Levine, 1992). Findings from studies of children with Specific Language Impairment (SLI) are relevant here. Like children with dyslexia, children with specific language impairment (SLI) also commonly show deficiencies in their phonological language skills (Bishop, 1997). However, the language difficulties of children with SLI are not limited to the domain of phonology, with their impairments spanning a range of non-phonological language ability clusters including semantics, syntax and verbal discourse (Bishop & Snowling, 2004). Similarly, their mathematical performance is compromised not only in the procedural arithmetic domain (Donlan, Cowan, Newton, & Lloyd, 2007; Fazio, 1996, 1999), but also on higher-level mathematical reasoning tasks such as initial quantity unknown mathematical word problems (Cowan, Donlan, Newton, & Lloyd, 2005), suggesting that non-phonological language skills may also play a role in certain components of mathematics. However, because children with SLI also show a phonological deficit, it is difficult to interpret exactly what this role is. By looking at poor comprehenders it is possible to look at the effects of having low language ability on component maths skills, in children whose broader oral language deficits are uncontaminated by concurrent phonological difficulties.

The WIAT-II offers another measure of mathematical competency; Mathematical Reasoning. Rather than assessing procedural arithmetic skills as the Numerical Operations subtest does, this more language-dependent component tests children's ability to reason about number through a series of verbally-presented items, often couched in the form of word problems. A recent study by van Eimeren and colleagues suggested that these two WIAT components have different brain bases (van Eimeren, Niogi, McCandliss, Holloway, & Ansari, 2008). They used magnetic resonance diffusion tensor imaging to explore whether individual differences in performance on the Numerical Operations and Mathematical Reasoning tests were associated with differences in white matter microstructure in the left hemisphere. The scans revealed differential patterns of association between each of the two subtests and microstructural differences in left hemisphere white matter regions. This finding suggests that Numerical Operations and Mathematical Reasoning draw on different sets of skills, which are in turn dependent on spatially discontinuous white matter tracts in the brain.

In line with this, performance on the Numerical Operations and Mathematical Reasoning components of the WIAT has previously been found to dissociate in children who have specific underlying cognitive deficits. Gathercole, Briscoe, Thorn, Tiffany, and the ALSPAC Team (2008) explored the language, memory, and learning abilities of a group of children selected on the basis of specific deficits in their phonological short term memory skills. These children showed poor phonological memory and awareness, despite normal vocabulary knowledge and language ability. As would be predicted from discussion about the links between phonological processing skills and arithmetic computation prowess, they were

significantly impaired relative to control children on the Numerical Operations task. However, they performed nearly as well as the controls on the more language-dependent Mathematical Reasoning task, consistent with their spared non-phonological language skills.

Given the findings of Gathercole et al., as well as the relatively high language demands of the Mathematical Reasoning measure, children who have language difficulties might show impairments in this test, even in the absence of any concomitant deficits in basic arithmetic ability. As discussed above, poor comprehenders show weaknesses in oral language (Nation et al., 2004), including difficulties in the semantic domain (e.g., Nation & Snowling, 1998). Problems with understanding word problems, with linguistic comprehension, and with the processing and manipulation of semantic information, may all impact on an individual's ability to complete the items that comprise the Mathematical Reasoning test. Thus it was predicted that poor comprehenders would be impaired relative to controls with good reading comprehension on this mathematical task. It is likely that children with SLI would also be impaired on the task, as they show similar non-phonological language deficits to poor comprehenders, and have previously been shown to be impaired on items similar to those contained within the Mathematical Reasoning measure (Cowan et al., 2005). However, as discussed above, by taking poor comprehenders as our experimental group it is possible to examine the effects of non-phonological oral language weaknesses on mathematical reasoning performance without the confounding effects of phonological language problems.

Experiment 7.1

In Experiment 7.1 therefore, I administered the Numerical Operations and Mathematical Reasoning components of the WIAT-II to poor comprehenders and control children with good reading comprehension. On the basis of their language profiles it was predicted that poor comprehenders would show an asymmetric profile of competency on the two WIAT-II mathematical ability measures. I hypothesised that their spared phonological processing skills would lead to normal performance on the procedural arithmetic measure (Numerical Operations) while their non-phonological language deficits would lead to inferior performance relative to controls on the Mathematical Reasoning test, due to its greater dependency on oral language ability.

Method

Participants

The same poor comprehenders (N = 14) and controls (N = 14) that took part in the three experiments reported in Chapter 4 also took part in this experiment (see Experiment 4.1 for description of the two groups).

Measures

Mathematical ability. Children completed both the Numerical Operations and Mathematical Reasoning components of the WIAT-II (Wechsler, 2005). The Mathematical Reasoning subtest uses a series of verbally presented problems accompanied by visual cues to provide a measure of children's ability to reason about mathematics. The Numerical Operations subtest is a paper-and-pencil test that assesses procedural fluency in the mathematical domain by requiring children to solve written calculation problems of increasing difficulty. These tests are co-

normed on the same population, with UK norms provided for ages 4 to 16 years 11 months.

Verbal ability. A measure of verbal ability was provided by the Vocabulary subtest of the WASI. See Experiment 3.1 for description of this test.

Phonological short term memory. The forward digit span component of the BAS II (Elliot et al., 1996) was used to assess children's phonological short term memory. See Experiment 4.1 for description of this test.

Procedure

Children underwent two testing sessions on two separate days, during which they completed all of the above measures under the supervision and guidance of a trained experimenter. Testing sessions took place in participating schools, in a quiet area near to the child's classroom.

Results

Data were entered into a 2 x 2 mixed-design ANOVA with group (poor comprehenders vs. controls) as a between-subjects factor and WIAT-II component (Mathematical Reasoning vs. Numerical Operations) as a within-subject factor. Neither the main effect of group ($F(1,26) = 0.94, p > .10$) or that of WIAT-II component ($F(1,26) = 2.61, p > .10$) were significant, but there was a significant interaction between these two variables ($F(1,26) = 6.482, p = .017, \eta_p^2 = .20$), shown in Figure 7.1.

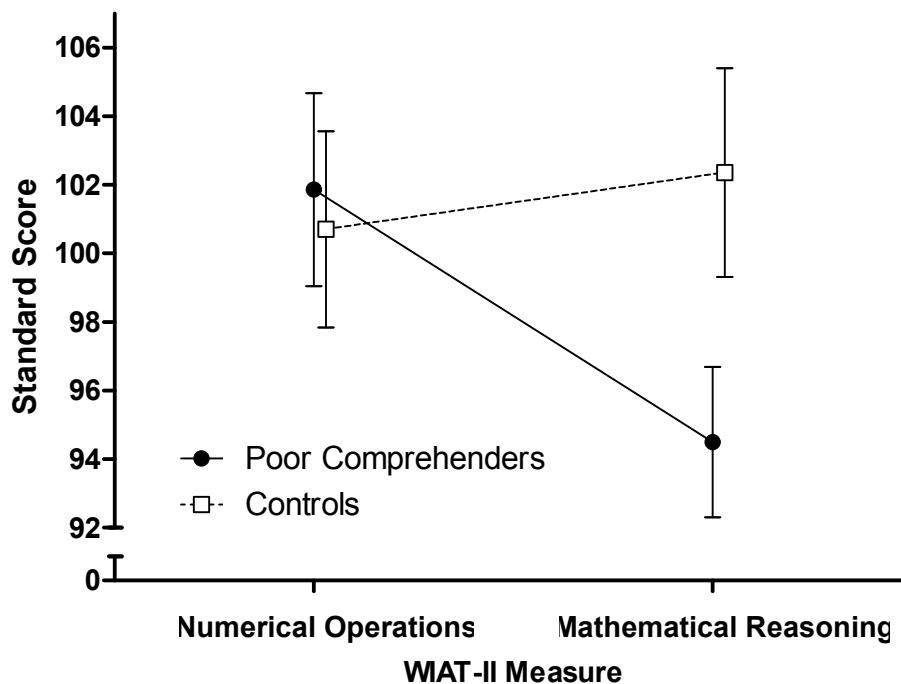


Figure 7.1. Mean standard scores on the Numerical Operations and Mathematical Reasoning tasks for poor comprehenders and controls. Error bars show the standard error of the mean.

Planned comparisons confirmed that while there was no difference between the groups in their performance on the Numerical Operations subtest ($t(26) = 0.284$, $p > .10$), the poor comprehenders ($M = 94.50$, $SD = 8.24$) performed significantly less well than the controls ($M = 102.36$, $SD = 11.42$) on the measure of Mathematical Reasoning, $t(26) = 2.09$, $p = .047$, $r = .14$). Consistent with earlier work (Stothard & Hulme, 1992), poor comprehenders ($M = 46.64$, $SD = 6.35$) showed no significant deficits relative to controls ($M = 49.43$, $SD = 5.18$) on the phonological short term memory measure ($t(26) = 1.27$, $p > .10$), but they ($M = 47.21$, $SD = 5.38$) demonstrated significantly lower verbal ability than the controls ($M = 56.78$, $SD = 10.11$), $t(26) = 3.13$, $p = .004$, $r = .51$. Furthermore, within the whole sample ($N = 28$),

performance on the WASI vocabulary measure correlated significantly with Mathematical Reasoning standard score, $r = .57$, $p = .001$, but not with score attained on the Numerical Operations measure, $r = .16$, $p = > .10$. Consequently, a hierarchical regression analysis addressed whether the non-phonological language deficits displayed by the poor comprehenders were associated with their inferior performance on the Mathematical Reasoning test (Table 7.1).

Table 7.1. Hierarchical regression predicting performance on the Mathematical Reasoning component of the WIAT-II.

	R Square	R Square Change	F	p	Final β
<i>Step 1</i>					
Age					.075
Non-verbal ability	.195	.195	3.03	.066	.281
<i>Step 2</i>					
Verbal ability	.407	.211	8.55	.007	.450*
<i>Step 3</i>					
Group membership	.410	.003	0.121	.731	-.066

Note: * $p < .01$

Although the findings from the analysis must be treated with a degree of caution due to the relatively small sample size, they are entirely in line with the other analyses, as well as the predictions made on the basis of previous research. When entered as control variables at Step 1, age and non-verbal ability (WASI Matrix Reasoning) together accounted for approximately 20% of the variance in Mathematical Reasoning performance. Oral language, as quantified by WASI vocabulary performance, was added at step 2, and explained an additional 21% of the variance.

To definitively establish that group differences in performance on the Mathematical Reasoning measure were associated with differences between the groups in terms of their oral language ability, the dichotomous predictor variable of group membership (poor comprehenders vs. controls) was entered at step 3 of the model. If differences between the groups on the outcome variable could be entirely accounted for by vocabulary, then adding group membership as a predictor variable should not account for any significant additional variance on top of that already explained by WASI vocabulary performance. However, if group differences were being driven by a factor, or factors, other than oral language aptitude, then we would expect adding group membership to the model to explain significant additional variance. As Table 7.1 shows, adding group membership to the model at step 3 explained no additional variance over and above that already accounted for by expressive vocabulary performance.

Discussion

In this experiment, I aimed to investigate the mathematical abilities of children who are poor comprehenders. Although no previous research has explored poor comprehenders' mathematical profiles, I was able to make predictions about how they may perform on the basis of a) knowledge of the typical language profile of a poor comprehender, and b) research on typically developing children and those with SLI or dyslexia, which has shown how individual differences in different language domains can impact on various aspects of mathematical performance. Poor comprehenders show impaired non-phonological language skills in the face of spared phonological processing abilities. It was predicted that their spared phonological skills would lead to normal performance on the procedural arithmetic measure

(Numerical Operations), while their non-phonological language deficits would mean they were less able to cope with the semantic and linguistic comprehension demands of the Mathematical Reasoning test. The results fully supported these hypotheses. As predicted from their language profiles, poor comprehenders did not differ significantly from controls on the Numerical Operations task, but performed at a significantly lower level than the controls on the co-normed Mathematical Reasoning subtest.

It could be argued that the children with a poor comprehender reading profile are performing less well on the assessment of mathematical reasoning than the matched controls because of general problems with attention, with task orientation, or as a result of low academic self-concept arising from their comprehension difficulties. However, if it was the case that general attentional or behavioural factors were driving the group differences on the Mathematical Reasoning measure, then it would be expected that the same factors would also have a detrimental impact on performance in the Numerical Operations component of the WIAT. As mentioned above, there were no significant differences between the groups on the latter task, with poor comprehenders actually scoring a little higher on average than the controls. This therefore suggests that an alternative explanation is needed to account for the group differences that emerged on the Mathematical Reasoning test.

The poor comprehenders showed significant weaknesses relative to controls in expressive vocabulary, suggesting that as predicted, group differences in performance on the Mathematical Reasoning measure are associated with oral

language weaknesses in the poor comprehender sample. To confirm that this was the case, data were entered into a multiple regression analysis with mathematical reasoning performance as the outcome variable. Vocabulary score was a significant independent predictor of mathematical reasoning ability, even after controlling for age and non-verbal IQ. Furthermore, group membership accounted for negligible additional variance when entered into the regression model after expressive vocabulary ability, suggesting that the group differences on the Mathematical Reasoning test were being primarily driven by differences between the groups in terms of their oral language capabilities. Due to the relatively small sample size in this study (an inevitable consequence of using very tightly-defined participant groups), the results of this hierarchical regression must be treated with a certain degree of caution, and future work should aim to replicate these findings with a larger sample of poor comprehenders and controls. However, the findings produced are entirely in line with those of my other analyses, as well as the predictions made on the basis of previous research.

The results of Experiment 7.1 have demonstrated a link between mathematical reasoning performance and underlying non-phonological language skills, but what underlies this link remains a matter for debate. It could be that poor comprehenders have no deficits in mathematical reasoning *per se*, but that the format of the WIAT-II Mathematical Reasoning measure is such that their underlying mathematical reasoning competencies are masked by their linguistic comprehension weaknesses. However, if this is the case then it would be expected that poor comprehenders would show the greatest deficits on those items that make the highest demands on linguistic comprehension, i.e. the story problems. The structure

and procedure of the mathematical reasoning measure place limitations on any attempts to conduct items analyses, but nevertheless, it does allow a very preliminary assessment of this hypothesis. Poor comprehenders performed worse overall on the mathematical reasoning measure, but the group differences were not solely carried by performance on these story problems, suggesting a more general impairment in mathematical reasoning (see Appendix B). It may be therefore that the poor comprehenders' difficulties are a more direct consequence of their language problems, in that language proficiency is necessary to be able to reason mathematically.

A final possibility is that a third factor is influencing performance on measures of both verbal ability and mathematical reasoning. The groups were matched on non-verbal ability, so it is not the case that the poor comprehenders were just generally of lower ability than the controls. However, one plausible hypothesis is that working memory ability could influence performance in the vocabulary and mathematical reasoning measures administered in this study, with this underlying third factor explaining the links found between the two skill sets. Previous research, both within this thesis (see Chapter 4) and within the extant literature (Cain, 2006; Nation, et al., 1999; Yuill, et al., 1989), has demonstrated that poor comprehenders show impairments relative to controls on working memory tasks. The origin of these deficits remains a matter of debate (see Chapter 8 for discussion), but the potential presence of working memory weaknesses in poor comprehenders does offer an alternative explanation for the finding of group differences on the Mathematical Reasoning task but not on the Numerical Operations measure. Because the procedural arithmetic test that the children

completed was a written measure, it is likely that the working memory demands were lower than the orally administered mathematical reasoning task, hence providing an explanation for the interaction based not on language profiles but on the working memory abilities of the groups.

Experiment 7.2

In order to address this possibility, I decided to explore whether differences between the groups would emerge if the working memory demands of the Numerical Operations task were increased. To achieve this, I converted the written arithmetic problems presented in the Numerical Operations test into mental arithmetic problems by presenting them orally to the children and requiring them to work out the answers in their heads. This created a series of items that became increasingly more demanding of children's working memory, requiring them to hold information online whilst they manipulated additional information (e.g. $41 + 14 =$; $80 - 56 =$; $24 \times 5 =$). In Experiment 7.1, the poor comprehenders showed deficits relative to the controls on the Mathematical Reasoning task, but not on the Numerical Operations task. If this pattern of results was simply due to the greater working memory demands of the Mathematical Reasoning measure, as suggested above, then increasing the working memory demands of the Numerical Operations test should cause group differences to emerge on this task; the poor comprehenders should perform at a lower level than the controls.

Method

Participants

The same poor comprehenders (N = 14) and controls (N = 14) that participated in Experiment 7.1 also took part in this experiment.

Materials

The mental arithmetic items were created by selecting those items from the Numerical Operations task that were suitable for conversion, and presenting them orally to the child as mental arithmetic problems. There was a total of 17 items, which progressively increased in the demands they placed on working memory. They ranged from simple, single step arithmetic (e.g. '8 + 5 = '), through to complex, multi-step problems (e.g. '698 + 426 = ').

Procedure

Children were instructed that they were going to hear some sums, and that they had to try and work each one out in their head. They were also cautioned that the experimenter would only be able to say each sum once, and were advised therefore to listen very carefully. The experimenter recorded the child's response. As with the original Numerical Operations task, the test was terminated if children got six consecutive incorrect responses, and no credit was given for subsequent items.

Results

In order to establish that floor or ceiling effects were not masking any group differences, it was important to confirm that the mean proportion of correct responses was not approaching either 0 or 1. Participants obtained a mean proportion correct on the mental arithmetic task of .55 ($SD = .15$), thus performing significantly above 0 ($t(27) = 19.37, p < .001$) and significantly below 1 ($t(27) = 16.09, p < .001$). Poor comprehenders ($M = 8.64, SD = 2.62$) scored slightly, but not significantly, lower than the controls ($M = 9.93, SD = 2.37$) on the mental arithmetic task, $t(26) = 1.36, p > .10$.

Discussion

This experiment aimed to explore whether differences in the working memory demands of the Mathematical Reasoning and Numerical Operations components of the WIAT-II could account for the pattern of results observed in Experiment 7.1. If group differences are apparent on the Mathematical Reasoning task but not the Numerical Operations measure because of the greater working memory demands of the former test, then it would be expected that group differences would also emerge on the latter measure if its working memory demands were increased. I increased the working memory demands of the Numerical Operations task, by converting the items from written to mental arithmetic. However, there was still no evidence of significant group differences; poor comprehenders and controls performed at a similar level on this mental arithmetic version of the Numerical Operations task. This suggests that differences in the working memory demands of the two WIAT-II components are not playing a major role in the pattern of performance observed in Experiment 7.1. It seems likely then that it is indeed the increased linguistic processing and comprehension demands of the Mathematical Reasoning measure that led to poor comprehenders' observed deficits on this task, despite their unimpaired performance on tasks tapping both written and mental arithmetic.

Experiment 7.3

The results from the first two experiments reported in this chapter suggested then that it is poor comprehenders' deficient verbal ability that is limiting their performance on the Mathematical Reasoning task, and that neither working memory, nor basic arithmetic ability, were playing a substantial role in the observed

group performance differences. However, due to the small sample sizes involved in Experiment 7.1 it was not possible to look at the contributions made by verbal ability, arithmetic ability and working memory simultaneously in my regression model. To overcome the issues associated with small sample sizes, as well as the inevitable limitations of working with such highly circumscribed groups of children on the generalisability of my results, I decided to further explore this issue in a large group of unselected children (N= 89). All the children completed the Mathematical Reasoning and Numerical Operations tasks described in Experiment 7.1, as well as measures of working memory and verbal and non-verbal ability. I was then able to run regression analyses to determine which variables were the best predictors of performance on the Mathematical Reasoning task.

If, as suggested by the results of my first two experiments, it is the case that there is a specific relationship between verbal ability and mathematical reasoning performance, then we would expect verbal ability to be a significant independent predictor of performance on the Mathematical Reasoning task in this whole sample of children, just as it was for the poor comprehenders. Although it is clear that arithmetic ability is one factor that could limit performance on the Mathematical Reasoning task, the lack of any deficits for poor comprehenders on either version of the Numerical Operations task implies that verbal ability is an important predictor of mathematical reasoning performance over and above basic arithmetical skills. I sought to test this idea in Experiment 7.3 by entering performance on the Numerical Operations task into the regression model. This would determine whether verbal ability is still a significant independent predictor of mathematical reasoning

performance, even when controlling for basic arithmetic ability (as measured by the Numerical Operations task).

Experiments 7.1 and 7.2 also suggested that working memory capacity did not contribute to the observed group differences on the Mathematical Reasoning task. If it is the case that there is not a strong, specific relationship between working memory and mathematical reasoning ability then we would not expect individual differences in working memory to be a significant independent predictor of performance on the Mathematical Reasoning task within this large sample of typically-developing children.

Method

Participants

The same 89 children (38 boys, 51 girls) who took part in the experiment reported in Chapter 3 also provided the data for this set of analyses. Three of the children failed to complete the Mathematical Reasoning task due to scheduling constraints in their schools, so their data was not included in the analysis.

Materials and procedure

Children completed the following measures over the course of two testing sessions. Each of the measures is described in detail in a previous section of the thesis; the Numerical Operations and Mathematical Reasoning components of the WIAT-II (see Experiment 7.1) were used to assess written arithmetic and mathematical reasoning ability respectively, the Vocabulary and Matrices subtests of the WASI (see Experiment 2.1) were used to measure verbal and non-verbal ability respectively, and the Backward Digit Span subtest of the BAS-II (see Experiment 3.1) was used as a measure of working memory.

Results

A hierarchical regression analysis was carried out to examine which variables predicted mathematical reasoning ability. The results of this regression analysis are shown in Table 7.2.

Table 7.2. Hierarchical regression predicting mathematical reasoning standard score.

	R Square	R Square Change	F	p	Final β
<i>Step 1</i>					
Age	.36	.36	22.82	< .001	.11
Non-verbal ability					.15*
<i>Step 2</i>					
Numerical Operations	.65	.29	49.23	<.001	.50**
<i>Step 3</i>					
Working memory	.66	.01	38.69	<.001	.09
<i>Step 4</i>					
Verbal ability	.73	.07	43.34	<.001	.31**

Note: * $p < .05$, ** $p < .001$

Age and non-verbal ability were entered as control variables at Step 1, and together accounted for 36% of the variance in mathematical reasoning performance. Adding performance on the Numerical Operations task at Step 2 accounted for an additional 29% of the variance in the Mathematical Reasoning. Working memory performance on the BDS accounted for minimal additional variance in mathematical reasoning performance when added at Step 3, accounting for only an additional 1%.

Furthermore, although it was a marginally significant independent predictor of mathematical reasoning at Step 3 ($\beta = .13, p = .08$), it was not a significant independent predictor of mathematical reasoning outcomes in the final regression model after verbal ability had been added at Step 4. When added at Step 4, verbal ability accounted for an additional 7% of variance in performance on the Mathematical Reasoning task on top of the 66% already accounted for by age, non-verbal ability, arithmetic performance and working memory. Verbal ability was a significant independent predictor of mathematical reasoning performance in the final regression model, confirming that it predicts unique variance over and above that predicted by performance on the Numerical Operations task.

Discussion

The aim of this final experiment was to explore predictors of mathematical reasoning performance in a large unselected sample of 7- to 8-year-olds. Results revealed that, in line with the findings of Experiment 7.1, verbal ability predicted unique variance in mathematical reasoning performance over and above that predicted by basic arithmetic ability. This suggests that verbal ability does play a role in performance on the mathematical reasoning task, and supports the hypothesis that poor comprehenders' impairments on this task arise not because of any problems with arithmetic but because of their verbal weaknesses. The results of this study also suggest that when the influence of age, verbal and non-verbal ability, and arithmetic performance are controlled, working memory is not playing a significant role in determining performance on the Mathematical Reasoning task. This corroborates the findings from Experiment 7.2, which suggested that working

memory did not contribute to the differences in performance between the poor comprehenders and controls in mathematical reasoning.

General Discussion

Experiment 7.3 added weight to the conclusions drawn from Experiments 7.1 and 7.2, namely that verbal ability plays a role in determining performance on the measure of mathematical reasoning, and that it is weaknesses in verbal ability that account for poor comprehenders impaired mathematical reasoning performance in the face of intact basic arithmetic skills. This exploration of the mathematical profiles of poor comprehenders, and of the links between language and mathematical reasoning, suggests that having good lower-level, procedural mathematical skills is no guarantee that adequate mathematical reasoning will develop. An analogy can be drawn here with the reading profiles of poor comprehenders, which demonstrate that good comprehension does not inevitably arise when good decoding is achieved. Importantly, it also supports the idea of a certain degree of independence between verbal ability and arithmetical ability; the two groups showed equivalent achievement on the procedural arithmetic measure, despite the poor comprehenders showing significantly lower verbal ability than the controls. This converges with findings from studies of patients who have suffered brain damage leading to selective impairments in either their verbal ability or their performance on arithmetic measures. For example, Cipolotti, Butterworth, and Denes (1991) report the case of CG who, after suffering a severe stroke that had damaged her left parietal lobe, presented with very poor arithmetic in the face of unimpaired oral language skills. Conversely, Cappelletti, Butterworth, and Kopelman (Cappelletti, Butterworth, & Kopelman, 2001) described patient IH who displayed extremely

defective language abilities, yet was able to carry out even complex multidigit arithmetic with no problems.

The findings from the three experiments in this chapter also offer interesting insights into the relationship between working memory and verbal ability. The results from Experiment 7.1 suggested that after accounting for verbal ability, group differences in other factors were not accounting for any additional variance in mathematical reasoning performance, implying that working memory was not playing a significant role in determining group differences on this measure. What Experiment 7.3 added was to show that when verbal ability was added into the regression model after working memory, it not only contributed significant independent variance, it also reduced the power of working memory to explain variance in mathematical reasoning performance. This shared variance suggests that the influence that performance on the working memory task had on differences in outcomes on the Mathematical Reasoning task could largely be accounted for by differences in verbal ability, and so adds support to ideas expressed earlier in this thesis (see Chapter 4) concerning the key role that verbal ability plays in verbal working memory performance. The working memory task that was used in Experiment 7.3 was a verbal working memory task, which is likely to have contributed to these findings. It would be interesting to explore the role that a visuospatial working memory task would play in predicting variance in mathematical reasoning outcomes. Visuospatial working memory has previously been implicated in mathematical ability (Andersson & Lyxell, 2007; Geary, 2010; Kyttala, Aunio, & Hautamaki, 2010; Logie, Gilhooly, & Wynn, 1994), but it would be interesting to see whether it made a unique contribution to individual differences on the Mathematical

Reasoning task over and above Numerical Operations performance. Unfortunately a visuospatial working memory measure was not available for all the children who participated in Experiment 7.3, but this would be an interesting avenue to explore in future research.

Overall the findings show that poor comprehenders' difficulties are not restricted to the domain of literacy, but rather that their underlying impairments can selectively affect performance in those areas of mathematics which load particularly highly onto verbal ability, semantic processing, and linguistic comprehension abilities. This has important educational implications, and may account for the findings of Experiment 6.1, in which teachers rated poor comprehenders as performing significantly less well than controls in mathematics. It is likely that on any assessment of mathematical ability that places high demands on these skills, poor comprehenders' underlying mathematical abilities may be underestimated. For example, many elements of the mathematics component of the Standard Assessment Tests (SATs) that children in the UK take at the end of Year 6 (11 years of age) contain verbal instructions, items such as mathematical story problems, and 'explain' questions which require the child to verbally elucidate mathematical concepts, e.g. 'Explain why a number which ends in 3 cannot be a multiple of 4' (The Qualifications and Curriculum Authority, 2007). This highlights the need for early identification of poor comprehenders on the basis of their language profiles, so that appropriate intervention can take place to ameliorate their language weaknesses, and thereby prevent consequent difficulties, not just in the domain of reading comprehension, but also across the curriculum.

Chapter 8: General discussion

This chapter summarises the key findings of the studies presented in the last six chapters of this thesis, and discusses the implications of these findings for our understanding of poor comprehension. The impact of the results on current aetiological theories of poor comprehension will be discussed, as well as their broader implications for theories of working memory. Suggestions will be made regarding early identification of poor comprehenders, and potentially effective intervention strategies to remediate their comprehension difficulties will be presented. Issues that arise when studying poor comprehenders will also be explored throughout, as will the most effective ways to overcome these issues.

The research presented in this thesis has had two overarching aims; the first, to supplement our knowledge concerning the aetiological underpinnings of poor comprehension, and the second, to investigate the impact of being a poor comprehender on behavioural and educational outcomes in the school context. The experiments documented in Chapters 2-5 addressed the first of these aims.

Causation in poor comprehension

One approach to explaining the aetiology of poor comprehension has posited that poor comprehenders have deficits in appropriately regulating the contents of working memory (cognitive inhibition); the central executive is deficient at inhibiting irrelevant information from entering into working memory and at suppressing no longer relevant information from working memory (e.g., Carretti, et al., 2005; De Beni & Palladino, 2000; De Beni, et al., 1998; Palladino, et al., 2001). The resultant

working memory deficits mean that working memory is not able to support reading comprehension in the way that it should, leading to the observed comprehension deficits in these children (see Chapters 1 and 4 for discussion). Figure 8.1 shows a schematic diagram that summarises this account.

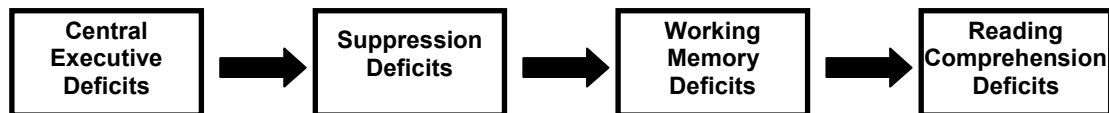


Figure 8.1. Schematic representation of deficits within the working memory system leading directly to reading comprehension deficits.

Experiment 2.1 examined poor comprehenders' ability to suppress no longer relevant information from working memory, and found that previous demonstrations of suppression deficits in simple experimental recall tasks extended to the level of the narrative; when listening to stories, poor comprehenders found it harder than controls to update their mental model of the narrative, with earlier, interfering information that should have been suppressed impacting negatively on their ability to answer questions about the stories. These findings supported the idea that poor comprehenders' have deficits in regulating the contents of working memory, and provided a direct mechanism whereby suppression deficits could impact on comprehension at the level of the narrative. However, as with all previous studies of cognitive inhibition in poor comprehenders, the experiment was exclusively rooted in the verbal domain. As a result it could not inform us as to whether poor comprehenders' suppression deficits are reflective of a domain-general working memory impairment at the level of the central executive; if deficits

on working memory and suppression tasks are due to central executive deficits in regulating the contents of working memory, then poor comprehenders should show deficits on working memory and suppression tasks that involve both verbal and non-verbal information.

The experiments reported in Chapters 3 and 4 attempted to address this by examining links between comprehension and cognitive inhibition in both the verbal and the non-verbal domain. In Experiment 3.1, examination of the links between comprehension and verbal and non-verbal suppression ability in a large sample of typically developing children revealed an association between comprehension performance and verbal suppression ability. There was however no evidence for a relationship between non-verbal suppression ability and comprehension, suggesting a specific link between comprehension ability and *verbal* suppression ability, and raising the possibility that poor comprehenders may indeed show verbal only-deficits in cognitive inhibition and working memory. The three experiments presented in Chapter 4 confirmed this hypothesis. The poor comprehenders and controls completed a verbal and a non-verbal standardised working memory measure, as well as verbal and non-verbal versions of a newly-designed measure of suppression ability. Results revealed domain-specific (verbal-only) deficits for poor comprehenders on each of the working memory and suppression tasks they completed.

The specific pattern of memory deficits reported in Chapter 4 calls into question the validity of Baddeley's model of working memory. The finding that poor comprehenders show deficits that are specific to working memory (in that they are impaired on working memory, but not short term memory, tasks), and to the verbal

domain within working memory, should theoretically not be possible within Baddeley's working memory framework. The lack of deficits in verbal STM rules out a problem at the level of the phonological loop, with the specificity of the deficits to working memory pointing to a problem at the level of the central executive.

However, Baddeley argues that the central executive is a domain-general executive control component of working memory, meaning that if working memory deficits are present which cannot be accounted for by storage deficits, they should affect both verbal and non-verbal working memory. In order to posit a deficit in poor comprehenders that is specific to working memory, and that accommodates the results reported in Chapter 4, a different model of working memory to Baddeley's multicomponent model is necessary. Shah and Miyake (1996) argued that there is not one domain-general central executive, but rather two separate pools of central executive resources, one of which contributes to the processing of verbal information, and the other to the processing of visuospatial information. If this idea of a functional distinction between verbal and visuospatial working memory at the level of the central executive is correct, then it could be that the findings of Experiments 4.1 and 4.2 arose as a result of a deficit in poor comprehenders that is specific to the verbal central executive. This verbal central executive deficit would lead to the chain of processes documented in Figure 8.1, but would be confined to the *verbal* working memory system.

However, the results from Chapters 3 and 4 also support an explanation for poor comprehenders' deficits based on general difficulties with the representation and processing of verbal material due to underlying language weaknesses. Figure 8.2

provides a schematic representation of this account, and can be contrasted with Figure 8.1.

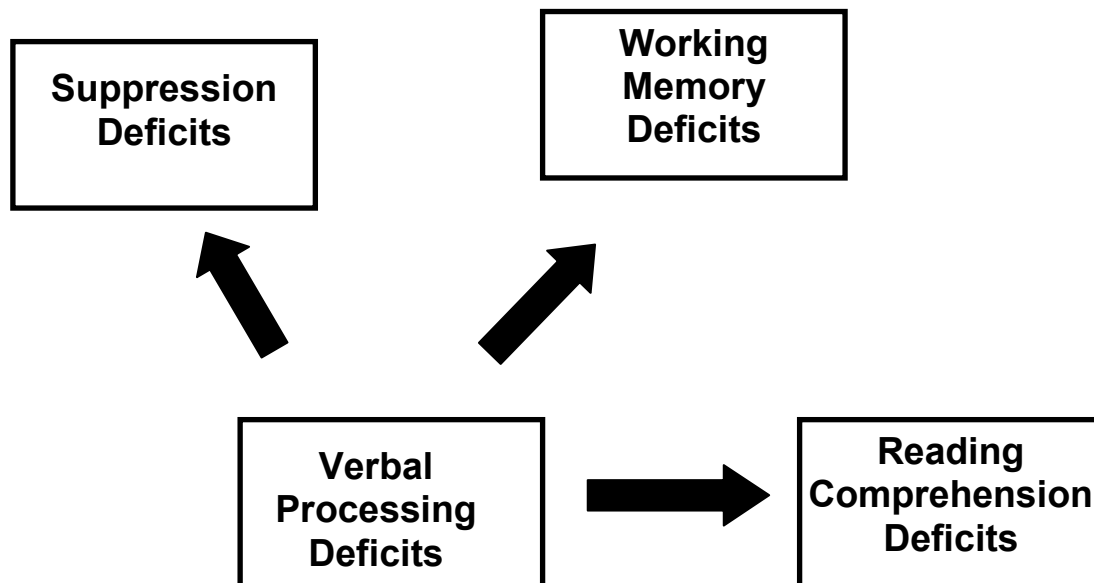


Figure 8.2. Schematic representation of verbal processing deficits leading to reading comprehension deficits, with working memory and suppression deficits as by-products of these general verbal weaknesses.

Rather than poor comprehenders having specific central executive deficits which lead to the observed deficits on suppression, working memory and comprehension tasks, the alternative theory represented in Figure 8.2, argues that poor comprehenders are showing deficits on suppression and working memory tasks because of underlying language weaknesses that impact on the representation and processing of verbal material, rather than a problem specifically within the central executive component of the working memory system. These language weaknesses impact on any task that requires processing of verbal material, with poor comprehenders' deficits becoming more pronounced the higher the verbal

processing demands of the task. On this view, any apparent verbal working memory and suppression deficits in poor comprehenders are not playing a causal role in poor comprehension, but are instead merely a by-product of the verbal demands of the tasks that measure them. The results reported in Chapter 4 do not allow us to definitively differentiate between these two alternative explanations. However, recent developments in the field of working memory training have opened up a possible avenue of research that would allow us to address this question.

It has long been believed that working memory cannot be trained; it has been shown to be highly heritable (Friedman, et al., 2008; Koten, et al., 2009; Kremen, et al., 2007), and does not seem to be substantially influenced by environmental experience (Engel, Santos, & Gathercole, 2008). However, a computerised program to train working memory has recently been developed by Cogmed, with early results suggesting that the program successfully boosts working memory ability across a range of ages, and in both typically developing groups and those with known working memory deficits (Holmes, Gathercole, & Dunning, 2009; Klingberg, et al., 2005; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009; Westerberg, et al., 2007). The program involves intensive daily training on working memory tasks over a period of several weeks. The training program is also adaptive, in that it identifies the individual's working memory capacity and continuously pushes them at the threshold of that capacity, and it is this adaptive component, in combination with the intensity, which is believed to account for the success of the program. Holmes et al. (2009) selected children with low working memory skills and trained them on the Cogmed program; half of the children completed the normal adaptive version of the program, while the other half completed a control, non-adaptive version. They found

significant improvements in working memory for the children who completed the adaptive training, with these gains in working memory ability transferring to untrained working memory tasks, and sustaining for at least six months after training had taken place. Furthermore, when assessed six months after training there was some evidence to suggest that the improvements in working memory had knocked on to improve academic attainment as well, with children showing improvements on a standardised test of mathematics.

As discussed above, if the Cogmed working memory program can effectively train and improve working memory, then it offers a way to differentiate between the two competing explanations for my domain-specific findings. If one assumes that poor comprehenders' comprehension deficits arise because of limitations placed by genuine deficits in verbal working memory, then training verbal working memory should remove this limitation and comprehension should improve as a result. By contrast, if we assume that deficits on verbal working memory tasks are merely a by-product of general language weaknesses, which also act as the main limiting factor on comprehension ability, then training and improving verbal working memory should not significantly improve comprehension. Figure 8.3 shows a design that such a training study could take.

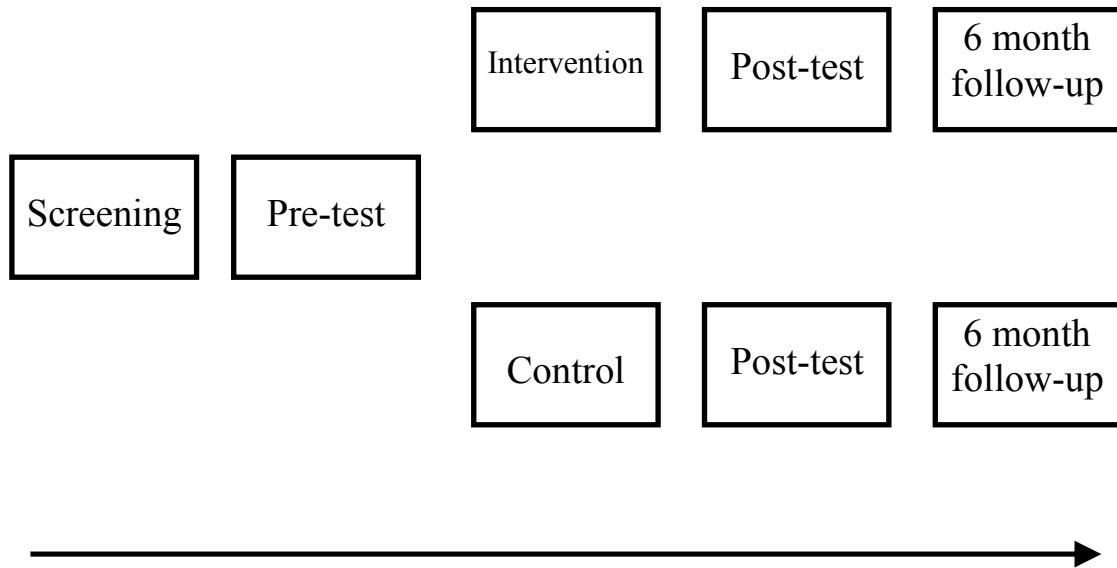


Figure 8.3. Structure of working memory training study run as RCT.

The first stage would involve screening for a sample of poor comprehenders who showed verbal working memory deficits. Their working memory and comprehension abilities would be tested before the intervention took place. They would then be randomly allocated to either the intervention group, who would complete the adaptive version of the training, or the control group, who would complete the control non-adaptive version. The verbal working memory training involves tasks similar to those comprised in working memory test batteries such as the Automated Working Memory Assessment (Alloway, 2007). For example, one task involves children having to read a series of digits and then recall those digits in reverse order. Assessments at post-test would establish their working memory and comprehension scores after the intervention, and assessments six months later would identify if any gains shown immediately after the post-test were sustained.

If, as previous studies have suggested, the intervention successfully trains working memory, the intervention group should show gains in their verbal working

memory scores that are significantly greater than any shown by the control group. The inclusion of a control group who complete a non-adaptive (but otherwise equivalent) version of the training programme is very important, as it would allow us to conclude that any improvements in comprehension are due to working memory improvements resulting from the adaptive aspect of the training rather than improvements in other variables that would result from exposure to the training program, the crucial one for our hypothesis of course being language. After establishing gains in verbal working memory performance in the intervention group, it would then be possible to establish whether these gains transfer to gains in comprehension score either immediately at post-test or six months down the line at follow-up. As discussed above, if improving verbal working memory results in improvements in reading comprehension, then this may suggest that deficits specific to working memory are limiting comprehension ability in poor comprehenders. If improvements in working memory do not lead to improved comprehension, then it may be that the alternative explanation is correct; deficits on working memory tasks are a by product of general language processing deficits, with these language deficits also acting as the main limiting factor on comprehension.

Broader deficits in poor comprehenders

Chapters 2-4 focused on cognitive inhibition, and the links between this aspect of inhibitory control and comprehension. Cognitive inhibition however, is just one aspect of executive inhibitory control, a construct which comprises many different types of inhibitory processes. As discussed in Chapter 5, the links between

these different inhibitory processes are not well specified, so it was not known whether poor comprehenders' deficits in cognitive inhibition would transfer to other aspects of executive inhibition. Chapter 5 reported a series of experiments that aimed to explore wider aspects of inhibitory control in poor comprehenders. Participants completed tasks selected to measure interference control (inhibition of an irrelevant dimension of a stimulus) and behavioural inhibition (inhibition of a prepotent response). These tasks took place in both the verbal and the non-verbal domains to enable me to continue my exploration of the domain-specificity of any observed poor comprehender deficits. Although there were some questions regarding the construct validity of the tasks used (see Chapter 5 for discussion), on the whole, results suggested broad deficits in executive inhibition in poor comprehenders which spanned both the verbal and the non-verbal domain. These findings contrasted with those reported in Chapter 4, and seemed to fit better with the executive approach to explaining poor comprehension detailed in Chapter 1. An explanation was put forward for the finding of wider executive deficits in Chapter 5 that was still compatible with a verbal account of poor comprehenders' deficits. I postulated, based on previous work that had demonstrated the importance of language in executive tasks, that poor comprehenders may not have genuine deficits in executive inhibition, but that their poor performance on executive inhibition tasks is mediated by their verbal deficits. However, the regression reported in Experiment 3.1, which examined predictors of reading comprehension outcomes, showed that working memory capacity (as measured by the BDS task) made a small but significant contribution to variance in reading comprehension even when controlling for the effects of verbal ability. This suggests that weaknesses in executive function that are

not accounted for by weaknesses in verbal ability do place a limit on reading comprehension, raising the possibility that executive function deficits could be a limiting factor on comprehension performance in some poor comprehenders.

One possibility that incorporates both findings of verbal deficits and general executive deficits, and accounts for the significant independent contributions of verbal ability and working memory capacity to comprehension outcomes, is that there exist subgroups of poor comprehenders with distinct aetiological profiles. One subgroup of poor comprehenders may have verbal deficits which place the primary limit on their comprehension development, whilst another may have generalised executive deficits as the key limiting factor on their comprehension outcomes. Thus when looking at group-level differences between poor and skilled comprehenders it may be the case that the relative proportion of these two subgroups within the sample of poor comprehenders will influence the nature of the results. For example, if the sample of poor comprehenders had a greater proportion of children for whom language ability was the main limiting factor on their comprehension performance, then we would expect a stronger tendency for the group to show deficits on verbal, but not non-verbal, tasks. By contrast, if the sample had a higher proportion of poor comprehenders who had executive deficits at the root of their comprehension problems, then we may expect them to show more domain-general problems on working memory and other executive tasks. This could at least partially account for discrepancies both within my own results reported in this thesis (verbal-only deficits in Chapter 4 vs. domain-general deficits in Chapter 5; see discussion in Chapter 5) and within the broader literature on poor comprehenders (Cornoldi, et al., 1996,

found domain-general working memory deficits; Nation, et al., 1999, found verbal-only working memory deficits).

Of course, in reality the situation is unlikely to be as clear cut as the picture outlined above; interactions between language and executive function operate in both directions, meaning that a poor comprehender who has fundamental language deficits is likely to also show some evidence of deficits on executive tasks, and any poor comprehender who has executive deficits is also likely to face some impact of these executive deficits on both language acquisition and language tasks themselves. Teasing apart these effects by using longitudinal studies to establish developmental primacy, as well as causality in poor comprehension, is likely to be very challenging. Indeed, it is likely that subtly different pictures would emerge for each poor comprehender under study. What the above discussion highlights therefore, is that poor comprehension is an aetiologically heterogeneous reading disorder; many factors can contribute towards a child being a poor comprehender, and these factors are likely to interact with each other, as well as each child's own compensatory abilities in order to determine outcomes. Studying poor comprehenders as a group has provided, and will continue to provide, important insights into causality in poor comprehension, but given the clear aetiological heterogeneity of the disorder it is perhaps time to start considering complementary approaches that take this into account.

One such approach would be to identify subgroups of poor comprehenders with different underlying core cognitive deficits, as discussed above. Although it would still be the case that there would be some degree of variability within the subgroups, this should nonetheless reduce the gross variability in causation (and

hence outcome in experiments examining causation) that is seen when poor comprehenders are considered at the whole group level. In order to carry out this kind of work, efforts will have to be made to increase the numbers of poor comprehenders recruited for studies; typical samples of 15-20 poor comprehenders will simply not be large enough to allow the study of subgroups whilst still retaining sufficient statistical power. When we consider the key reason why we want to clarify causality in poor comprehenders, which is to identify appropriate early interventions to avoid or ameliorate comprehension deficits, the advantage of a subgroups approach is clear. In fact, in terms of intervention, the most effective strategy would probably be to examine causation at the single case level. Each poor comprehender's unique profile of cognitive deficits associated with their weaknesses in reading comprehension would be identified, and targeted interventions would be offered that aimed to improve those underlying cognitive skills and hence remove the limit they place on reading comprehension. This approach of individually assessing cognitive strengths and weaknesses in order to develop individualised interventions is one that is being increasingly advocated for children with reading problems (see Fiorello, Hale, & Snyder, 2006), although problems associated with cost may prove a limiting factor on the widespread use of such approaches.

Behavioural outcomes in poor comprehenders

The experiments reported in Chapters 6 and 7 addressed the second aim of this thesis, which was to explore behavioural and educational outcomes in poor comprehenders. Chapter 6 reported the results of a questionnaire study which asked

teachers to rate poor comprehenders and controls on a variety of measures of behaviour and academic performance. Behavioural measures included the SDQ which provides information on children's behaviours, emotions and relationships within the school environment, the WMRS which identifies classroom behaviours that may be a manifestation of working memory deficits, and the CTRS-R (S) which assesses problem behaviours typically associated with attention deficits. Educational attainment was assessed with a questionnaire that asked teachers to rate the performance of the child in question relative to their same-aged peers on a range of different curriculum areas. Poor comprehenders *were* picked up as having deficits relative to controls both behaviourally and academically, but these were by no means universal.

Previous work (J. W. Adams, et al., 1999) had suggested that behaviour ratings on all problem subscales of the SDQ were associated with poor comprehension, but the potentially confounding effect of co-occurring word reading deficits meant that a specific relationship between comprehension and SDQ problem behaviour ratings could not be established. The finding that poor comprehenders did not show significant differences from decoding ability-matched controls on any of the subscales on the SDQ suggested that previously established links between reading comprehension ability and behaviour may indeed have been confounded by comorbid word reading difficulties. This raises a general issue concerning the importance of studying children with *specific* reading comprehension difficulties. The way in which I have selected poor comprehenders, which involves rigorous matching with controls in terms of decoding ability, text reading accuracy, and non-verbal ability, is fast becoming the dominant paradigm when exploring factors associated

with poor comprehension. However, it is still the case that papers are being submitted for publication in which claims are made about links between comprehension and other variables on the basis of experiments which use children with poor reading comprehension without controlling for the potentially confounding effect of their reading accuracy. A related point concerns the use of tests that purport to measure reading comprehension but which are actually highly dependent on reading accuracy. As discussed in Chapter 2, reading comprehension tests show a great deal of variability in terms of which underlying skills they are most dependent on (Cutting & Scarborough, 2006; Keenan, et al., 2008; Nation & Snowling, 1997). Some tests, such as the Suffolk Reading Scale (SRS; Hagley, 1987) show a particularly high dependence on decoding ability (Nation & Snowling, 1997). Selecting children with poor comprehension on the basis of such tests is likely to result in children who have concurrent, or potentially even specific, word reading difficulties.

To return to the behavioural outcomes reported in Chapter 6, poor comprehenders were rated as showing significantly higher frequencies of behaviours associated with both working memory deficits and inattention; this was despite a lack of significant behavioural problems associated with hyperactivity, conduct, and interactions with peers, suggesting that poor comprehenders were not just displaying behavioural problems across the board. This specific pattern of behavioural deficits is consistent with an underlying cognitive deficit in working memory, with isolated inattentive symptoms argued to be indicative of a working memory deficit (Gathercole, Alloway, et al., 2008). Experiment 4.1 showed that at a group level poor comprehenders showed deficits in their verbal working memory but

not in their non-verbal working memory. Specific deficits in verbal working memory were attributed to general problems with language processing, rather than an actual memory deficit, rendering the finding of behavioural problems associated with working memory deficits surprising. One possibility to account for these findings is that the problem behaviours on the rating scales that were associated with working memory deficits were also linked more strongly than other problem behaviours with language ability; group differences in these problem behaviours could therefore have been driven by the language difficulties of the poor comprehenders. For example, many of the items in the WMRS (one of the scales on which poor comprehenders showed deficits relative to controls) could potentially be accounted for by underlying problems with language ability (e.g. 'does not respond, or is reluctant to answer when asked direct questions', 'does not follow classroom instructions accurately', 'unable to explain what s/he should be doing in a particular activity when asked'), whereas this seems less possible for many items on the hyperactivity subscale of the CTRS-R (S), a scale on which poor comprehenders showed no deficits relative to controls (e.g. 'restless in the "squirmy" sense', 'runs about or climbs excessively in situations where it is inappropriate', 'leaves seat in classroom or in other situations in which remaining seated is expected').

Alternatively, as discussed above in relation to the finding of broader executive deficits in poor comprehenders, the notion of subgroups of poor comprehenders could be useful in accounting for these findings. Although the majority of poor comprehenders in Experiment 4.1 showed verbal-only working memory deficits (with some showing verbal working memory standard scores that were two standard deviations below their spatial working memory scores), a

subgroup (N = 4) showed significant deficits in both verbal and non-verbal working memory, reflective of a general working memory deficit. It may be therefore that a subgroup of poor comprehenders with 'genuine' working memory deficits were carrying the group differences in problem behaviours associated with working memory reported in Chapter 6; the finding of a relationship between non-verbal, but not verbal, working memory and problem behaviours associated with deficient working memory supported this assertion. Furthermore, of the poor comprehenders who were rated as showing above-average levels of problem behaviours associated with working memory deficits on the WMRS, the majority showed domain-general working memory deficits, and none showed verbal-only working memory deficits. This again supports the idea that the poor comprehenders who have 'genuine' working memory deficits (rather than deficits on working memory tasks that are driven by underlying language impairments) are the ones who are displaying the problem behaviours associated with working memory deficits, and highlights once more the importance of examining results for subgroups of poor comprehenders in future experimental work in this area.

Educational outcomes in poor comprehenders

In terms of educational outcomes, poor comprehenders were rated as having more difficulties than the controls in areas of the curriculum which were likely to be heavily dependent on complex language and comprehension abilities, such as writing composition. By contrast, they were not rated as performing significantly less well than the controls in subjects which do not have a strong language component to

them, such as art. It is not the case that the poor comprehenders were simply impaired in all the more 'academic' areas of the curriculum however, as they showed no deficits relative to controls in terms of teacher ratings of their spelling abilities, most likely as a result of their spared phonological processing ability. It seems probable that poor comprehenders face a double detriment to their educational development. Firstly, the lower level comprehension deficits that drive their poor comprehension, such as weaknesses in language ability or working memory, are likely to directly impact on the ability to learn effectively in the classroom situation. In addition, the poor comprehension that results from these lower level deficits is also likely to have a detrimental effect on academic performance in those subjects that require more complex understanding, as children will be unable to effectively use their reading comprehension skills to learn.

One area of the curriculum that was noted by teachers as being an area of weakness for poor comprehenders was mathematics. In Chapter 7, I speculated that the situation may be more complex than poor comprehenders simply being poor at mathematics across the board. I reported results that showed that they had intact basic arithmetic ability, which was attributed to their spared phonological processing skills. By contrast they showed deficits on a measure of mathematical reasoning, which was more dependent on verbal ability, involving items such as word problems; this was attributed to their non-phonological oral language weaknesses. Regression analyses supported the idea that group differences in verbal ability were playing a key role in the group differences in mathematical reasoning performance. Furthermore, regression analyses using data from a large sample of typically developing children showed that verbal ability was a significant predictor of

mathematical reasoning performance over and above basic arithmetic ability, confirming that verbal ability does play an important role in mathematical reasoning performance. The studies reported in Chapter 7 again highlighted how the cognitive deficits that underlie poor comprehension can impact on wider areas of the curriculum. It seems likely that again, being a poor comprehender could also have an impact in and of itself; to successfully solve the word problem items of the mathematical reasoning task, children need to comprehend the simple narratives that comprise these problems so that they can extract the required arithmetical operation from its verbal surround. Failure to do so would impact on performance, even in the face of excellent arithmetic skills.

Stability of poor comprehension over time

Although not a primary concern of this thesis, another interesting point to consider concerns the stability of the poor comprehender profile over time. Of the 14 poor comprehenders selected for the studies reported in Chapter 4 when they were in Year 3, 13 were available for follow up in Year 5. Ten of them (77%) still demonstrated a clear poor comprehender profile (i.e. they showed a 15 standard score point discrepancy between their decoding and comprehension performance) when re-tested approximately two years later. These findings suggest that children who are having specific comprehension difficulties at the age of 7 are very likely to still be experiencing those difficulties at the age of 9, and ties in with previous findings that have indicated a strong degree of stability to poor comprehension (Cain & Oakhill, 2006). It is likely that this stability exists for a variety of reasons. Firstly,

the cognitive deficits that underpin poor comprehension in these children (e.g. working memory, oral language) are likely to remain stable over time unless they are identified and attempts made to remediate them. As discussed previously in this chapter, a system of identifying the underlying cognitive deficits in each poor comprehender and providing targeted interventions would be an effective one. However, such a system is not currently in place; poor comprehenders go largely unidentified by their teachers, and as a consequence it seems likely that any underlying deficits they have will not be addressed, hence leading to the observed stability of comprehension failure. A second factor that is likely to contribute to children who are poor comprehenders at 7 years old remaining poor comprehenders is that if a child finds it hard to take meaning from what they read they are likely to find reading unrewarding, and hence to read less. Reading less will mean that they lack the benefits that reading brings to the comprehension skills of their typically developing peers (e.g. exposure to new vocabulary), and so will become even poorer by comparison.

Despite evidence that, for many poor comprehenders, their comprehension difficulties remain with them as they progress through primary school, it is still the case that three of the children who were in my poor comprehender sample when they were in Year 3 no longer met the profile of a poor comprehender in Year 5. This could have come about because of two reasons; either, because these children's comprehension performance as assessed in Year 3 was not a genuine reflection of their comprehension ability (i.e. they were not 'genuine' poor comprehenders), or because they *were* poor comprehenders in Year 3 but their problem has ameliorated by some means over the subsequent two years. To turn to the former explanation

first, it is undoubtedly the case that many transitive factors will influence performance on the NARA-II comprehension measure (used throughout this thesis to assess comprehension performance) in addition to comprehension skill. If a child's performance is influenced by one of these transitive factors then an artificial impression could be created of poor comprehension. For example, if a child was tired on the day of testing, their motivation to attempt to answer comprehension questions may be lacking; the much more straightforward, less effortful process of word reading would likely be less affected by such a factor. Using multiple measures of comprehension (e.g., using the newly-developed York Assessment of Reading for Comprehension (YARC; Snowling, et al., 2009) alongside the NARA-II), administered across different sessions on different days, may go some way to limiting the effects of such transient factors on performance and improving further the stability of the poor comprehender profile.

The second explanation for the lack of stability in a subset of the poor comprehenders focuses around a real amelioration of comprehension skills over the course of the two years between test and re-test. It must be noted first however, that despite the fact that the three children in question no longer met criteria for being a poor comprehender, it was still the case that they all showed below average comprehension (gaining standard scores that were below the mean for their age), and that their comprehension scores were lower than their decoding scores, implying that any 'recovery' that they may have made was not absolute. Indeed, the fact that they no longer showed sufficiently low comprehension scores to meet criteria may have been simply an artefact of the error of measurement of the test. Nonetheless, it remains a possibility that there could have been some genuine

improvement in these children's comprehension ability. Although it is impossible to know what might have prompted such improvements at an individual level, one can speculate on factors that may have played a role. It could be the case that these children have compensatory abilities that have allowed them to overcome cognitive deficits that initially drove their poor comprehension. For example, a child with poor oral language could show initial deficits in comprehension, but a real strength in non-verbal intelligence could lead to the development of alternative strategies and approaches that could go some way to overcoming these deficits. Another possibility is that the children have received, or responded successfully to, explicit teaching on reading comprehension administered either in the school, or by parents who have noticed a problem.

A preliminary solution: Early identification and targeted intervention

The findings concerning educational outcomes reported in Chapters 6 and 7 show that by the time children reach Key Stage 2 (7-11 years old), being a poor comprehender is associated with poor performance in a variety of areas of educational development. Furthermore, the demonstrable stability of the poor comprehender profile over time confirms the need for early identification of poor comprehenders, and effective remediation to avoid later wide-ranging, long-lasting educational deficits. The question that arises then is how we identify poor comprehenders at an early enough stage to remediate their difficulties before they impact on educational development, when identifying a poor comprehender typically relies on the child having developed good enough decoding skills for their

comprehension to lag significantly behind. One approach may be to identify poor comprehenders based not on their reading ability profiles but instead on the basis of the cognitive deficits which lead to their poor comprehension and which should be present even before they start to read. Longitudinal studies have begun to identify the profiles of language deficits that are present in poor comprehenders from the time they first start school. Both Catts et al. (2006) and Nation et al. (in press) found that children identified as poor comprehenders either in secondary school or in the later years of primary school showed distinct profiles of language strengths and weaknesses from age 5 onwards, with poor non-phonological language weaknesses, despite intact phonological language skills. This profile of language ability seems to be present from an early age and to endure in poor comprehenders, thus offering a useful indication of vulnerability to poor comprehension if identified in a child at school entry. As discussed previously, the idea of identifying the cognitive deficits that may underlie comprehension weaknesses in each poor comprehender and developing targeted interventions is a useful one. This early intervention approach simply takes this idea one step further by seeking to identify children who are at risk of becoming poor comprehenders based on established profiles of cognitive deficits that are known to predict later reading comprehension problems.

Findings from a recent large-scale intervention study carried out by Clarke and colleagues (Clarke, Snowling, Truelove, & Hulme, in press) showed that intervention to improve oral language skills does have a positive effect on comprehension outcomes, and so suggests a possible avenue for early intervention by this means. As part of a randomized controlled trial designed to explore the impact of three different interventions on reading comprehension skills in children

identified as poor comprehenders, they examined the effect that training oral language skills had on comprehension ability. The oral language training programme targeted various aspects of spoken language, including vocabulary and figurative language, and used the established techniques of Reciprocal Teaching (RT; Palincsar & Brown, 1984) and Multiple Context Learning (MCL; Beck, McKeown, & Kucan, 2002) to maximise the efficacy of the training. It was found that oral language training resulted in both immediate, and sustained, gains in reading comprehension outcomes. Furthermore, these gains were at least partially mediated by the significant gains in expressive vocabulary that resulted from the oral language training. As discussed above, these results are exciting because they would enable an early intervention plan to be put in place for children at risk of becoming poor comprehenders. Those children who meet the language profile identified by Nation et al. (in press) and Catts et al. (2006) as being present from an early age in children who go on to become poor comprehenders could be given an adapted version of the oral language training programme developed by Clarke et al. (in press), with the aim of removing the limitation that their poor oral language skills places on their comprehension development. This pre-emptive intervention strategy, although initially requiring significant outlay by educational services, would probably end up being cost-effective due to the reduction in later spending on remediating the wide range of educational problems associated with being a poor comprehender.

Concluding remarks

To conclude, this thesis has presented evidence that has informed our understanding of aetiological factors that may drive poor comprehension, and has clearly demonstrated the value of exploring the role that underlying language abilities play in determining poor comprehenders' performance on verbal memory tasks. The finding of verbal-only deficits on working memory and suppression tasks has shown that previous theories that have posited domain-general central executive deficits as a fundamental skill weakness in poor comprehenders are incorrect. The need for future research to look for the presence of aetiologically-distinct subgroups in samples of poor comprehenders has also been highlighted, an approach which may go some way to addressing the discrepancies that have been observed in this research, and in previous research with these children. Research presented in this thesis has also revealed the extent to which poor comprehenders' difficulties impact on their behavioural and educational outcomes, thus emphasising the need for early identification and effective intervention.

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Appendices

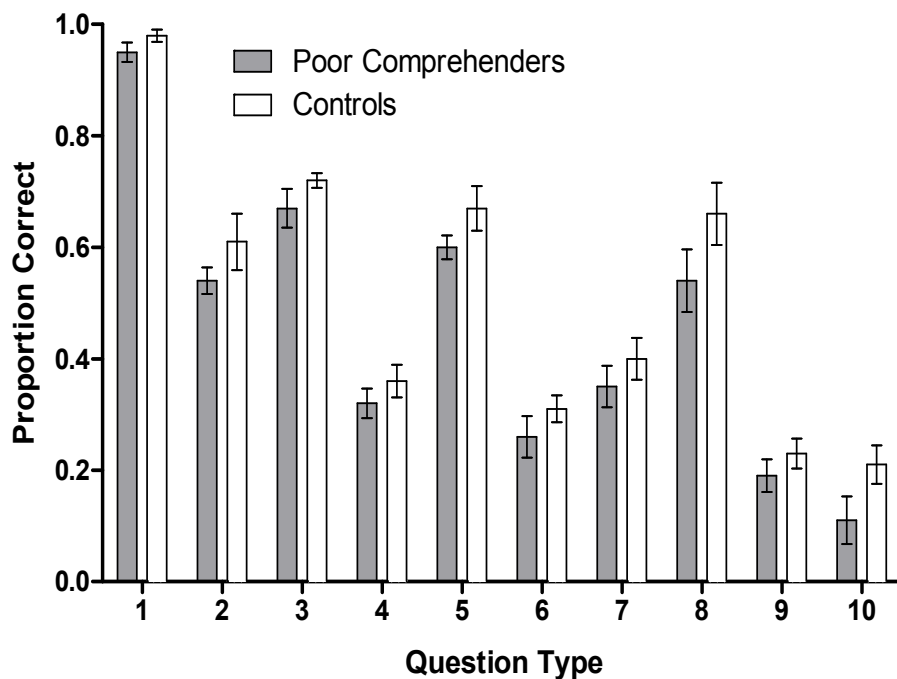
Appendix A: Correlations between working memory and comprehension scores and ratings on the subscales of the CTRS-R(S)

	1.	2.	3.	4.	5.	6.	7.
1. Verbal Working Memory	1.00						
2. Non-verbal Working Memory	.34**	1.00					
3. Reading Comprehension	.46**	.26*	1.00				
4. ADHD	.09	-.17	-.16	1.00			
5. Cognitive problems/ Inattention	-.14	-.38**	-.50**	.62**	1.00		
6. Hyperactivity	-.06	-.11	-.19	.59**	.58**	1.00	
7. Oppositional Behaviour	.04	.07	-.20	.58**	.44**	.66**	1.00

Note: * $p < .05$, ** $p < .01$

Appendix B: Item analysis of mathematical reasoning task

The figure below shows the proportion of correct responses for the poor comprehender and control groups on each of the ten question types specified by the WIAT-II: 1, use whole numbers to describe quantities; 2, use geometric and spatial reasoning to solve problems; 3, use grids and graphs to make comparisons, draw conclusions, or answer questions; 4, create and solve addition, subtraction, multiplication, or division problems; 5, use patterns to solve problems; 6, use non-standard and standard units to measure; 7, solve problems using money; 8, tell time and use time to compare and order events; 9, use quantities less than a whole; 10, use theoretical and experimental probability to draw conclusions, answer questions, and make predictions.



As the figure shows, the controls outperformed the poor comprehenders by a small margin on each of the ten question types. However, none of these differences reached significance (all $ps > .05$), suggesting that no particular sub-group of questions is carrying the main effect of group.

When considering the results of this analysis, it is important to recognize the limitations that are placed on it by the structure and procedure of the mathematical reasoning measure. Firstly, children discontinue the test after they make six consecutive incorrect responses, meaning that the two groups of participants were not attempting the same number of questions overall. Moreover, the different types of questions are not evenly distributed throughout the test, with some types weighted more heavily towards the start, and some towards the end. Taken together these two aspects of the mathematical reasoning task mean that results of the items analysis should be treated with a degree of caution.