Working Memory capacity in English monolingual and Afrikaans/English bilingual Grade 1 learners

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“Learning to read is indisputably the premier academic achievement of early schooling. It prepares children for their educational futures and is the key to the possibilities that their futures hold for them. Thus, if knowing two languages at the time that literacy is introduced, or learning to read in a language that is not the child’s dominant one, or acquiring literacy simultaneously in two languages affects the outcome of literacy instruction, then it would be important to know that”

(Bialystok, Luk & Kwan, 2005, p. 43).

Declaration

I hereby declare that this research report is my own unaided independent work. It has not been submitted before for any other degree or examination at this or any other academic institution, nor has it been published in any form.

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Abstract

Many learners in South Africa first encounter English when it is used as a medium of instruction at the start of formal schooling. This has ramifications for literacy acquisition and academic performance. Working memory is responsible for distributing cognitive resources among the various processing and storage tasks. It has been pivotal in many cognitive theories linking working memory to academic skills like reading comprehension and mathematics ability. In addition, research indicates that both Short Term Memory (STM) and Working Memory (WM) are instrumental in cognitive processing but that in bilinguals their roles are more complex than they are in monolinguals. This research explored the capacity of WM and the role of WM in reading comprehension and mathematical ability in two South African populations: a monolingual English group (L1) and a bilingual Afrikaans/English group (L2). No significant differences were found in the WM capacity of the two groups. In the second part of the study it was found that both reading comprehension and bilingualism depend on the same verbal domain resources of WM, which act as constraining factors for the L2 group. However, in the L1 group, there appeared to be less competition for verbal domain resources and more for visuospatial resources probably due to the phase of literacy acquisition these learners were in. In terms of WM and mathematical ability it was found that bilinguals exceed their storage capacity (STM) before they run out of processing capacity (WM). STM therefore is a constraining factor for this group. However, for the L1 group, visuospatial processing is the constraining factor. The research concludes that bilinguals use WM both for semantic processing of their non-dominant language and for complex cognitive processing. While the WM capacity for monolingual and bilingual learners appears to be equivalent, the way the resources are allocated during cognitive tasks differ.

Keywords: bilingualism, working memory

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1 Introduction

This research investigated how monolingual English speaking learners (L1) compared to bilingual Afrikaans/English learners (L2) in terms of working memory and complex cognitive functioning. Firstly, learners in the two groups were compared on how they performed in the Automated Working Memory Assessment (AWMA), a computerised instrument developed by Alloway, Gathercole and Pickering (2004). Although the AWMA has been used extensively in the UK, where it was developed, its use in South Africa is limited. In addition, AWMA is well documented on monolingual populations but not in bilingual populations.

Research in the field of psycholinguistics focussing on cognitive processing in bilinguals (da Costa Pinto, 1991; de Groot, 1996; McElree, Jia & Litvak, 2000; Thorn & Gathercole, 1999) and the role played by working memory with regards to cognitive processing (Ardila, 2003; Gutierrez-Clellen, Calderon & Weismer, 2004) indicated that Short Term Memory (STM) and Working Memory (WM) were both instrumental in cognitive processing in bilinguals but that their roles were different and generally more complex than they were in monolinguals. However, the specific manner in which the use of STM and WM differed between monolinguals and bilinguals was not always clear and yet this might impact on the way in which bilingual learners acquire new knowledge or use existing knowledge and the way bilingual learners perform on assessments gauging their scholastic progress.

South Africa, for example, is a multi-cultural country with 11 official languages. Thus the occurrence of bilingualism and multilingualism is more common than monolingualism. According to Campbell, Dollaghan, Needleman and Janosky (1997), where test-takers differed in their exposure to concepts or words, which is common with learners from differing linguistic, cultural, ethnic and socio-economic backgrounds, any assessment tool that aimed to tap the child's existing knowledge was at risk of identifying a difference in functioning rather than a disorder. Hence, poor performance might have been the result of a lack of language proficiency. This is particularly relevant to tests that rely heavily on vocabulary knowledge which includes most tests of intellectual and language ability. While acknowledging the difficulty of creating tests that are absolutely bias-free, the authors proposed the use of processing-dependent tests which were more dependent on psycholinguistic processing and less so on language knowledge.

Furthermore, Gathercole, Pickering, Knight and Stegmann (2004) noted that one way to reduce the bias between previous knowledge and basic cognitive capacity to learn may be to use fluid assessments of cognitive processing knowledge in addition to tests of crystallised knowledge. Bialystok, Craik, Klein and Viswanathan (2004) explained that measures of fluid intelligence related to executive control processes whereas crystallised intelligence measures related to well-learned knowledge and habitual procedures. Hence fluid measures assessed the capacity to perform cognitive operations akin to those involved in complex learning situations which lead to the acquisition of skills in mathematics and literacy. However, fluid measures had the advantage of using tasks and materials that were equally unfamiliar to all the test-takers, of being less influenced by environmental and demographic factors like ethnic background (Campbell et al., 1997) or maternal education level. In this fundamental way, fluid measures differed from measures of crystallised knowledge. In addition, measures of working memory capacity have been shown to correlate positively with indicators of general fluid intelligence such as Raven's Progressive Matrices (Conway, Cowan, Bunting, Theriault & Minkoff, 2002; Engle, Tuholski, Laughlin & Conway, 1999). Thus an instrument like the AWMA which measures working memory capacity could be used to gauge academic ability while simultaneously reducing bias in bilingual populations. In addition, examining the results of the AWMA might in and of itself provide valuable information as to how STM and WM use differs during cognitive processing in monolinguals and bilinguals.

With this in mind a comparison of English speaking learners (L1) and bilingual Afrikaans/English learners (L2) through use of an instrument such as the AWMA, which measures WM (processing and storage) and STM (storage only), was conceived. The AWMA tasks and materials were equally unfamiliar to all the test-takers and were therefore less likely to be influenced by environmental and demographic factors like ethnic background or socioeconomic status.

WM has been shown to be a predictor of progress towards early learning goals of literacy and numeracy (Alloway, Gathercole, Adams, Willis, Eaglen, & Lamont, 2005; Gathercole et al., 2004). Research conducted with monolingual adults indicated a correlation between WM task performance and reading and listening comprehension (Baddeley, 1986; Campbell, et al., 1997; Cowan, 1996; Daneman & Carpenter, 1980; Just & Carpenter, 1992; Weismer, Evans & Hesketh, 1999) and pointed to the crucial role played by WM in both calculation and the solving of arithmetic word problems

(Bull & Scerif, 2001; Fürst & Hitch, 2000; Gathercole et al., 2004; Hitch, 1978; Logie & Baddeley, 1987). However, most of the research linking WM to academic performance has been done with monolingual learners and little is known about how this would compare to South African learners who are often bilingual or multilingual.

To address the issue of how bilingual South African learners would fare in measures of memory compared to their monolingual counterparts a total of 61 Grade 1 learners from several English medium schools in Gauteng, South Africa were assessed using the AWMA. The aim was to determine whether different patterns of STM and WM usage could be discerned for the monolingual and bilingual groups.

The two groups were also assessed on their performance in tests of reading comprehension and mathematical ability with a view to comparing the performance of the two groups in terms of the AWMA measure and establishing whether a relationship existed between memory capacity and performance in reading comprehension and mathematics. The ultimate aim was to determine whether the relationship between memory capacity and reading comprehension and mathematics ability was different for the two groups. Thus the research brought together findings from the cognitive and psycholinguistic fields within psychology and extended current knowledge while also addressing an important challenge for education in South Africa.

If English monolingual and Afrikaans/English bilingual Grade 1 learners differed in their memory capacities then analysis of the various subtests of the AWMA could have provided valuable insight into patterns of STM and WM usage in the two groups. On the other hand, if the two groups had no significant differences in their memory capacities, then it would have followed from previous research that they would do equally well in scholastic domains like reading comprehension and mathematics. However, if their performance in the cognitive processing tasks was also different and other possible factors were controlled for, then it would indicate that the acquisition and/or use of a second language impacted on scholastic performance.

The research report is structured as follows. The remainder of this chapter takes the form of a literature review which details relevant studies and pertinent findings and concludes with a set of research questions. The Methods chapter details the research design, the sample, procedures and instruments that were used in the study. The Results chapter follows and indicates how the data was analysed and the results of the statistical procedures conducted. The Discussion chapter outlines the explanations posited for the results of this study as well as the implications of the results obtained.

2 Literature Review

The literature review presented here necessarily covers a range of theoretical and conceptual areas relevant to this study. In order to facilitate comprehension, it is laid out as follows. Firstly, competing models of Working Memory (WM) are documented together with salient studies and findings pertaining to the different conceptualisations of WM. Next the link from past research between WM and academic ability is outlined. This section covers reading, reading comprehension and mathematics performance. A section documenting research into the field of bilingualism is presented next. The studies referred to clarify the role played by WM in bilinguals and how this might be different in monolinguals. A rationale for the study and a list of the research questions, derived from the research aims, conclude this chapter.

2.1 Domain-general Working Memory Model: Baddeley and Hitch

The term “working memory” was adopted by Baddeley and Hitch (1974) to accentuate the differences between their conceptual understanding of short term memory (STM) having 3 separate components compared to the mainstream understanding of STM at the time which was understood to be a unitary construct. The authors observed a number of neuro-psychologically damaged patients who had impaired storage ability. Given secondary tasks designed to deplete the STM available to a subject, these patients retained the ability to perform simple cognitive tasks which refuted the notion of a unitary model. The authors therefore proposed a new memory model called “working memory” to describe a system for the temporary storage and manipulation of information during the performance of a range of cognitive tasks including comprehension, learning and reasoning (Baddeley, 1986; Baddeley, 2000a; Cowan, 1996).

The three proposed components comprised a “central executive” of limited capacity which directed the processing of information. It, in turn, was assisted by, and employed, two subsidiary slave systems: the “phonological loop” and the “visuo-spatial sketchpad” which essentially performed storage functions (Baddeley, 2000a; Logie, 1999). (See Figure 1, p.11)

In later research Baddeley (1986) showed that the **phonological loop** component could be further broken down into the “phonological store” and the “articulatory rehearsal process”. The phonological store was responsible for the temporary storage of acoustic or speech-based information but these memory traces appeared to fade and become irretrievable after about 1.5 to 2 seconds. However, if the memory trace was read into the articulatory rehearsal process, it could be fed back into the phonological store thus “refreshing” the fading memory trace. In this way the memory trace could be re-articulated. This is the process underlying the concept of *subvocal rehearsal* (Vallar & Baddeley, 1984). Alternately, incomplete representations of a word in the phonological loop can be primed from prior lexical knowledge (Gathercole & Adams, 1994) through *redintegration.* Here past knowledge is used to fill the gaps left by the lost memory trace. In addition to refreshing memory traces, the articulatory rehearsal process is also able to convert written material into phonological code which it then passes to the phonological store (Baddeley, 1996b). In this way, information gained from visual input (reading printed text) can be processed and stored and reading and comprehension is thus made possible.

It was postulated that the phonological loop evolved in order to facilitate the acquisition of language (Baddeley, 1996b; Baddeley, Gathercole & Papagno, 1998) and is implicated whether the language being acquired is the first or subsequent language. Language acquisition is enabled in two ways: firstly, the phonological store allows for the temporary representation of new phonemes and secondly, the articulatory rehearsal process allows learning through rehearsal of those phonemes (Baddeley, 2003). The capacity of the phonological store has thus also been shown to be a good predictor of second language acquisition in both children and adults (Baddeley, 1996b; Papagno, Valentine & Baddeley, 1991).

The **Visuospatial Sketchpad** is less clearly understood compared to the verbal subsystem partly due to its greater complexity. It also has a fixed capacity usually limited to three to four objects (Baddeley, 2003). Although it is common practice to refer to "visuospatial" as a single entity, neuropsychological studies indicated that these are, in fact, two distinct yet interacting subsystems (Baddeley, 1996b; Baddeley, 2003; Della Sala et al., cited in Pickering, 2001). Research also suggested that the visual and spatial processes draw on distinct cognitive resources (Pickering, 2001). In addition, Logie and Pearson (1997, as cited in Pickering, Gathercole, Hall & Lloyd, 2001) found that the visual part of the visuo-spatial sketchpad was not only distinct from the spatial aspect but developed faster in children than the spatial part of the sketchpad. Development of some parts of the system ahead of other parts is called “developmental fractionation” and supports the idea of the fractionation of the WM system into different subcomponents.

The purpose of the visuospatial sketchpad is to hold and manipulate visuospatial representations (Logie, 1999; Baddeley, 2003). Visuospatial representations can also be set up from verbal cues. This is useful when a person is listening to a mathematical problem or reading a descriptive passage. Verbal recall was found to be enhanced by the use of visual imagery but concurrent visual activity affected the quality of verbal recall (Baddeley, 1996b). This suggested that visuospatial resources were available to be used for verbal tasks unless there was demand for the resource by a concurrent visuospatial task. In such cases visuospatial resources were directed to those visuospatial tasks. Research also showed that while older children and adults tended to rely on a verbal form of coding while manipulating visual material (Cowan, 1996), younger children (below 10 years old) tended to use visual coding to process visual material (Brandimonte & Gerbino, 1992; Hitch, Halliday, Schaffstaal & Schraagen, 1988) suggesting developmental changes in how this resource is utilised.

In the original model, Baddeley and Hitch (1974) described the **Central Executive** (CE) as a general processing construct that dealt with any complex issue that could not be directly assigned to one of the two specialist sub-systems (the phonological loop or the visuospatial sketchpad). It was therefore envisaged as a general pool of resources that could either perform control functions or provide supplementary storage to the slave systems (Barnard, Scott & May, 2001).

Later versions of the WM model emphasised the executive function role of the CE by incorporating the Norman and Shallice (1986) model of attentional control (Baddeley, 1996a) which explained control as being either dictated by habit patterns, or schemas, that came into effect due to cues in the environment or by new schemas in situations where routine control was insufficient. Thus the CE was instrumental in higher cognitive functions where it was capable of focussing attention, dividing attention and switching attention as the task demanded. It was also responsible for controlling and co-ordinating the two slave subsystems and activating information in Long Term Memory (LTM) (Baddeley, 1986, 1996a; Barnard et al., 2001).

The **episodic buffer** is a limited capacity store that is controlled by the CE. Although it can be conceptualised as the storage part of the CE, the episodic buffer is essentially regarded as a separate subsystem. It enables information from the phonological and visuo-spatial subsystems to be integrated and to interact (Baddeley, 2000b). The episodic buffer is also responsible for accessing and retrieving information from LTM in order to supplement information currently in WM. In this way, WM affords the opportunity to consciously manipulate information and generate new representations from old information (Baddeley, 2000b; Logie, 1999).

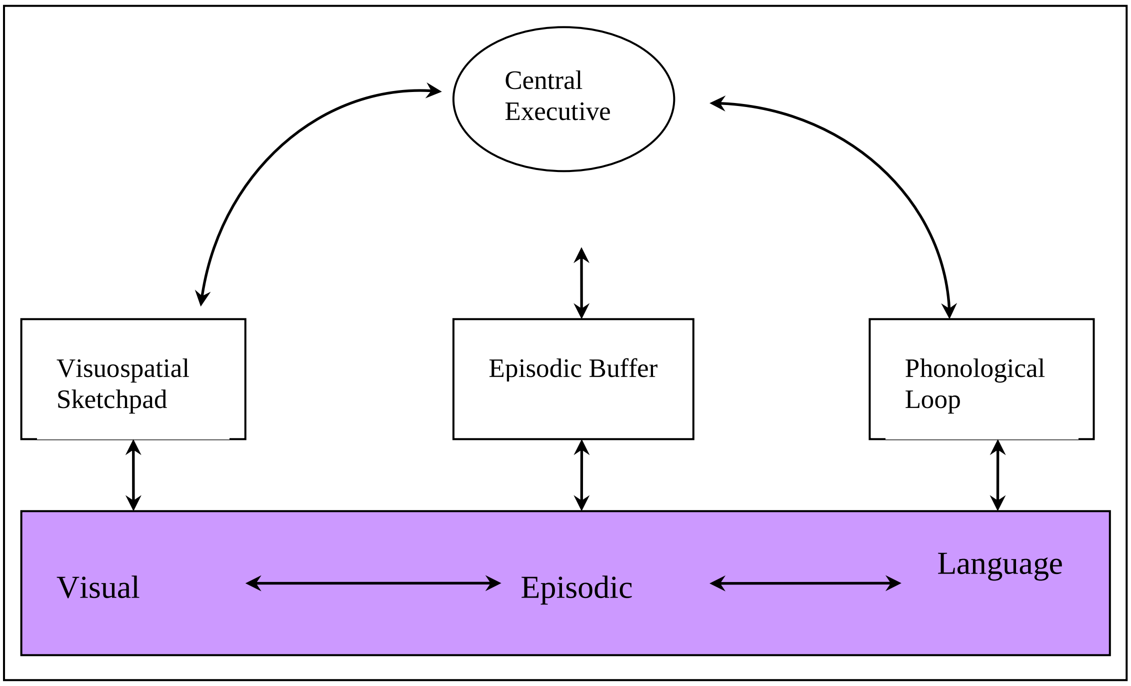

Figure 1: Baddeley's revised WM model. Shaded areas are representative of 'crystalised' cognitive systems capable of accumulating long-term knowledge. Unshaded areas are assumed to be 'fluid' capacities and are unchanged by learning other than indirectly through the 'crystalised' cognitive systems. (Baddeley, 2000b, p. 418; Baddeley, 2003, p. 835)

The domain general WM model referred to above was described in great detail partly to facilitate understanding of the terminology used and to explain the way the components work. In addition many other models are based on the domain general WM model or arose in response to critique of it. The Automated Working Memory Assessment (AWMA) is an example of work that extended the original model.

In 1995, Gathercole and Pickering started developing a test battery to provide an analysis of WM functioning in children and adults (Gathercole & Pickering, 2000a; Pickering, 2006). The researchers selected a set of tests from a range of sources with which to measure performance in the phonological loop, the visuospatial sketchpad and the CE of the WM system. According to Gathercole and Pickering (2000b) the tasks included in the battery were based on Baddeley and Hitch's (1974) theoretical account of WM and the large body of research that was subsequently stimulated. This model of WM located the combined processing and storage aspects of WM within the CE which had consistently been associated with a number of complex cognitive abilities such as language and reading comprehension, reading and arithmetic. Thus the tasks in the battery included WM tasks, involving simultaneous storage and processing of information, as well as STM tasks involving storage of information only. Taken together the authors felt that these provided a comprehensive measure of memory skills.

The prototype battery was administered to children aged 6 and 7 years of age and was called the Working Memory Test Battery for Children (WMTB-C). All subtests of the battery were designed to measure span of the selected domain. Thus difficulty level increased in consecutive sets until performance broke down. In analysing the data collected during the standardisation procedure, it was found that 9 of the subtests represented 3 distinct but related aspects of memory performance: verbal WM, verbal STM and visuo-spatial STM. This was confirmed by factor analysis showing that the subtests were associated with three different constructs of memory (Gathercole & Pickering, 2000b; Pickering, 2006).

Strikingly absent from the WMTB-C battery was a means of testing visuo-spatial WM. Pickering (2006) explained that tests of non-verbal CE functioning were not available to them at the time but were included in the automated and extended version of the WMTB-C called the Automated Working Memory Assessment (AWMA) (Alloway et al., 2004). Thus the AWMA battery included tests designed to measure verbal WM (V-WM), visuospatial WM (VS-WM), verbal STM (V-STM) and visuospatial STM (VS-STM).

For the present study the term *working memory system* is used to refer to the domain-general model of Baddeley and Hitch (1974). In this model the combined storage-and-processing aspects are located within the CE and storage-only aspects are located in the two slave systems. However, for purposes of analysis individual scores are reported as 4 constituent parts relating to function type (combined storage-and-processing is WM while storage-only is STM) and domain (verbal or visuospatial). Thus the four scores reported are for V-WM, VS-WM, V-STM and VS-STM as defined by Gathercole & Pickering (2000b) since the AWMA measure (Alloway et al., 2004) utilised in this study reported a score for each element.

2.2 Domain-Specific Working Memory Model: Just and Carpenter

Another model of working memory was proposed by Just, Carpenter and colleagues (Daneman & Carpenter, 1980; Just & Carpenter, 1992; Weismer, Evans & Hesketh, 1999). In 1992 Just and Carpenter introduced "The Capacity Theory of comprehension". The authors posited that WM played a critical role in storing the intermediate and final products of the computations involved in either reading a text or listening to discourse and that cognitive capacity constrained comprehension more for some people than for others. In this theory the term ***working memory for language (WMFL)*** referred to a set of processes and resources that specifically performed language comprehension. The authors agreed that WMFL was instrumental in both processing and storage and that the latter included the storage of final or partial results of complex sequential computations. However, they believed that rather than separate components for storage and processing, WMFL worked as one unit that could flexibly deploy its resources to either processing or storage depending on the task. *WMFL* in this theory corresponded roughly with the CE, in the domain-general model, that dealt with language comprehension and specifically excluded modality-specific buffers (Just & Carpenter, 1992).

Just and Carpenter (1992) proposed that both storage and processing were mediated by activation. Each element (word, concept or grammatical structure) in comprehension had an associated activation level. During comprehension, information became activated via encoding from written or spoken text, through being generated by a cognitive computation or through being retrieved from long term memory. That particular element would remain in WMFL to be further operated on or recalled as long as its activation level stayed above some minimum threshold (Daneman & Carpenter, 1980; Just & Carpenter, 1992). Since activation was the commodity that enabled maintenance of information as well as being the factor that determined whether a computation took place or not, Just and Carpenter (1992) suggested that the architecture of WMFL should reflect that the two functions (processing and storage) were drawing on a common pool of resources. They felt that there were both conceptual and empirical reasons for including the dual role of WMFL within a single system. At the same time, the authors argued that the focus of "The Capacity Theory of comprehension" was on the issue of capacity rather than on architecture. *Capacity* referred to the maximum amount of activation that was available in WMFL to support either function (storage or processing). The authors argued that comprehension often involved parallel processing which generated partial products which created more activation. Where it seemed that the maximum activation was about to be exceeded, activation was scaled back proportionally. In other words, when the task demands were high (due either to storage or processing needs) processing slowed down *and* some partial results that were being held were lost. There was thus a trading relation between storage and processing. Just and Carpenter (1992) tested "The Capacity Theory of comprehension" in a computer simulation using a model called CC READER and confirmed their findings.

The theory proposed by Just and Carpenter (1992) was based on the work of Kahneman's (1973, as cited in Just & Carpenter, 1992) capacity theory of attention and the results of the study by Daneman and Carpenter (1980). Kahneman's explanation for individual differences in language abilities was that a person with a larger capacity for language was able to draw on a larger supply of resources (total capacity explanation). Daneman and Carpenter (1980) accounted for individual differences with a processing efficiency explanation. Just and Carpenter (1992) stated that these two explanations were mutually compatible in their theory.

The implications of this theory for a model of WM were as follows. A domain-specific WM model focused on a global set of resources, which supported language computations (both lexical and syntactic processing and storage) as opposed to the phonological loop. In other words the functions of storage and processing were managed within one unit and this unit was specialised for language comprehension.

Shah and Miyake (1996) extended the work of Just and Carpenter (1992) and elucidated the domain specific model by describing it as "consisting of flexibly deployable, limited cognitive resources" (Shah & Miyake, 1996, p. 4). The authors tested 54 undergraduate students using the reading span task developed by Daneman and Carpenter (1980) as well as a spatial span task that they designed to be analogous to the reading span task in that it required simultaneous processing and storage.

Shah and Miyake (1996) found that concurrent processing requirements had a detrimental effect on the maintenance of same-modality information but not on different-modality information. They also demonstrated that the spatial span task correlated well with participants' performance on spatial tasks but not with language tasks. The reading span task, in turn, correlated well with language tasks but not with spatial tasks. Their results were thus consistent with those of Just and Carpenter (1992) but extended the theory to include the spatial domain. At the same time, Shah and Miyake (1996) pointed out that the domain specific model did not deny the existence of peripheral subsystems but that they saw the role of these subsystems as being passive, temporary buffers with only a limited role in actively manipulating and maintaining information during spatial thinking and language comprehension.

Studies have supported both the domain general model (Baddeley, 1983; Gathercole & Adams, 1994; Gathercole & Baddeley, 1993; Vallar & Baddeley, 1984; Wilson & Swanson, 2001) and the domain specific model (Daneman & Carpenter, 1980; Just & Carpenter, 1992; Miyake, Carpenter & Just, 1995; Shah & Miyake, 1996) but researchers have also challenged both the Baddeley & Hitch model (Neath, Surprenant & LeCompte, 1998) and Just and Carpenter's model (Fedorenko, Gibson & Rohde, 2006; Martin, 1995; Waters & Caplan; 1996).

In a comparison of theoretical models of WM, Miyake and Shah (1999, as cited in Barnard et al., 2001) outlined several common themes. Most noteworthy was that both long term knowledge and executive control were largely accepted as being instrumental in gauging WM performance. In addition, they observed that the limitations of WM capacity are widely held to be determined by multiple factors but that one of the salient features of WM, regardless of the model preferred, was that it had a limited capacity. The reason for this was that processing and storage occurred in real time. This meant that items being processed or stored were being rehearsed as they were being input or retrieved from long term memory. As the number of items being held in WM increased, the subject would reach a point at which the first item being rehearsed had faded before it could be rehearsed because there were so many other items to be rehearsed (Towse, Hitch & Hutton, 1998). Alternately, the activation levels were exceeded and some items in memory were discarded. Thus the fundamental difference between various WM models lay in how their architecture was conceptualised and not in their function of processing and storage.

WM capacity is typically measured using complex memory span tasks (also known as dual tasks) which require the individual to engage in some immediate processing while also storing information for later recall (Daneman & Carpenter, 1980; Gathercole & Alloway, 2004). In the domain general model these tests were designed to measure CE functioning and were therefore taken to be indicative of WM capacity (Pickering, 2006) since performance on working memory measures was constrained by WM capacity (Gathercole & Alloway, 2004). In contrast, STM tasks only measured storage capacity. In such tasks, the individual had to immediately recall a sequence of verbal or visuospatial information in the same order that it had been presented (Alloway, 2006). Digit span and word span, which are discussed below, are tests of verbal STM capacity. Subtests of the AWMA like the Mazes Memory and Dot Matrix are indicative of visuospatial STM capacity (Alloway et al., 2004)

Digit span refers to the number of digits that can be successfully recalled and measures phonological loop capacity or verbal STM (Pickering, 2006). Digit span differs significantly among speakers of different languages. Ellis (1992, as cited in Ardila, 2003) found that Welsh/English bilingual children had a greater digit span in English compared to Welsh. However, Welsh digit names tend to have longer vowel sounds and hence take longer to articulate than their English counterparts (da Costa Pinto, 1991). Hence more English digit names could be repeated mentally which lead to more being stored and recalled and which, in turn, indicated a greater digit span. Longer digit spans were reported for Chinese speaking individuals and Chinese digit names are correspondingly shorter (Ardila, 2003; da Costa Pinto, 1991). da Costa Pinto (1991) also found that extensive previous experience and practice of digits had an effect on digit span. Thorn and Gathercole (1999) concurred that familiarity with a language is beneficial for the short term storage of material in that language.

One of the earliest and most extensively used measures to date was based on the Capacity Model proposed by Daneman and Carpenter (1980) which was discussed earlier. Daneman and Carpenter (1980) found that WM was more or less the same for different people but different people, through the use of different strategies, for example, appeared to have more capacity because they were able to use their WM more efficiently. Interestingly, Ardila (2003) stated that while the word span and digit span depend on the specific language; the number of "semantic units" that could be processed was "probably equivalent across languages" (Ardila, 2003, p. 237).

Towse and Hitch (1995, as cited in Towse et al., 1998) proposed that working memory capacity was subject to developmental changes and that young children may engage in *task-switching* (alternating between processing and storage). They argued that slower processing extends the time over which memory items may be forgotten. Towse et al. (1998) studied 67 children between the ages of 6 and 10 years of age. They found non disruptive effects of concurrent storage load on processing. Their explanation was that either storage and processing did not compete at the same time in memory or that storage and processing drew on separate dedicated systems. The authors proposed a possible developmental progression away from *task-switching* in early childhood to *resource sharing* strategies in adults. Resource sharing occurs when the same resource can be flexibly allocated to either storage or processing and implies a trade-off between processing and storage demands. The results were replicated by Barrouillet and Camos (2001).

In another study Lanfranchi and Swanson (2005) found no differences in WM performance or STM performance between their L1 and L2 groups who were in Grade 1. They concluded that WM and STM operated primarily as language independent systems at the level of Grade 1. However, in Grade 2 the pattern changed and STM was shown to be language dependent while WM remained language independent.

In summary there appeared to be consensus on the limited capacity of WM within an individual and on the differences in capacity among individuals (Chiappe, Hasher & Siegel, 2000; Christoffels, de Groot & Kroll, 2006; Conway & Engle, 1996; Daneman & Carpenter, 1980; Engle, Cantor & Carullo, 1992; Just & Carpenter, 1992). One of the questions addressed by the present study was whether there would be a difference in memory capacity between the monolingual group and the bilingual group and, if so, what the nature of this difference would be.

2.3 Academic ability and Working Memory

2.3.1 Development of Working Memory in children

Developmental research indicated that there was a domain general processing system and domain specific storage systems in place from about the age of 4 years (Gathercole & Pickering, 2000a). This tripartite structure of WM also seemed to remain consistent until about the age of 15 years but Alloway, Gathercole and Pickering (2006) found that WM capacity displayed a steady developmental increase from about 5 years of age till about 15 years of age. In fact, WM capacity increased about threefold in this period with the advent of rehearsal processes being postulated as the chief source of developmental change in verbal memory span (Gathercole & Adams, 1994). At around 15 years of age, adult levels of performance were typically reached (Alloway, Gathercole & Pickering, 2006; Gathercole & Alloway, 2004). The authors noted, however, that WM capacity varied widely among children of the same age.

Hitch (1990, as cited in Pickering et al., 2001) found that cognitive functions did not mature at the same rate in children since they were carried out by different components. This principle is known as ’developmental fractionation’ and was replicated in the study by Pickering et al. (2001).

In a longitudinal study of young children, Gathercole & Adams (1994) found that subvocal rehearsal emerged for the group somewhere between 4 and 5 years of age. Articulation rate of spoken language is taken to reflect the speed of subvocal rehearsal. Increased subvocal rehearsal, in turn, is taken to be an indication of memory span. As explicit articulation increased across the childhood years with increasing familiarity with language, memory span showed a corresponding increase. However, subvocal rehearsal strategies employed by young children differed markedly from those used by older children and adults. The authors also found evidence for the use of stored phonological long term knowledge to supplement and boost immediate memory. For unfamiliar words this served to relieve sole dependence on phonological working memory for the maintenance of an unfamiliar lexical sequence.

2.3.2 Early Reading Acquisition

The LaBerge-Samuels model

The LaBerge-Samuels (1974) model of automatic information processing in reading used the concept of *automaticity* to explain why fluent readers were capable of decoding and comprehending text with ease while beginner readers had difficulty. Fundamental to the model is the concept of attention which is of limited capacity. Learning to read requires considerable attention. A beginner reader, therefore, compensates by switching attention alternately from decoding to comprehension as they read. Thus only one task is being done at a time. Fluent readers, however, are able to decode automatically and hence can focus all attention on comprehension. Decoding and comprehension is therefore done simultaneously. *Automaticity* is achieved when the reader is able to process information with little attention (Samuels, 1994).

Four components are identified for information processing in the LaBerge-Samuels (1974) model. These are Visual Memory, Phonological Memory, Episodic Memory and Semantic Memory. The strength of the model lies in it's depiction of the direction of information flow which is non-linear. Different readers use the same components in different ways at different times and to different extents depending on their level of reading skill. According to the model, a reader first processes visual features of the print, like lines and curves, which are then processed into letter formations, spelling pattern codes like "sh" and "th" and finally into word codes (Samuels, 1994). A beginner reader would therefore use more of this component than a fluent reader.

Similarly, the acoustic units in Phonological Memory are features, phonemes, syllables and words (Samuels, 1994). Readers of differing skill will use this component as well as Episodic Memory and Semantic Memory differently.

The Ehri model

In another model Ehri (2005) identified 3 stages in becoming a fluent reader. In the *pre-alphabetic stage* readers depend heavily on visual clues and learn visual spellings more easily than phonetic spellings since they lacked an adequate knowledge of letters. The next stage is the *partial alphabetic phase*. Here readers were only able to hold in mind partial representations of words and their ability to link visual form to pronunciation was functional but not fully developed. In the *full alphabetic phase*, readers had a good grasp of grapheme-phoneme relationship and these words could become bonded to pronunciations in memory. At this stage the reader was able to 'sight' read.

Readers read familiar words by accessing them in memory. This is called 'sight word' reading and relates to the LaBerge-Samuels concept of *automaticity*. However, in the early phases of learning to read, the process of learning sight words involves forming connections between graphemes and phonemes to form links between the spelling of the word to its pronunciation and to it's meaning in memory (Ehri, 2005). For unfamiliar words other strategies were used: *Decoding* when the reader sounded out and blended graphemes into phonemes; *analogizing* when known words were used to decipher new words; and *prediction* when the reader used the context and letter clues to guess the word (Ehri, 2005). Fluent readers also resort to these strategies when unfamiliar words are encountered (Samuels, 1994).

Van der Leij and Morfidi (2006) pointed out that the reader needed to identify the link between phonology and the written form of words. *Phonological coding*, the ability to use speech codes to represent information in the form of words and parts of words, and *phoneme awareness*, the conceptual understanding that spoken words are made up of individual phonemes or speech sounds, are two skills noted in the initial phases of learning to read when individual words are decoded by effortful translation of each grapheme-phoneme combination (Daneman & Carpenter, 1980; Van der Leij & Morfidi, 2006). Second language speakers often experienced a lack of fit between their phonological representations and the phonological structure of the new language they were trying to learn. Hence, their verbal STM often appeared limited in the second language (Chiappe, Siegel & Wade-Woolley , 2002) but this was often due to lack of proficiency in the second language.

2.3.3 Working Memory and Comprehension

Research conducted with monolingual adults indicated a correlation between WM, task performance and reading and listening comprehension (Baddeley, 1986; Campbell, Dollaghan, Needleman & Janosky, 1997; Cowan, 1996; Daneman & Carpenter, 1980; Just & Carpenter, 1992; Weismer, Evans & Hesketh, 1999). Gathercole et al. (2004) indicated, however, that the contribution of WM to scholastic attainment varies considerably across the school years with WM having a greater influence on children's emerging literary skills during the early years of learning to read and write. In other words, the capacity to simultaneously store and process information constrained the successful acquisition of literacy skills during the early school years.

It has been claimed that working memory plays a crucial role in reading and the comprehension of both auditory and written language because of the complex skills involved. Each word or sentence that has been heard or read has to be stored until it has been syntactically analysed and a system is needed to co-ordinate the various aspects of reading comprehension (Baddeley & Hitch, 1974; Vukovic & Siegel, 2006). In reading comprehension, the reader must simultaneously extract and decode words, interpret the meaning of individual words, integrate the meanings of several related words in the text, store the meanings of the words already read and use those to make inferences about the text, self monitor meanings already allocated and correct those meanings that are incongruent with the text (Baddeley & Wilson, 1988; Just & Carpenter, 1992; Vukovic & Siegel, 2006). STM and WM are needed for comprehension and WM is essential for storing both the intermediate computations in this process as well as the final product. Hence deficits in working memory could impact on comprehension at any stage of the reading or the comprehension process.

Evidence in support of the importance of STM and WM for comprehension has been predominantly from three types of studies: (1) dual task experiments like those conducted by Baddeley and Hitch (1974) where a secondary task assumed to consume WM resources is shown to interfere with comprehension; (2) correlation studies like that conducted by Daneman and Carpenter (1980) where individual differences in WM are shown to be related to comprehension: and (3) neuropsychological studies where the comprehension of patients displaying some specific WM deficit is studied (Baddeley & Wilson, 1988).

One of the earliest and most extensively used measures to date is based on the Capacity Model proposed by Daneman and Carpenter (1980) who developed a WM task which required simultaneous storage and manipulation of information to measure WM span. The motivation for the research was that STM spans had been found to have only weak correlations with cognitive activities like comprehension and reasoning. Daneman and Carpenter (1980) reasoned that the correlations would be higher if the tasks required both processing and storage and therefore developed a WM span measure. In this task, participants listened to sets of sentences. At the end of each sentence the subject had to verify whether the sentence was true or false (processing demands). At the end of each set of sentences, the subject had to recall the last word of each sentence (storage demands). The authors concluded that each subject's "span task reflected working memory capacity and that this capacity was a crucial source of individual differences in language comprehension" (Daneman & Carpenter, 1980, p. 463).

One explanation that the authors advanced for this observation is that high- and low-span readers differed in the efficiency with which they made computations – a process they called "chunking" (Daneman & Carpenter, 1980, p. 464). In this process, the authors argued, the high-span subjects were capable of recoding concepts and relationships into higher order units (or chunks) which would temporarily tax WM capacity but would ultimately afford the subject a payoff by increasing the functional capacity for subsequent processing. In this way, a high-span subject could hold more active concepts and relationships from other parts of the text in WM and consequently detect more interrelations. This, in turn, allowed the subject to draw inferences and to extrapolate information beyond the given text. The authors suggested that their study, taken together with similar developmental studies inferred that, while children and adults differed in their processing ability, there seemed to be little difference in their static WM capacity (Daneman & Carpenter, 1980).

In other words, WM is more or less the same for different people but different people, through the use of different strategies, for example, appear to have more capacity because they are able to use their WM more efficiently (Baddeley, 1996a). Inefficient processing, on the other hand, utilised more of the scarce WM resources that could otherwise have been used for storage. Thus the relationship between WM and comprehension reflects differences in language processing that impact on the short-term retention of the last words of the sentences (Adams, Bourke & Willis, 1999).

Research pertaining to the relationship between working memory and comprehension is, however, unclear as to whether the relationship involved the general WM system or whether the relationship reflected a component of WM like the phonological loop. Although the findings were mixed, some studies are reported here to illustrate the domains implicated.

Oakhill and Yuill (1991) investigated poor comprehenders - children who were capable of reading and pronouncing written words but who fared poorly in comprehending the prose that they had read. The authors found that these children had low WM spans and suggested that the children had concomitant deficits in their

Central Executive (CE) capacity. It appeared that individuals differed in the efficiency with which their CE processed reading-related material and poor comprehenders utilised a disproportionate amount of their WM resources for reading leaving little for comprehension (Vukovic & Siegel, 2006). In a longitudinal study Vukovic and Siegel (2005) corroborated the findings of Oakhill and Yuill (1991) and showed that WM accounted for unique variance in reading comprehension independent of skills like word recognition and word fluency. The longitudinal study by Vukovic and Siegel (2005) implicated Verbal Working Memory (V-WM) only, as did the meta-analysis by Daneman and Merikle (1996).

In another study, involving children aged 7 to 8 years old with a broad spectrum of reading ability Cain, Oakhill and Bryant (2000) reported that a task with verbal WM demands accounted for 11.4% of the variance in reading comprehension when other factors like age and intelligence scores were controlled. A later longitudinal study by Cain, Oakhill & Bryant (2004) confirmed this relationship but concluded that the general WM system influenced reading comprehension. Thus both verbal and visuo-spatial domains were implicated. Swanson and Howell (2001) found a significant correlation between reading comprehension and a composite linguistic measure (consisting of V-WM and numerical WM). They concluded that both V-WM and visuo-spatial working memory (VS-WM) contributed to the performance of reading comprehension. Swanson and Siegel (2001) posited that reading comprehension was more strongly correlated with V-WM than it was to VS-WM but cautioned that studies investigating the relationship between reading comprehension and VS-WM were limited and the findings were mixed.

It is therefore still unclear whether comprehension is influenced by a general WM system or by a specific domain of WM. However, since the WM system is a limited resource system, there is a restriction on how much information the CE can successfully co-ordinate. Tasks that are resource intensive, that demand sustained attention or excessive processing, like comprehension, leave few resources for concurrent tasks to be carried out. Therefore one would expect that any competition for WM resources would impact on such tasks as comprehension that is resource intense in its own right. One of the aims of the current study was to investigate whether a correlation could be found between working memory and reading comprehension in both the monolingual and bilingual groups. An additional aim was to investigate whether there was competition for WM resources in the bilingual group by comparing their performance in each set of tasks to that of the monolingual group. In other words, would the relationship between WM and reading comprehension differ in the two groups and if so, what would the nature of the difference be?

2.3.4 Working Memory and Mathematical ability

Several studies pointed to the crucial role played by working memory in both calculation and the solving of arithmetic word problems (Bull & Scerif, 2001; Fürst & Hitch, 2000; Gathercole et al., 2004; Hitch, 1978; Logie & Baddeley, 1987). In addition, working memory deficits had also been identified as a central factor in learners with mathematical difficulties (Geary, 1993; Hitch & McAuley, 1991).

The reasons given for why WM would impact on mathematics ability were complex and multi-faceted. One suggestion from Geary et al. (1991, as cited in Gathercole et al., 2004) was that children exhibiting poor mathematical ability failed to acquire long-term representations for basic number facts since information from WM decayed before associations could be formed. Other authors suggested that problems with inhibitory control in the CE might be responsible for poor mathematics performance (Bull & Scerif, 2001; Swanson, 2006). Gathercole et al. (2004) proposed that continual demands of simultaneous processing and storage necessary in complex mathematical computations exceeded the general purpose workspace provided by WM. Therefore, low WM capacity would limit the individual's ability to meet the demands of complex mathematical computations, leading to errors even if the individual was competent in basic mathematics.

Bull, Johnson and Roy (1999) focused on mathematics and the role of the CE and Bull and Scerif (2001) showed that children with lower mathematical ability showed concomitant difficulties with inhibiting a learned strategy and switching to a new strategy which is one form of executive functioning. However, the authors found that the children displayed no difficulty in generating a new strategy nor was there a problem keeping the new strategy in mind once it had been established. This implicated the use of the CE in mathematical tasks and supported the idea of the fractionation of the CE since it appeared that some parts of the CE were working normally in these children with only some aspects being deficient. These children also demonstrated difficulties with maintaining information in working memory (Bull & Scerif, 2001).

Gathercole et al. (2004) found that, in their study, CE deficiencies in the children with poor mathematical abilities related to general capacity rather than specific difficulties in processing. Wilson & Swanson (2001) also found that group differences in mathematics performance were related to the general WM system. Their regression analysis showed that both verbal and visuo-spatial WM scores predicted mathematics performance.

Research indicated that the phonological loop was implicated in counting (Logie & Baddeley, 1987) as well as storing information during the execution of complex calculations. Swanson and Sachse-Lee (2001) found that learners with arithmetic difficulties also displayed impaired performance in phonological processing. In addition, Fürst and Hitch (2000) showed that separate roles were performed by the executive and phonological components of WM during mental arithmetic.

Apart from the phonological loop and the CE, Reuhkala (2001) found that visuospatial working memory (VS-WM) played an important role in mathematical ability. Since mathematics often incorporated symbols or symbol combinations the author argued that VS-WM would be necessary to correctly perceive a number because the subject would have to identify the location of the digits relative to one another and understand any other algebraic symbol attached to that number. The author found that both the ability to temporarily store visuo-spatial information and the ability to mentally manipulate images, which reflected VS-WM capacity, were implicated in mathematical ability (Reuhkala, 2001).

Further evidence for the importance of VS-WM in mathematical ability came from Cornoldi, Rigoni, Tressoldi and Vio (1999) who observed that children with non-verbal learning disabilities, including mathematical disabilities, had VS-WM deficits. Finally, Alloway, Gathercole, Adams and Willis (2005) showed that mathematics ability was associated with tasks that tap the episodic buffer.

Taken together these studies indicated mixed findings with some reporting the involvement of the whole WM system and some reporting evidence for a specific domain of WM. Once again, though, since WM is a limited resource system, it is expected that tasks that are resource intensive, that demand sustained attention or excessive processing, like mathematical processing, would leave few resources for concurrent tasks to be carried out. Therefore one would expect that any competition for WM resources would impact on mathematical tasks. This study investigated whether a correlation between WM and mathematical ability could be found in both the L1 and L2 groups. Another aim was to investigate whether there was competition for WM resources in the bilingual group by comparing their performance in each set of tasks to that of the monolingual group. In other words, would the relationship between WM and mathematical ability differ in the two groups and if so, what would the nature of the difference be?

2.4 Bilingualism and Working Memory

2.4.1 Types of Bilingualism

For most laypeople, the term *"bilingual"* refers to somebody who speaks two languages. However, for those who study how a second language (L2) is acquired or how two languages are represented mentally, the term "*bilingual*" is far more complex. For instance, there are different types of bilinguals: a "*balanced bilingual*" is somebody with more or less equal proficiency in the two languages that they speak regardless of how long they have been speaking the languages or which language was learned first; "*receptive bilingual*" refers to people who understand two languages but can only express themselves in one (Halsband, 2006); a "*sequential bilingual*" is somebody who first learned one language and subsequently acquired another language while a "*simultaneous bilingual*" refers to people who learned to speak their languages at the same time in infancy (Werker & Byers-Heinlein, 2008). Initially *simultaneous bilinguals* have one undifferentiated language system and mixing of the languages (code mixing) is common. However, Werker & Byers-Heinlein (2008) found that code mixing did not imply language confusion but instead often reflected an attempt to communicate with limited linguistic resources. Therefore, as proficiency increased or as the person got older he/she was better able to differentiate between the two languages.

Differentiating between languages, in turn, raises the issue of how languages are stored in the bilingual brain. It seems that there is now consensus among researchers that each language has its own lexical store for phonological and orthographic representation but that conceptual representations are held in a common store (McElree et al., 2000; Snodgrass, 1984).

An important issue relates to when and how children should learn to use a second language and whether there is an advantage to speaking more than one language. Young children show a distinct advantage for acquiring a second language and often they are able to learn the words and the accent with ease (Halsband, 2006). The author cited various studies that showed that bilinguals often demonstrated greater cognitive flexibility but limited cognitive advantage over monolinguals. Bialystok et al. (2004) added that bilinguals often showed advantages in creativity and problem solving and that bilingual children developed control processes to a greater extent than did monolingual children. Psycholinguistic studies of adult bilinguals confirmed that in language processing both languages of the bilingual are kept active while processing occurred in one of them (Bialystok et al., 2004). Hence bilinguals had more practice at exercising inhibitory control as part of the experience of being bilingual. (This is explained in greater depth later in this chapter.)

However, research into cognitive processing in bilinguals has often produced conflicting results. Bialystok, Luk and Kwan (2005), for example, cited various studies which showed that bilingual children often had smaller vocabularies in each language compared to their monolingual counterparts and cautioned that this might disadvantage bilinguals in the early phase of literacy acquisition. However, bilinguals often had to maintain a vocabulary base in each of two languages and access to each lexicon was dependent on the links established between words and concepts

(Bialystok et al., 2004). Thus bilinguals may exhibit a latency effect – a slight delay in the processing of language. This was more likely in the early stages of acquiring the second language when the person was still an "*unbalanced bilingual*" and proficiency in the two languages was unequal.

Bilinguals may fail to acquire full fluency in either of their languages (Umbel, Pearson, Fernandez & Oller, 1992). Although it is common for some people to fail to attain proficiency in their second language, it is also the case that in some instances the second language displaces the first so that proficiency is not attained in the first language either. This is particularly relevant to South Africa and reflects the relative status afforded to English (Kamwangamalu, 2002). In addition, there is no clear evidence that bilinguals are more advanced in their development of phonological awareness compared to monolinguals (Bialystok et al., 2005). The authors, however, cited two reasons for why the progress of literacy for bilinguals compared to monolinguals was different: bilinguals develop many background skills for literacy differently to monolinguals and bilinguals often transferred skills acquired for reading in one language to their second language.

Umbel, et al., (1992) suggested that the socio-cultural context in which many bilingual children grow up might contribute to the inconsistency of results because of the other factors that impact on studies with bilinguals. These included culture, education, reason for being bilingual and whether the experience was "*additive*" or "*subtractive*". The authors explained that in an *additive* bilingual experience society and the family attributed positive values to both languages spoken. In addition, the acquisition of a second language in no way threatened to displace the first language. A *subtractive* bilingual experience meant that one of the spoken languages was not valued outside the home. Under these circumstances, the competing, socially dominant language posed a threat to the home language and was in danger of displacing it. Umbel et al. (1992) cited research that showed that children with an additive experience of bilingualism were more likely to show an advantage over monolingual peers while a subtractive experience was linked with a bilingual disadvantage.

Gutierrez-Clellen et al. (2004) quoted various studies in which no group differences in memory capacity were noted when bilinguals were compared on their dominant language to monolinguals. Harris, Cullum and Puente (1995) compared bilingual adults to monolingual adults on their memory spans and found that the bilinguals scored lower when tested in English, their second language. Yet, when the groups were tested on their respective dominant language, no group differences were found. This was also the finding of Umbel et al. (1992).

2.4.2 Lexical processing

A crucial phase in language production is that the speaker retrieves words from their lexicon to enable communication of a particular concept. Any activation at the conceptual level causes a corresponding activation in the matching lexical node. However, the semantic system will activate not only the intended word but several other words that are semantically related. For example, when looking at a picture of a dog the subject's semantic system will activate the word "dog" but could also activate other words like “cat” and “bone” that are semantically related to “dog” (Costa & Santesteban, 2004).

Since several lexical representations are activated, some selection mechanism is needed to determine which of the activated lexical representations are to be processed further and which to be ignored. Some models of lexical access assume that the node with the highest level of meaning will be selected as corresponding with the speaker’s intended meaning. Other models assume that, in addition, the selection mechanism is also sensitive to the level of activation of non-target words that have been activated and that act as competitors to the target word (Costa & Santesteban, 2004).

One of the most remarkable competencies of bilingual speakers is the ability to separate their two languages during speech production. Current models of lexical access indicate that lexicalisation in one language of a bilingual results in the semantic system activating the lexical nodes of both languages (Colomé, 2001; Costa & Santesteban, 2004). In other words, bilingual speakers are able to successfully select and produce words from one of their lexicons while simultaneously restricting access to the other lexicon. The process that enables this is referred to as *lexical selection* (Caramazza, 1997; Dell, 1986: Kroll, Dijkstra, Janssen & Schriefers, 2000; Levelt, Roelofs & Meyer, 1999).

Some models of lexical access proposed that the selection mechanism is language specific (Costa & Caramazza, 1999, as cited in Costa & Santesteban, 2004). This implies that the selection mechanism only considers the activation levels of words in the intended language of communication. Other models assume that the selection mechanism is independent of language. From this point of view, lexical nodes are activated in both languages but the speaker is capable of successfully selecting the correct lexical node in the correct language. Some authors argue that the semantic system is able to activate the correct language words to a greater extent than it activates the non-target language words (La Heij, 2004, as cited in Costa & Santesteban, 2004; Poulisse & Bongaerts, 1994).

Green, (1998) on the other hand, proposed that bilinguals are able to reactively inhibit lexical items from the non-target language through use of the executive functions that are generally used to control attention and inhibition. Evidence for inhibition was also found by McElree et al. (2000) who evaluated conceptual retrieval in 3 groups of bilinguals: balanced Russian/English; Russian-dominant Russian/English bilinguals and English-dominant Russian/English bilinguals for whom English (L2) had become their primary language. Although the study by McElree et al. (2000) was conceived as an investigation of the way in which bilinguals comprehend their two languages, the results also have implications for how bilinguals produce and utilise language. The authors argued that inhibition impacted on the speed of conceptual retrieval which influenced both language production and language comprehension.

Kroll and de Groot (1997, as cited in McElree et al., 2000) proposed a Revised Hierarchical framework that specified exactly how lexical and conceptual representations are interconnected. The authors suggested that in the early stages of L2 acquisition, links between the L2 lexicon and the conceptual store were non-existent to weak but that these links gradually strengthened with L2 experience. In the early stages of L2 acquisition, therefore, the primary means for L2 semantic processing was by translation to L1. A significant component of L2 acquisition was, therefore, the development of mappings between lexical and conceptual representations. In other words, the conceptual retrieval process was modified as proficiency in L2 increased and richer conceptual structures could be retrieved (McElree et al., 2000).

The major finding in the study by McElree et al. (2000) was that conceptual retrieval was slower in the processing of the non-dominant language in unbalanced bilinguals indicating that mapping from form to meaning was weaker in the non-dominant language. In contrast, conceptual information from L1 and L2 were equally available and accessible for the balanced bilinguals. Ardila (2003) added that not only was language processing for L2 slower but the semantic search was also less efficient. This time delay would impact negatively on bilinguals in any task involving complex cognition.

The slower time course for the non-dominant forms is understood as follows. Where form to meaning mappings are weak (as they are assumed to be in less proficient bilinguals) conceptual information cannot be retrieved directly. The non-dominant lexical form must be implicitly associated with its corresponding dominant lexical form to facilitate conceptual retrieval which is in keeping with the Revised Hierarchical Model of Kroll and de Groot (1997, as cited in McElree et al., 2000). The time delay is therefore due to the additional mediational process that is required. The results also have bearing on how WM in bilinguals concurrently serves a dual purpose (both for language and for reading comprehension). There is thus competition for this resource and hence WM, by virtue of the time delay, becomes a constraining factor in reading comprehension in bilinguals.

2.4.3 Working memory in bilinguals

Ardila (2003) noted that in bilinguals, brain activation patterns during working memory (WM) tasks were observed to be more complex when L2 was being used. The author suggested that processing information in L2 was more demanding than corresponding processing in L1 and concluded that WM may be less efficient when processing information in L2. In lexical decision tasks there was a significant correlation between reaction time and word frequency. In other words, it took more time to find the meaning of a low frequency word. In bilinguals, L2 words often functioned as low frequency words. Hence, language processing was slower and semantic search was less efficient than it would be for a monolingual. This served to functionally decrease the capacity of WM which in turn affected language understanding and hence reading comprehension (Ardila, 2003).

2.5 Rationale

2.5.1 Relevance to South Africa

South Africa is a multilingual country with 11 official languages and a host of other unofficial languages being spoken by its people. Moreover, the South African Constitution (The Constitution of South Africa, 1996) guarantees equal status to the official languages to cater for the diversity of language and culture among South Africans.

Despite the widespread distribution of languages other than English, though, as Kamwangamalu (2002) notes, English is afforded a place of high esteem in South African society and is viewed as a symbol of status and a means for upward social mobility. However, this often leads to the demise of indigenous languages when they come into contact and competition with English which, in turn, results in a subtractive experience of bilingualism.

Nonetheless many South African parents opt for their children to be schooled in English as is evident from the post-apartheid era influx of other language speakers into English medium schools. This included both African language speakers and Afrikaans speakers. The situation persists in the present despite the numerical advantage for African languages in South Africa (Kamwangamalu, 2002). Estimates based on the 1991 census suggest that about 45% of South Africans have a speaking knowledge of English although it is the first language of only 8.2% of the population.

It would seem, therefore, that the number of English first language speakers is disproportionate to the status afforded English in South Africa (Kamwangamalu, 2002). The important conclusion that can be drawn from this is that bilingualism and multilingualism in South Africa is the norm rather than the exception but despite legal efforts to grant equal status to the different home languages of the people of South Africa, the reality is that English is perceived as a ‘better’ language. For many South

Africans this leads to a subtractive experience of bilingualism which impacts on many different facets of life.

WM has been shown to be a predictor of progress towards early learning goals of literacy and numeracy (Alloway et al., 2005; Gathercole et al., 2004) If it can be shown that English monolinguals and Afrikaans/English bilinguals have no significant differences in their WM abilities, then it follows that they should do equally well in scholastic domains like reading comprehension and mathematics. However, if their performances differ and other possible factors are controlled for, then it would indicate that the acquisition and use of a second language is responsible for the difference in scholastic performance. This would make sense since, from the information presented in this chapter, it seems that the use of two languages and academic tasks compete for the same limited capacity WM resources.

The reality is that many learners in South Africa are bilingual or multilingual and are not schooled in their first language. In fact for many South African learners, L2 significantly displaces L1 such that L1 rarely develops to the same extent academically as L2. This renders it difficult for these learners to be assessed in L1. However, it has been pointed out that traditional measures of aptitude are biased against bilingual speakers. An assessment of WM using a battery like AWMA could provide an inexpensive way to identify learners at risk for developing learning disorders and distinguishing them from learners with poor language proficiency. But would such a test be reliable if the use of two languages and academic tasks compete for the same limited capacity WM resources?

2.6 Research aims

The research is divided into 2 sections. In the first part of the study the WM capacity was measured in two groups of South African Grade 1 learners: a monolingual English group (L1) and an Afrikaans/English bilingual group (L2). These results were then compared in order to establish whether the groups differed in WM capacity.

The second aim of the study was to compare WM capacity to learners' skills in key scholastic domains – reading comprehension and mathematics ability. Previous studies have established close associations between children's capacity to store and manipulate material over short periods of time and their scholastic progress in the domains of language and mathematics (Bull, Johnson & Roy, 1999; Gathercole & Pickering, 2000a; 2001; Gathercole, Pickering, Knight & Stegman, 2004; Jarvis & Gathercole, 2003). The present study aimed to establish whether these earlier findings would hold in the monolingual group (L1) and the bilingual (L2) group. The final aim was to determine whether the relationship between performance on the working memory measures and mathematical ability or working memory and reading comprehension was different for the L1 and L2 groups. These aims are operationalised in the following research questions.

Research Question 1: Will there be a significant difference between the working memory performance in the L1 and L2 groups?

Research Question 2: What is the relationship between performance on the working memory measures and reading - comprehension in the L1 and L2 groups and do the working memory scores predict performance in reading comprehension for the two groups?

Research Question 3: What is the relationship between performance on the working memory measures and mathematical ability in the L1 and L2 groups and do the working memory scores predict performance in mathematical ability for both groups?

Research Question 4: Is the relationship between performance on the working memory measures and mathematical ability or working memory and reading comprehension different for the L1 and L2 groups?

3 Method

This chapter outlines the research design of the study, a description of the sample, the instruments utilised to obtain the data and the procedure followed in conducting the study.

3.1 Research Design

The research took the form of a quantitative, ex-post facto study. The research design to compare working memory to reading comprehension and mathematics used non-experimental, non-probability sampling. Hence the sampling was non-random (Terre Blanche & Durrheim, 1999).

The dependent variables were *Verbal Short Term Memory (V-STM), Verbal Working Memory (V-WM), Visuo-Spatial Short Term Memory (VS-STM)* and *Visuo-Spatial Working Memory (VS-WM), reading-comprehension, mathematical ability* and *RCPM* (a measure of non-verbal intelligence) which are all interval measures. The independent variable was *home language* which is a nominal measure.

In terms of the demographic data, “gender” was nominal while “age” was an interval measure. The variables under observation were naturally occurring, pre-existent and no manipulation of the independent variable was necessary. The research design can be summarised as an empirical, comparative, cross-linguistic design (Mouton, 2001) since the research questions suggested firstly, a comparison between two language groups and secondly, an association between the dependent and independent variables.

3.2 Sample

A total of 61 Grade 1 learners from English medium primary schools in Johannesburg, South Africa were selected to participate in the study. Participating schools were selected from different suburbs and from areas of different socio-economic standing. Learners for the L2 group were selected from English medium primary schools that were in close proximity to an Afrikaans-speaking community. All learners participated on a voluntary basis.

Criteria for exclusion from the study were that the learner was repeating Grade 1, that the learner spoke other languages besides English and Afrikaans, that the learner had experienced any emotional, physical or psychological difficulties or had experience of learning difficulties. The participants in the study were divided into two groups. One group (L1) consisted of 30 English-speaking Grade 1 monolinguals. These learners spoke only English at home and were being schooled in English. The other group (L2) was a bilingual group of 31 learners who spoke Afrikaans as their first language and English as a second language. These were learners who spoke Afrikaans at home but were being schooled in English.

The following information was obtained from the Biographical Questionnaire (Appendix D) which was filled in by learners' parents/legal guardians.

Table 3.1. shows the gender composition of the groups. Of the 61 learners who participated in the study, 23 (38%) were male and 38 (62%) were female. In the L1 group there were 11 (37%) males and 19 (63%) females. In the L2 group there were 12 (39%) males and 19 (61%) females. Cognitive development in children is often argued to be gender related. Some studies (Martin & Hoover, 1987; Wilson & Swanson, 2001) suggested that males and females developed at different rates and that performance on particular cognitive tasks may be biased because of gender. However, in the current study the L1 group consisted of 11 boys and 19 girls and the L2 group consisted of 12 boys and 19 girls. Since the gender composition of the two groups was equivalent, any difference in performance in the 2 groups was likely to be due to factors other than gender.

Table 3.1.: Gender composition in the L1 and L2 groups

	L1 (English monolingual) (N=30)	L2 (Afrikaans/English bilingual) (N=31)
Males	**11 (37%)**	**12 (39%)**
Females	**19 (63%)**	**19 (61%)**

The mean age for the total sample of 61 learners was 88.3 months or 7 years, 4 months with a standard deviation of 4.98 months. The range of the total sample was from 77 months (6 years, 5 months) to 97 months (8 years, 1 month).

Inspection of Table 3.2. indicates that the mean age in the L1 group was 87.9 (7 years, 4 months) while the mean age in the L2 group was 89 months (7 years, 5 months). Thus any differences in performance are unlikely to be attributable to age differences in the two groups.

Table 3.2.: Description of age in the L1 and L2 groups

		Age (in months)		
	N	**Range**	**Mean**	**SD**
L1	**30**	**81 - 95**	**87.9**	**4.56**
L2	**31**	**77 - 97**	**89.0**	**5.40**
Total	**61**	**77 - 97**	**88.3**	**4.98**

Finally in terms of non-verbal intelligence, the groups were equivalent with the L1 group having a mean score of 19.77 while the mean score in the L2 group was 20.10. This is discussed further later in the chapter. However, it is mentioned here since any differences in performance are unlikely to be attributable to non-verbal intelligence differences in the two groups.

3.3 Instruments

Three instruments were used to conduct the research. These were administered in English to all participants of the study. Details of the instruments are given below.

3.3.1 Automated Working Memory Assessment (AWMA) (Alloway, Gathercole & Pickering, 2004)

The AWMA is a computerised tool for assessing working memory (WM) and short term memory (STM) in children aged 4 to 11 years. The entire AWMA assessment consists of 12 subtests. Six of these subtests involve storage-plus-processing components and are collectively termed WM tasks. Three of the 6 measures relating to WM ("Odd one out", "Mister X" and "Spatial Span") measure visuo-spatial ability or VS-WM. The other 3 ("Listening Recall", "Counting Recall" and "Backward Digit recall") measure verbal ability or V-WM.

The other six subtests involve storage-only components and are referred to as STM tasks. Of these "Digit Recall", "Word Recall" and "Non-word Recall" measure verbal ability, or V-STM, while "Dot Matrix", "Mazes Memory" and "Block Recall" measure visuo-spatial ability, or VS-STM. Following is a brief description of the individual subtests taken from Alloway (2006).

The first subtest was *Digit Recall*. In this subtest, the subject heard a sequence of digits and had to recall these in the same order as that in which they were spoken. The subtest started with 2 digits and increased by one in each successive block. The test terminated when the subject was unable to recall 4 correct trials in a block of 6 trials. The subject heard a sequence of words in the *Word Recall* task. He/She then had to recall and repeat these words in the correct order. The subtest started with 2 words and increased by one in each successive block. The test terminated when the subject was unable to recall 4 correct trials in a block of 6 trials. The next subtest was the *Non Word Recall* task. Here the subject was presented with a series of made up words and had to recall the sequence in the correct order. This subtest followed the same format as the *Word Recall* task except that non-words were used instead of words. These 3 subtests together measured Verbal Short Term Memory (V-STM).

In the *Listening Recall* subtest the subject listened to a series of sentences. The subject then had to state whether each sentence was "true" or "false". At the end of the trial the subject was asked to recall the last word of each sentence in the same order as it was presented. The trials began with a single sentence and increased by one in each successive block. Testing terminated when the subject was unable to recall 3 correct trials in a block of 6 trials. In the *Counting Recall* task, the subject was presented with a visual array of red circles and blue triangles randomly displayed on the screen. The subject was required to disregard the triangles and to count only the circles. The length of time that the array remained on the screen was not fixed. Usually the subject indicated that he/she had finished counting and the tester moved to the next screen. At the end of the trial the subject was required to recall the number of circles counted in each trial in the correct order. The trials began with a single array being displayed and increased incrementally after 4 successful trials in a block. The test terminated when the subject was unable to correctly recall 4 trials. The *Backward Digit Recall* subtest was next. Here the subject was required to listen to a series of spoken digits and to recall these in the reverse order. The trials began with 2 digits and increased incrementally after 4 successful trials in a block. The test terminated when the subject was unable to correctly recall 4 trials in a block. Taken together, these 3 tasks measured Verbal Working Memory (V-WM).

The next subtest was called the *Dot Matrix* where the subject was shown a 4 X 4 matrix with a red dot. The subject had to recall the position of the dot which remained on the computer screen for 2 seconds. The sequences, which started with one dot and increased in each block, were random and no location was repeated more than once in any given trial. Next was the *Mazes Memory*. Here the subject was shown a maze with a red line indicating an exit route. This remained on the computer screen for 3 seconds. Afterward the subject had to trace the route with a finger on the computer screen through a blank maze exactly as it initially appeared. The last test in this batch concerning Visuo – spatial Short term Memory (VS-STM) was the *Block Recall* task. Here the subject was shown a video of randomly placed blocks being touched at a rate of 1 block per second. The subject had to reproduce this sequence in the correct order by using a finger to indicate on a picture of the blocks on the computer screen.

In the *Odd One Out* task, the subject had to detect the object that was different in successive arrays of 3 objects presented for 2 seconds. The subject also had to recall the location of the mismatched objects in the correct order at the end of the trial by tapping the correct location on the computer screen. In the *Mister X* task the subject was presented with 2 cartoon “Mister X” figures, one with a blue hat and one with a yellow hat. The subject had to identify whether the Mister X with the blue hat was holding the ball in the same or different hand as the Mister X with the yellow hat. The figure with the blue hat could be rotated through 360º. At the end of the trial the subject also had to correctly recall the location of each ball that Mister X with the blue hat had presented. This was done by pointing to a picture with 8 possible locations. Finally in the *Spatial Span* task, the subject had to compare the orientation of a rotating shape with a red dot on it to another stationary one without a red dot to the left of it. The subject had to decide whether these two shapes were the same or the opposite of each other. The shape with the red dot could also be rotated through 360º. At the end of the trail, the subject had to point out the location of the red dot on a schematic representation of 3 possible positions. These 3 subtests measured Visuo – spatial Working Memory (VS-WM).

The test-retest reliabilities of the AWMA subtests, based on a population of 105 British learners aged between 54 and 137 months is shown in Table 3.3. and ranges from α = 0.64 to α = 0.84 (Alloway, Gathercole & Pickering, 2006, p. 1702 - 1703).

Table 3.3.: Test-retest reliabilities of the AWMA subtests

Subtest	Reliability
Verbal short-term memory (V-STM)	
Digit recall	0.84
Word recall	0.76
Nonword recall	0.64
Verbal working memory (V-WM)	
Listening recall	0.81
Counting recall	0.79
Backward digit recall	0.64
Visuo-spatial short term memory (VS-STM)	
Dot matrix	0.83
Mazes memory	0.81
Block recall	0.83
Visuo-spatial working memory (VS-WM)	
Odd-one-out	0.81
Mr X	0.77
Spatial span	0.82

Verbal Short Term Memory (V-STM), Verbal Working Memory (V-WM), Visuo – spatial Short term Memory (VS-STM) and Visuo – spatial Working Memory (VS-WM) represent the 4 dependent variables related to memory in this study.

3.3.2 Raven's Coloured Progressive Matrices (RCPM) (Raven, Curt & Raven, 1997)

The RCPM is a multiple choice test of abstract reasoning, originally developed by Dr John C. Raven in 1938. It is a non-verbal instrument designed to gauge non-verbal intelligence in children between the ages of 6½ and 11 years of age. The test was presented as three sets of twelve coloured figural matrices (A, Ab and B) printed in a book. Sets A and B are drawn from the original Ravens Standard Matrices. A further set of 12 items has been inserted between the two as set Ab giving a total of 36 items for the RCPM.

In each test item, the subject was asked to identify the missing segment required to complete a larger pattern. The learner was required to select the correct piece from a set of alternatives to complete the matrix. This was done either by pointing out the correct piece or by saying the number of the figure. The final score was the number of correctly chosen pieces. Most items were presented on a coloured background to make the test visually stimulating for younger subjects. The instructions required minimal verbal explanation which made it suitable for assessing learners whose home language was not English and whose level of English proficiency was not high.

The test-retest reliability on the original test was $\alpha = 0.90$ with no difference for ethnicity or gender and a correlation of $r = 0.61$ was found between RCPM and WISC-R (Wechsler Intelligence Scale for Children – Revised) full scale scores. This indicates that the RCPM is a sound measure of general intellectual ability (Raven, Curt & Raven, 1997). The RCPM scores are included here as a means of controlling for individual differences in intellectual ability. RCPM scores represented the dependent variable *RCPM*.

3.3.3 Wechsler Individual Achievement Test, 2nd ed. (WIAT-II), (The Psychological Corporation, 2001).

The following five subtests from the battery were used in this study: Word Reading (WR), Reading Comprehension (RC), Pseudoword Decoding (PD), Numerical Operations (NO) and Mathematical Reasoning (MR).

The *Word Reading* subtest consisted of 80 items which included naming letters, phonological skills (where the subject had to identify the beginning or ending sound of a word or identify the letter associated with a particular sound) and reading aloud from a list of words. This subtest gauged knowledge of letters and sounds hence comprehension was not being evaluated. In the *Pseudoword Decoding* subtest, the subject was given a list of 55 nonsense words to read aloud. These were words of varying length that followed the rules of English spelling but were nonetheless meaningless. The *Reading Comprehension* subtest consisted of 27 items and entailed matching words to pictures, reading sentences aloud and answering oral questions about reading passages.

The scores for the *Word Reading, Pseudoword Decoding* and *Reading Comprehension* subtests were combined to give a composite score called WIAT –

Comp which represented the dependent variable *reading-comprehension* used to gauge a learner's reading-comprehension ability.

Numerical Operations was a 12 item subtest which entailed identifying and writing numbers, counting and solving paper-and-pencil calculations. Only a few items for each computational skill were used. The *Mathematical Reasoning* subtest consisted of 20 items involving counting, identifying shapes and solving verbally framed "word problems" presented both orally and in writing. The subject was allowed to use a pencil and paper if necessary.

The scores for the *Numerical Operations* and *Mathematical Reasoning* subtests were combined to give a composite score called WIAT – Math which represented the dependent variable *mathematical ability* used to gauge a learner's mathematical ability.

Finally, demographic data was collected from the Biological Questionnaire (Appendix D) that parents/legal guardians of the subjects had to fill in prior to commencement of testing. Although not an instrument, the Biographical Questionnaire is mentioned here since it provided information on the subjects' age and gender and the data for determining the independent variable *home language* used in this study.

3.4 Procedure

Since the study involved the assessment of children, ethical clearance had to be obtained from the Ethics Committee of the University of the Witwatersrand. A copy of the ethics clearance certificate is included as Appendix F. In addition, consent for the study had to be obtained from the Gauteng Department of Education (refer to Appendix A). Thereafter, the principals of various schools were approached to seek consent for the study (refer to Appendix B). Of the thirteen schools approached, eight school principals gave informed consent. A letter giving details of the study was then sent to all parents/legal guardians of Grade 1 learners at the school (Appendix C). A biographical questionnaire (Appendix D) was sent to the parents/legal guardians who had consented and information from this questionnaire was used to determine whether the learners qualified for membership of either the L1 or L2 group.

Each learner identified for the study was assigned a code to ensure confidentiality of the information obtained. Learners who were repeating the grade were excluded from the study, as were learners with psychological, neurological or learning difficulties as reported by the parent. Learners who spoke other languages in addition to English and Afrikaans were also excluded. Finally, a letter of assent was signed by each learner (Appendix E).

Each learner was tested in a quiet area of the school or in an unused room. The learners were taken out of class one at a time to minimise disruption to the rest of the class. The purpose and process of testing was explained to each learner together with a time frame for when the testing would be done. Thus each learner knew when and at what time to present themselves after the initial session. The learner was also informed that they could withdraw from the study at any time with no consequences and that testing could be stopped if they felt tired or unable to continue. Nine learners did not complete testing and were not included in the study.

Testing consisted of 3 sessions of 30 minutes each and was usually spread over 2 days. The AWMA was presented to learners on a laptop in 2 sessions of approximately 30 minutes each. The first 6 tests were always presented first followed by a break before the remaining 6 tests were administered. The tests were administered strictly in this sequence to vary task demands across successive tests. The automated presentation of instructions, practice examples and test items ensured a level of consistency across all subjects that were tested and served to reduce experimenter error.

The Ravens and WIAT subtests took another 30 minutes to administer. All tests were administered in the same order to attempt to control for the effects of tiredness and practice across all subjects and especially between the two groups. The candidates in each school were tested class by class regardless of which group they had been assigned to. This was to keep disruptions to the class to a minimum.

4 Results

4.1 Introduction

This chapter documents the quantitative data analyses conducted in order to compare monolingual English learners to bilingual Afrikaans/English learners in terms of their WM capacity and to compare each group's performance of WM to the group's reading-comprehension and mathematics ability. The statistical results obtained are also reported accompanied by graphs and tables where relevant.

As outlined in Chapter 2, the Automated Working Memory Assessment (AWMA) is a computerised assessment tool consisting of 12 subtests of memory. The scores of the subtests were automatically collapsed by the AWMA program to reflect 4 composite scores which represented the 4 dependent variables *V-STM, V-WM, VS-STM* and *VS-WM* related to memory.

Two dependent variables were obtained from the *Wechsler Individual Achievement Test (2nd ed.*) (WIAT – II). The scores for the *Word Reading, Pseudoword Decoding* and *Reading Comprehension* subtests of the WIAT-II were combined to give a composite score called WIAT – Comp which represented the dependent variable *reading-comprehension* used to gauge a learner's reading-comprehension ability while the scores for the *Numerical Operations* and *Mathematical Reasoning* subtests were combined to give a composite score called WIAT – Math which represented the dependent variable *mathematical ability.* RCPM scores, which reflect non-verbal intelligence, represented the dependent variable *RCPM*. Finally, data for the independent variable *home language* was gained from the Biographical Questionnaire (Appendix D).

The chapter is organised as follows. Firstly, the distribution of the research data is discussed. Then for each research question outlined in Chapter 1, the descriptive statistics comprising the means and standard deviations is presented together with the inferential statistics based on the analyses conducted to investigate the various research questions. Tables are included where necessary to summarise data or to clarify the statistics. Only raw scores were used in all statistical analyses. Composite scores were used as variables in the statistical analyses conducted unless otherwise indicated. Data was analysed using SAS version 9.1 and SAS Enterprise Guide version 3.0.

4.2 Distribution of Data

A key criterion for the use of parametric techniques in statistical data analysis is a normal distribution of scores obtained on each dependent variable (Howell, 2008). One of the techniques which can be used to determine normality is the Kolmogorov-Smirnov test of normality. A table showing the results of the Kolmogorov-Smirnov test on the variables for each language group is included as Appendix G.

The p-values on the various tests were examined, and since none were significant, it was concluded that the data pertaining to each dependent variable was normally distributed (Howell, 2008). Since the requirements for normal distribution of data were met, parametric analysis was conducted.

4.3 Comparison of working memory measures in the L1 and L2 groups

Research Question 1: Will there be a significant difference between the working memory performance in the L1 and L2 groups?

Table 4.1. shows a breakdown of means, standard deviations, minimum and maximum scores of the various subtests of the AWMA for the L1 and L2 groups. From the table it was clear that there was a pervasive advantage for the L2 group across all three subtests making up the *VS-WM* composite score. In the Odd One Out subtest the mean was 12.97 for the L1 compared to 13.81 for the L2, in the Mister X subtest it was 6.30 for the L1 compared to 6.45 for the L2 and in the Spatial Span subtest it was 10.23 for the L1 compared to 11.87 for the L2. It was therefore not surprising that the mean L1 score for *VS-WM* (29.50) was slightly lower than that for the L2 group (32.13).

Table 4.1.: Summary of scores of AWMA subtests

	L1				L2			
Test	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
DR	26.23	3.43	21	33	25.48	4.23	18	35
WR	17.50	3.95	12	25	16.65	3.33	12	25
NWR	14.17	4.32	7	24	13.71	3.23	6	21
LR	8.80	3.36	1	15	8.61	3.49	3	15
CR	15.90	3.94	9	24	14.90	4.60	8	24
BDR	8.17	3.09	0	13	9.03	2.18	5	13
DM	17.03	3.50	12	25	17.19	3.50	11	24
MM	16.47	4.61	8	25	15.35	5.83	0	27
BR	17.50	3.15	10	24	17.68	4.21	10	30
OO	12.97	2.57	6	17	13.81	2.87	7	19
MX	6.30	2.98	1	13	6.45	2.58	2	14
SS	10.23	4.07	0	18	11.87	4.37	1	20

***Key**:* DR = Digit Recall, WR = Word Recall, NWR = Non-word Recall, LR = Listening Recall, CR = Counting Recall, BDR = Backward Digit Recall, DM = Dot Matrix, MM = Mazes Memory, BR = Block Recall, OO = Odd One Out, MX = Mister X and SS = Spatial Span.

In order to determine how the L1 group performed compared to their L2 counterparts on the working memory tests, a two independent sample *t*-test was applied. This test is utilised when there are two independent groups of research participants and the sample mean of one group is to be tested against the sample mean of the other group. In doing so it is possible to gauge whether the difference is large enough to justify the conclusion that the two samples were drawn from different populations (Howell, 2008). The results of the *t*-test are presented in Table 4.2.

Table 4.2.: Results of the two-independent sample *t*-test of significance of means of the dependent variables V-STM, V-WM, VS-STM and VS-WM between the L1 and L2 groups

Dependent Variable	Df	n	t - statistic	Pr > |t|	Mean (L1)	Mean (L2)
V-STM	59	61	0.89	**ns**	57.90	55.84
V-WM	59	61	0.17	**ns**	32.87	32.55
VS-STM	50.2	61	0.32	**ns**	51.00	50.23
VS-WM	59	61	-1.28	**ns**	29.50	32.13

Key: V-STM = Verbal Short-term Memory, V-WM = Verbal Working Memory, VS-STM = Visuo-spatial Short-term Memory and VS-WM = Visuo-spatial Working Memory.

Note: *Df* = Degrees of Freedom

ns = not significant

The results in Table 4.2. indicate that there were no significant differences in the *V-STM, V-WM, VS-WM* and *VS-STM* variables between the L1 and L2 groups which implied no significant difference in the working memory performance of the L1 group as compared to that of the L2 group.

For the *V-STM, V-WM* and *VS-WM* variables equality of variance was established. However, the exception was the *VS-STM* variable which was significant at the 0.05 level indicating unequal variances in the L1 and L2 groups. For this reason the results reported in Table 4.2. reflect equal variance scores (Pooled) for *V-STM, V-WM* and *VS-WM* while the *t*-test for unequal variances (Satterthwaite) is reported for *VS-STM*. The *Df* value is therefore different for the *VS-STM* score.

In order to determine whether there were statistically significant differences between the L1 and L2 learners on the individual subtests of the AWMA, a two-independent sample *t*-test was used once again with the individual subtests as the analysis variables. Equality of variance was established for all the subtests but no significant differences were found between the performances of the L1 group as compared to that of the L2 group. The implications of this finding are discussed in the following chapter.

4.4 Relationship between working memory measures and reading-comprehension

Research Question 2: What is the relationship between performance on the WM measures and *reading - comprehension* in the L1 and L2 groups and do the WM scores predict performance in *reading - comprehension* for the groups?

More specifically will there be a significant correlation between the dependent variables *V-STM, V-WM, VS-STM* and *VS-WM* and the dependent variable *reading-comprehension* for each of the groups? In addition, will performance in *reading-comprehension* be predictable from the *V-STM, V-WM, VS-STM* and *VS-WM* scores for each of the groups?

Table 4.3. shows a breakdown of means, standard deviations, minimum and maximum scores of the various subtests of the WIAT - Comp for the L1 and L2 groups.

Table 4.3.: Summary of scores of WIAT – Comp subtests

	L1				L2			
Test	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Word Reading	62.67	8.84	46	77	58.10	9.44	42	77
Reading Comprehension	47.00	11.79	14	68	39.58	15.10	4	66
Pseudo-word Decoding	16.33	10.77	2	36	11.10	8.60	0	29

Inspection of Table 4.3. indicates that the means in all 3 subtests making up the WIAT – Comp variable were higher for the L1 group than for the L2 group. In the Word Reading subtest the mean is 62.67 for the L1 compared to 58.10 for the L2, in the Reading Comprehension subtest the mean is 47.00 for the L1 compared to 39.58 for the L2 and in the Pseudo-word Decoding subtest the mean is 16.33 for the L1 compared to 11.10 for the L2 group. In other words, the L1 group performed consistently better in all 3 *reading-comprehension* subtests compared to the L2 group.

In order to determine the relationship between working memory and *reading-comprehension* a series of correlation analyses was conducted (Howell, 2008). The Pearson Correlation Coefficients calculated by the tests are presented in Table 4.4.

Table 4.4.: Pearson's Correlation between V-STM, V-WM, VS-STM, VS-WM and WIAT-Comp (*reading-comprehension*) for the L1 and L2 groups

	WIAT- Comp (L1) **n = 30**	**WIAT- Comp (L2)** **n = 31**
V-STM	0.36	0.666***
V-WM	0.14	0.747***
VS-STM	-0.04	0.392*
VS-WM	0.43*	0.477*

***Key**:* V-STM = Verbal Short-term Memory, V-WM = Verbal Working Memory, VS-STM = Visuo-spatial Short-term Memory and VS-WM = Visuo-spatial Working Memory. *WIAT-Comp = reading comprehension.*

Note:

*significant at $p < 0.05$

***significant at $p < 0.001$

Table 4.4. illustrates that for the L1 group the only significant correlation is that between VS-WM (r = 0.43, p = 0.02) and *reading-comprehension* at the 0.05 level of significance. V-STM (r = 0.36, p = 0.05) is moderately correlated with *reading comprehension* while VS-STM has a very weak negative correlation (r = -0.04, p = 0.82) with *reading-comprehension*. Interestingly V-WM has a weak correlation (r = 0.14) with *reading-comprehension* and the correlation is not significant.

In marked contrast, in the L2 group *reading-comprehension* was highly correlated with V-WM (r = 0.747, p < 0.001) and V-STM (r = 0.67, p <0.001) and moderately correlated with VS-STM (r = 0.392, p = 0.03) and VS-WM (r = 0.477, p = 0.01). V-

WM and V-STM were significant at the $p < 0.001$ level of significance. VS-STM and VS-WM were significant at $p < 0.05$.

In order to further investigate the relationship between working memory and *reading-comprehension* in the L1 group, a correlation analysis was conducted using the subtests of the WIAT-Comp. The results are presented in Table 4.5.

Table 4.5.: Pearson's Correlation between V-STM, V-WM, VS-STM, VS-WM and the subtests making up reading-comprehension for the L1 group

Pearson Correlation Coefficients (L1) n = 30			
	WRC	RC	PD
V-STM	0.33	0.30	0.35
V-WM	0.17	0.13	0.09
VS-STM	-0.09	-0.09	0.06
VS-WM	0.45*	0.42*	0.32

Key: V-STM = Verbal Short-term Memory, V-WM = Verbal Working Memory, VS-STM = Visuo-spatial Short-term Memory and VS-WM = Visuo-spatial Working Memory. *WRC = Word Reading, RC = Reading Comprehension and PD = Pseudo-word Decoding*

Note: *significant at $p < 0.05$

Inspection of Table 4.5. shows that two of the correlations between *V-STM, V-WM, VS-STM, VS-WM* and the subtests making up *reading-comprehension* (word reading,

reading comprehension and pseudo-word decoding) are significant at the 0.05 level. *VS-WM* is moderately though significantly correlated with the word recall ($r = 0.45$, $p = 0.01$) and reading comprehension ($r = 0.42$, $p = 0.02$) subtests of the WIAT- Comp. However, none of the correlations are strong.

The second part of the research question was to explore the predictive value of the dependent variables *V-STM, V-WM, VS-STM* and *VS-WM* for the dependent variable *reading-comprehension* in the L1 and L2 groups. According to Terre Blanche and Durrheim (1999) a multiple regression analysis enables the separate and collective contributions of many independent variables to be reviewed. Based on the research question posed and the nature of the data, it was decided that the Stepwise Multiple regression model was the most appropriate form of regression to use since the aim was to predict the criterion variable (*reading-comprehension*) from a set of possible predictors (*V-STM, V-WM, VS-STM* and *VS-WM*). The Stepwise model is basically a combination of simultaneous forward selection and backward elimination. Initially the variable with the largest variance is selected from all the possible predictor variables indicated. Thereafter, the significance of the remaining predictor variables is recalculated and the next variable with the largest significance is added. As each variable is added, variables already selected are considered for elimination if they no longer contribute significantly. In this way, variables are systematically added and eliminated until the only variables remaining in the model are those that make a significant contribution and all variables that do not contribute have been eliminated (Howell, 2008). The significance levels were set to the default values of 0.5 for entry and 0.1 for elimination.

WIAT-Comp was entered as the dependent variable while *V-WM, VS-WM, V-STM* and *VS-STM* were entered as the explanatory (predictor) variables. The regression was grouped by the independent variable *home language* represented here as “Group”. The results for the regression analysis to determine which variables were significant predictors of *reading-comprehension* for the L1 group showed that there was 1 contributing factor, *VS-WM,* which accounted for 19% of the variance in *reading comprehension*.

In contrast there were 2 contributing factors, *V-STM* and *V-WM*, to the variable reading-comprehension for the L2 group as shown in Table 4.6. below. Table 4.6. shows that 56% of the variance can be explained by the *V-WM* predictor which is significant at the $p< 0.001$ level. *V-STM* accounts for only 5% of the variance in explaining reading comprehension in the L2 group.

Table 4.6.: Forward Stepwise Regression Analysis showing proportion of variance explained by predictor variable for reading-comprehension in L2

Variable Entered	**Partial R-Square (Δ r^2)**	**Model R-Square (r^2)**	**F Value**
V-WM	0.56	0.56	$p < 0.001$
V-STM	0.05	0.61	**ns**

Key: V-WM = Verbal Working Memory, V-STM = Verbal Short-term Memory.
Δr^2 = the proportion of variance explained by the predictor variable, and the strength of the relationship between the predictor and criterion variables. F- value refers to the significance of the regression model.

Note: **ns** = not significant

4.5 Relationship between working memory measures and mathematics

Research Question 3: What is the relationship between performance on the WM measures and *mathematical ability* in the L1 and L2 groups and do the working memory scores predict performance in *mathematical ability* for the groups?

More specifically will there be a significant correlation between the dependent variables *V-STM, V-WM, VS-STM* and *VS-WM* and the dependent variable *mathematical ability* for each of the groups? In addition, will performance in *mathematical ability* be predictable from the *V-STM, V-WM, VS-STM* and *VS-WM* scores for each of the groups?

Table 4.7. shows a breakdown of means, standard deviations, minimum and maximum scores of the various subtests of the WIAT - Math for the L1 and L2 groups.

Table 4.7.: Summary of scores of WIAT – Math subtests

	L1				**L2**			
Test	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Numerical Operations	11.40	1.28	8	14	11.19	1.51	8	15
Mathematical Reasoning	17.53	1.43	14	20	17.52	1.50	14	20

Inspection of Table 4.7. indicates that the means in both subtests making up the WIAT – Math variable were similar for the L1 and L2 groups. In other words, there was no difference in performance between the two groups.

In order to determine the relationship between working memory and *mathematical ability* a series of correlation analyses was conducted (Howell, 2008). The Pearson Correlation Coefficients calculated by the tests indicated that no significant correlations between the *V-STM, V-WM, VS-STM, VS-WM* variables and *mathematical ability* in the L1 group and that the correlations were all weak. It should be noted that, as expected, there is a higher correlation between *VS-WM* and *VS-STM* and *mathematical ability* than there is between *mathematical ability* and the 2 verbal memory measures *(V-WM and V-STM).*

For the L2 group all correlations between *V-STM, V-WM, VS-STM* and *VS-WM* and WIAT - Math were significant. *Mathematical ability* was moderately correlated with *V-WM* (r =0.519, p = 0.003), *V-STM* (r = 0.456, p = 0.010), *VS-STM* (r = 0.533, p = 0.002) and *VS-WM* (r = 0.492, p = 0.005). *V-WM* and *VS-STM* were significant at the $p < 0.01$ level of significance. *V-STM* and *VS-WM* were significant at $p < 0.05$.

The second part of research question 3 was to explore the predictive value of the dependent variables *V-STM, V-WM, VS-STM* and *VS-WM* for the dependent variable *mathematical ability* in the L1 and L2 groups through use of Forward Stepwise regression analysis with the significance levels set to the default values of 0.5 for entry and 0.1 for elimination. WIAT- Math was entered as the dependent variable while *V-WM, VS-WM, V-STM* and *VS-STM* were entered as the explanatory variables. The results for the regression analysis to determine which variables were significant predictors of *mathematical ability* showed that there was only 1 significant contributing factor to *mathematical ability* in the L1 group and this was *VS-WM* which accounted for 11% of the variance.

In contrast there were 2 significant contributing factors to *mathematical ability* in the L2 group which were *V-STM* and *VS-STM*. *VS-STM* accounts for 28% of the variance for *mathematical ability* and is significant at the $p< 0.01$ level. *V*-STM accounts for only 11% of the variance in explaining mathematical ability in the L2 group.

4.6 Comparison of the relationship between working memory measures and reading comprehension and working memory measures and mathematics in the two groups

Research Question 4: Is the relationship between performance on the working memory measures and *mathematical ability* or working memory and *reading - comprehension* different for the L1 and L2 groups?

The final aim was to test whether the relationship between *V-STM, V-WM, VS-STM* and *VS-WM* and *reading-comprehension* and *V-STM*, *V-WM, VS-STM* and *VS-WM* and *mathematical ability* differed across the L1 and L2 groups.

In order to address this research question a Fisher z-score was calculated. Since the variables for *reading comprehension* and *mathematical ability* differ in magnitude and dispersion it was necessary to first transform the correlation co-efficients into standard scores or *z*-scores to facilitate interpretation and comparison of the two groups. The differences in the 2 coefficients showed that the two groups differed only in their relationship between *V-WM* and *reading comprehension* where the Fisher z-score was **- 3.07** ($p < 0.05$). All other relationships between *V-STM, VS-STM* and *VS-WM* and *reading comprehension* were equivalent in the two groups. In addition the relationships between *V-WM, V-STM, VS-STM* and *VS-WM* and *mathematical ability* were equivalent in the two groups. In other words, the correlations between *V-STM, VS-STM* and *VS-WM* and *reading comprehension* and between *V-WM, V-STM, VS-STM* and *VS-WM* and *mathematical ability* did not differ significantly in the two groups.

5 Discussion

5.1 Introduction

This study compared South African English monolingual learners to Afrikaans/English bilingual learners in terms of WM capacity as well as on measures of reading comprehension and mathematical ability. The study aimed firstly to investigate whether there would be differences in individual WM capacity in the two populations. Secondly, the relationship between WM and *reading comprehension* and between WM and *mathematical ability* was investigated in each of the two groups. Finally, the relationships between WM and *reading comprehension* and between WM and *mathematical ability* in the L1 group were compared to those in the L2 group to ascertain whether these relationships might be different in each population.

The rationale for the study is threefold. Firstly, investigations by other researchers have produced conflicting results with regards to WM capacity in individuals and in different populations (Alloway, Gathercole & Pickering, 2006; Chiappe, Hasher & Siegel, 2000; Christoffels, de Groot & Kroll, 2006; Conway & Engle, 1996; Daneman & Carpenter, 1980; Engle, Cantor & Carullo, 1992; Gathercole & Alloway, 2004; Just & Carpenter, 1992). While some researchers point to differences of capacity in different populations (Alloway, Gathercole & Pickering, 2006; Christoffels, de Groot & Kroll, 2006; Gathercole & Alloway, 2004), others indicate that when mitigating factors are accounted for, capacity is essentially the same for all individuals

(Daneman & Carpenter, 1980). This study also investigated individual differences in WM capacity but did so using the AWMA in two South African populations.

Secondly, the study investigated the relationship between WM capacity and reading comprehension and WM and mathematical ability. Although previous research pointed to a correlation between WM and cognitive processing (Baddeley, 1986; Bull & Scerif, 2001; Cain, Oakhill & Bryant, 2004; Campbell, Dollaghan, Needleman & Janosky, 1997; Cowan, 1996; Daneman & Carpenter, 1980; Fürst & Hitch, 2000; Gathercole et al., 2004; Hitch, 1978; Just & Carpenter, 1992; Logie & Baddeley, 1987; Vukovic & Siegel, 2005; Weismer, Evans & Hesketh, 1999), it had not been confirmed in the two populations used in this study and this was the second motivating factor. The third motivating factor was that the results of such an investigation would provide insight into how bilinguals utilise WM and STM compared to their monolingual counterparts and that this information could inform educators involved with assessment of academic progress of both populations.

A total of 61 Grade 1 learners from several English medium schools in Gauteng, South Africa were assessed using the Automated Working Memory Assessment (AWMA) which is a computerised instrument that measures Working Memory (WM) (used for processing and storage) and Short Term Memory (STM) (used for storage only) and hence gives a composite score for verbal WM (V-WM), visuospatial WM (VS-WM), verbal STM (V-STM) and visuospatial STM (VS-STM). The two groups were also assessed on their performance in tests of reading comprehension and mathematical ability and these scores were compared to the AWMA scores of the two groups. Here the differences between the groups were more evident. A more extensive discussion of the results follows based on each of the research questions specified in an earlier chapter

The chapter is organised such that the results of this study reported in the previous chapter are discussed followed by an extensive discussion of how these results fit into broader research and the theoretical and practical implications thereof. A section relating to the limitations of the study concludes the chapter.

5.2 Performance on Working Memory measures: L1 vs. L2

In order to determine how the L1 group performed compared to their L2 counterparts on the working memory tests, a two independent sample *t*-test was applied. In this way the sample mean of the L1 group could be tested against the sample mean of the L2 group to gauge whether the two samples were drawn from different populations (Howell, 2008).

The results of the two independent sample *t*-test indicated that there were no significant differences in the *V-STM, V-WM, VS-WM* and *VS-STM* variables between the L1 and L2 groups. This implies that in terms of the dependent variables *V-STM, V-WM, VS-STM* and *VS-WM* there was no significant difference (at $p < 0.05$) between the performance of the L1 and L2 groups.

The results support earlier findings by authors such as Daneman & Carpenter (1980) who found that WM is the same for different people although how individuals used

WM differed. The results also confirmed the findings of the Lanfranchi & Swanson (2005) study insofar as it pertained to their Grade 1 group. In that study, the authors found no differences in WM performance or STM performance between their L1 and L2 groups who were in Grade 1. They concluded that WM and STM operated primarily as language independent systems at the level of Grade 1. In the present study no differences were found between the L1 and L2 groups either with STM or with WM. As expected, although there were individual differences among members of each group, the overall performance of the groups were not significantly different.

5.3 Relationship between performance on Working Memory measures and Reading Comprehension

Research conducted with monolingual adults indicated a correlation between WM task performance and reading and listening comprehension (Baddeley, 1986; Campbell, Dollaghan, Needleman & Janosky, 1997; Cowan, 1996; Daneman & Carpenter, 1980; Just & Carpenter, 1992; Weismer, Evans & Hesketh, 1999). Gathercole et al. (2004) indicated, however, that the contribution of WM to scholastic attainment varies considerably across the school years with WM having a greater influence on children's emerging literary skills during the early years of learning to read and write.

In the L1 group the only significant correlation was between *VS-WM* ($r = 0.43$, $p = 0.02$) and *reading-comprehension*. The results for the regression analysis showed that there was one contributing factor, *VS-WM* which accounted for 19% of the variance in *reading comprehension*. In reading comprehension the reader must first extract and decode words before trying to make sense of their meaning. Hence decoding plays an important part in reading comprehension. At Grade 1 level most learners are in Ehri's (2005) partial alphabetic phase and have not completely developed their reading skills and this would, in turn, impact on their comprehension ability. At this stage of reading development, learners are more dependent on visual codes than more advanced readers. According to Samuels (1994) beginner readers who have not yet achieved automaticity switch attention between decoding and comprehension in order to process text. Beginner readers rely more heavily on the Visual Memory component of the LaBerge-Samuels model than a more advanced reader since they decode more.

Swanson and Howell (2001) found a significant correlation between reading comprehension and a composite linguistic measure as well as to a composite visuo-spatial measure. In the study they looked at a group of 9 year olds and concluded that both V-WM and VS-WM contributed to the performance of reading comprehension. How is it then that VS-WM is a constraining factor in reading comprehension in this study while V-WM was not? The answer lies in the particular stage of reading competency that these learners were probably at. The visuospatial domain is implicated because of partially developed reading skills. In other words, VS-WM is being filled with the partial products of decoded words while the learner attempts to read these words. The amount of words the learner can decode in a given time impacts on the learner's level of comprehension of a given text. Thus it is that their VS-WM indirectly affects and constrains reading comprehension. Hence, although V-WM and VS-WM usually impact on reading comprehension, in this group VS-WM becomes "filled up" before V-WM does and therefore VS-WM is the constraining factor.

In the L2 group *reading-comprehension* was highly correlated with *V-WM* ($r = 0.747$, $p < 0.001$) and *V-STM* ($r = 0.67$, $p <0.001$) and moderately correlated with *VS-STM* ($r = 0.392$, $p = 0.03$) and *VS-WM* ($r = 0.477$, $p = 0.01$). In addition, 56% of the variance could be explained by the *V-WM* predictor while *V-STM* accounts for only 5% of the variance. In striking contrast to the L1 group where the visuospatial domain contributed the most variance, the verbal domain seems to be the constraining aspect in the L2 group.

The results agree with previous studies implicating V-WM and V-STM as variables that constrain comprehension in bilingual learners. Ardila (2003) noted that in bilinguals, brain activation patterns during WM tasks are observed to be more complex when L2 is being used suggesting that processing information in L2 is more demanding. WM may be less efficient when processing information in L2 since semantic search in L2 takes longer than it would for a monolingual. This serves to functionally decrease the capacity of WM available for processing.

The reason for this according to Kroll and de Groot (1997, as cited in McElree et al., 2000) is that in the early stages of L2 acquisition (as is the case with the unbalanced bilinguals in the L2 group), links between the L2 lexicon and the conceptual store are non-existent to weak and the primary means for L2 semantic processing is by translation to L1. Hence the same limited resources (verbal WM and verbal STM) are being used for semantic search and for reading comprehension in bilinguals. Memory resources in the verbal domain are therefore the constraining factor in the L2 group since both storage and processing resources are utilised for reading comprehension and for L2 language use.

In terms of the aims of the study it would appear that a correlation between working memory and reading comprehension as shown in previous studies (Baddeley, 1986; Campbell, Dollaghan, Needleman & Janosky, 1997; Cowan, 1996; Daneman & Carpenter, 1980; Just & Carpenter, 1992; Weismer, Evans & Hesketh, 1999) has been reproduced in each of the groups. However, since the current study utilised a measure that allowed for the composite memory scores to be broken up into four constituent parts, the results pointed to differences in which specific aspects of memory are correlated with *reading-comprehension* in each group. In the L1 group, the correlations are weak to moderate and the only significant correlation is between *VS-WM* and *reading comprehension*. In the L2 group, the correlations are moderate to high and all the correlations are significant. This might indicate that the entire memory system is utilised more by the L2 group as a result of the additional processing that takes place due to the use of two languages as well as the particular stage of reading proficiency that these learners are at.

5.4 Relationship between performance on Working Memory measures and Mathematical ability

Several studies have pointed to the crucial role played by working memory in both calculation and the solving of arithmetic word problems and one of the aims of the present study was to investigate this relationship with the L1 and L2 groups. For the

L1 group the correlations between the working memory measures and *mathematical ability* were weak and none of the scores were significant. The results of the regression analysis showed that there was only one significant contributing factor to *mathematical ability* in the L1 group and this was *VS-WM* which accounted for 11% of the variance. The latter result is in keeping with Reuhkala's (2001) study which showed that visuospatial working memory (VS-WM) played an important role in mathematical ability since mathematics often incorporates symbols or symbol combinations which utilize the visuospatial domain. Both the ability to temporarily store visuo-spatial information and the ability to mentally manipulate images, which reflect VS-WM capacity, are implicated in mathematical ability (Reuhkala, 2001). Further evidence for the importance of VS-WM in mathematical ability comes from Cornoldi *et al.* (1999) who observed that children with non-verbal learning disabilities, including mathematical disabilities, have VS-WM deficits.

In contrast to the L1 group, for the L2 group, all correlations between *V-STM*, *V-WM*, *VS-STM* and *VS-WM* and *mathematical ability* were moderate and significant. In addition, 28% of the variance for *mathematical ability* could be explained by the *VS-STM* predictor while *V-STM* accounted for only 11% of the variance.

The prediction that *V-STM* and *VS-STM* are the key factors to mathematical performance ability is interesting since both relate to storage only and not to processing. Gathercole et al. (2004) proposed that complex mathematical computations require much simultaneous processing and storage. This demand would necessarily put great strain on WM resources if language processing, including translation from L2 to L1, were to happen at the same time as mathematical computations and if partial products of both processes had to be stored.

Although studies such as Wilson & Swanson (2001) found that both verbal and visuo-spatial domains predicted mathematical performance, the implication of both domains in bilingual learners is particularly important. Translation from L2 into L1 or semantic searches happening concurrently with mathematical processing would explain why verbal and visuospatial domains were constraining factors in predicting mathematical performance in the L2 group but not in the L1 group and why storage and not processing was the constraining factor in the L2 group. Partial products of language translations as well as mathematical computations would compete for storage space.

Thus, although the study found no relationship between working memory and *mathematical ability* in the L1 group, the results pointed to a correlation between working memory and *mathematical ability* in the L2 group. The finding that VS-WM was a predictor for *mathematical ability* in the L1 group was not unusual nor was the implication of STM in both domains for predicting *mathematical ability* in the L2 group.

Hence, in addressing the research question regarding whether the relationship between working memory and *mathematical ability* would be different for the two groups, the answer is that it most certainly is. Cognitive functioning in one's second language, at a point when one is not equally proficient in the two languages, puts additional strain on cognitive processes and the ability to store the results of such processing. This effectively puts bilingual learners at a disadvantage when being assessed on complex cognitive functioning like mathematical tasks. Even where it would appear that performance in such measures are equivalent (as in the WIAT-Math measures), the results indicated that bilingual learners utilize more memory resources more intensely than monolingual learners.

5.5 Comparison of Relationships using Fisher z transformations

Pearson's correlation co-efficient is not normally distributed. This makes it difficult to compare the correlations computed in the two groups. Using Fisher's z transformation, however, allowed a comparison of the variables in the two groups. This showed that the groups differed only in their relationship between *V-WM* and *reading comprehension* where the Fisher z-score was **- 3.07** ($p < 0.05$). All other relationships between *V-STM, VS-STM* and *VS-WM* and *reading comprehension* were equivalent in the two groups. In addition the relationships between *V-WM, V-STM, VS-STM* and *VS-WM* and *mathematical ability* were equivalent in the two groups. What this means is that the way the variables (*V-WM, V-STM, VS-STM* and *VS-WM* and *mathematical ability)* relate to each other in each of the groups is equivalent. However, the way *V-WM* and *reading* comprehension specifically relate to each other is different in the two groups. One way of interpreting this would be that as the reading comprehension task gets more difficult, more V-WM resources are required by the individual. Another interpretation could be that as performance in reading comprehension improves, fewer V-WM resources are required by the individual since the memory resources function more efficiently. Unpacking the direction of influence or establishing causation is beyond the scope of this research. What has been shown, though, is that regardless of the nature of the relationship between *V-WM* and *reading comprehension*, it is nonetheless different in the L1 and the L2 groups.

5.6 Contribution to knowledge

The study aimed to compare how bilingual South African learners would fare in measures of WM compared to monolingual learners and whether the relationship between working memory and reading comprehension and between working memory and mathematical ability advocated by other studies would hold in these populations. The study also investigated whether the relationships between WM and reading comprehension and WM and mathematical ability would be different for the two groups. In this regard the study had both practical and theoretical contributions to make to existing knowledge.

In comparing the two groups of South African learners in measures of WM, this study provided substantial evidence for there being no significant differences in WM capacity between the two groups. This confirms the findings of other studies like that of Lanfranchi and Swanson (2005) that WM capacity is independent of language/s spoken. Thus the findings of other researchers can be extended to South African English monolingual and Afrikaans/English bilingual Grade 1 learners to show that working memory performance is not significantly different in the two groups.

The relationship between working memory and reading comprehension has also been shown in each of the groups. However, since the current study utilised a comprehensive working memory measure that allowed for the memory scores to be broken up into the component parts, the results point to differences in which specific aspects of memory were correlated with reading comprehension in each group. Firstly, it seemed that level of reading proficiency impacted on reading comprehension and secondly, in unbalanced bilingual learners, the verbal domain was under additional strain when simultaneous language processing and reading comprehension competed for the same resources. The study therefore pointed to bilingual learners utilising their working memory resources differently from monolingual learners.

With reference to the third research question, this study found no relationship between working memory and *mathematical ability* in the L1 group, but evidenced a correlation between working memory and *mathematical ability* in the L2 group. While confirming the involvement of the visuospatial domain in the L1 group it was in the implication of both domains in predicting *mathematical ability* in the L2 group that the study furthers current knowledge. Hence, in addressing whether the relationship between working memory and *mathematical ability* would be different for the two groups, the answer is that it most certainly is. Cognitive functioning in one's second language puts bilingual learners at a disadvantage when being assessed on complex cognitive functioning like mathematics. This indicates that the entire memory system is utilised more by the L2 group as a result of the additional processing that takes place due to the use of two languages.

The practical implications of the study are that learners who are bilingual or multilingual have the same WM capacity as monolinguals but performance in academic tasks might differ depending on their level of proficiency in their language of instruction due to having to simultaneously utilise the same resource for different cognitive processing tasks.

The broader implications of these findings are that it provides a strong argument for mother tongue education although this might not be a pragmatic or a desirable alternative. However, given that memory usage is more complex and more taxing for the bilingual learner, learners who are at risk academically for any reason should be given the choice to be instructed in their home language.

Furthermore, where mother tongue instruction is not possible, processing measures are preferable to traditional measures of crystallised knowledge when used with bilingual and multilingual learners. However, processing measures are themselves not completely unbiased especially when used with unbalanced bilinguals and results of such measures should be interpreted with caution.

Lastly, the findings of this study should inform the teaching strategies employed by educators of bilingual learners. By presenting tasks and teaching skills in a manner that takes into account the fact that bilingual learners use memory resources differently, educators and assessors can accommodate bilingual learners and ensure that each learner gets the maximum benefit of instruction.

It is for these reasons that the present study seems particularly relevant to South Africa both from a theoretical and practical point of view. Given the high incidence of bilingualism and multilingualism, it is imperative that any research that can contribute to a better understanding of the issues surrounding WM and bilingualism in South Africa especially from an education point of view be pursued to give each learner the opportunity to reach his/her full potential.

5.7 Threats to validity and limitations of the study

A study of this nature is by design focused and contained given the time frame available for its completion. Although every attempt has been made to make the study as representative as possible, the following factors may compromise the generalisability or external validity of the research results.

Firstly for the purposes of this study a relatively small sample (n = 61) was included. However, a small sample is less accurate as an estimation of the population than a larger sample would have been. This is compounded by the fact that convenience sampling was used. A purposive, non-probability sampling method, as utilised in this study, cannot guarantee that the sample is representative of the whole population and results of this study are thus not generalisable. However, learners were selected from a range of schools in different geographical areas, from different socioeconomic communities and from different ethnic backgrounds to ensure that a broad range of learners were included in the study and hence to make the sample as representative as possible.

Another factor was that the learners who participated in the study did not share an equivalent level of proficiency in English. The bilingual group was thus largely made up of unbalanced bilinguals. Some concepts and words included in the tests were unfamiliar to some of the children, which placed them at a disadvantage during testing. Bilingual learners also displayed greater difficulties with reading tasks. Thus bilingual learners' scores on both the *Word Recall* and *Reading Comprehension* tasks would have been affected. However, addressing issues of differing levels of language proficiency was beyond the scope of this study and is mentioned here so that other studies might take it into account. It would be interesting to know, for example, if balanced bilinguals displayed different patterns of memory usage compared to unbalanced bilinguals.

The third factor was that the AWMA subtest instructions and test items were presented by a female voice with a British accent. Although equally unfamiliar to all the participants, it presented a greater problem for some bilingual learners who failed to recognise familiar words like "hair", "fur" and "pill" because of the accent. This might have interrupted the processing part of the task, and was likely to have negatively impacted on the recall process. However, this was not something that could have been predicted beforehand and the problem with the accent only became apparent during the course of the data collection. It should be noted for any future research that aims to use the AWMA test battery.

Other factors that need to be considered are that each language pair poses a unique relationship because of the phonetic, phonological and syntactic nature of the languages. Therefore the results cannot be easily generalised to all other language pairs in South Africa but is restricted to Afrikaans/English bilinguals. The two languages used in the study have differing social statuses in different communities in South Africa and this might impact on the results in a different group of learners. In addition, bilingualism is intimately bound by socio-economic status. While every attempt was made to include learners from a variety of socio-economic neighbourhoods it could be a factor which clouds the differences between monolinguals and bilinguals and may inadvertently attribute advantages or disadvantages to one group or the other.

Finally it should be noted that all participants in this study were enrolled in their first year of schooling and the mean age of the two groups was equivalent. Thus is it is likely that they were at an approximately equivalent educational and cognitive developmental level which was necessary for comparison.

5.8 Directions for Future Research

In South Africa, the majority of children grow up to be bilingual or multilingual. For most of these children their first exposure to their second language happens as they enter formal education and are expected to simultaneously master a second language and gain skills in literacy and numeracy. Being educated in a second language impacts on how these learners utilize their working memory resources and this, in turn, could affect their progress towards success in literacy and numeracy.

While many studies have examined balanced bilinguals, the majority of bilinguals are not equally proficient in both languages. It is imperative in future research that this distinction be made. In addition, to fully understand the development of the relationship between working memory and reading comprehension or working memory and mathematical ability, a longitudinal study in which these two relationships are monitored is important. Finally, it would be beneficial to compare Afrikaans/English bilingual learners in their L1 and L2 and to investigate how those scores compare.

5.9 Conclusion

South Africa has 11 official languages and most of the population is bilingual or multilingual. Despite this, there is a disproportionately high demand for English-medium schooling and the prevalence of English-medium schools by far outweighs the number of other language medium schools in the country. Yet many young children starting school in South Africa have never encountered English before.

Research conducted with monolingual adults indicates a correlation between working memory (WM) task performance and reading, reading and listening comprehension, mathematical calculation and the solving of arithmetic word problems. Thus WM has been shown to be a predictor of progress towards early learning goals of literacy and numeracy.

Research also indicates that processing information in L2 is more demanding than corresponding processing in L1 and WM may appear to be less efficient when processing information in L2. Thus it would appear that WM is implicated in the production, reception and utilisation of two languages.

This research attempted to bring together these two threads by exploring the capacity of working memory and the role of working memory in reading comprehension and mathematical ability in two populations: a monolingual English group (L1) and a bilingual Afrikaans/English group (L2).

The first aim of the study was to compare working memory capacity in the L1 and L2 groups. No significant differences were found. The second part of the study addressed the relationship between reading comprehension and working memory and the relationship between mathematical ability and working memory in the two groups.

The research concluded that bilinguals made extensive simultaneous use of WM both for semantic processing of their non-dominant language and for complex cognitive processing like reading comprehension and mathematics. While the working memory capacity for monolingual and bilingual learners appeared to be equivalent, the way the resources are allocated during complex cognitive tasks differed in the two groups.

As Bialystok et al. (2005) pointed out, the acquisition of literacy is a crucial phase in a child’s life and the repercussions of the outcomes of literacy acquisition are far reaching. If the use of two languages and academic tasks compete for the same limited capacity WM resources, then it is important for researchers, parents, educators and other stakeholders to actively aim to understand the interplay of bilingualism and complex cognitive tasks and the effect of both on working memory so that learners' education is not compromised.

WM provides an essential interface between the methods and concepts adopted by fields like cognitive psychology, neurobiology and psycholinguistics. It seems certain that working memory will continue to be a lively area of research and that it will play a productive role in still other areas in the future. However, WM measures used with bilinguals must be interpreted with caution.

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7 Appendices

Appendix A – Dept. of Education clearance certificate

Appendix B. – Letter to the Principal

Dear Sir/Madam,

WORKING MEMORY CAPACITY IN GRADE 1 LEARNERS

Further to our telephone conversation, herewith the information regarding my research. My name is Tahiti van Rooyen and I am undertaking the following research as part of my MA Clinical Psychology degree at the University of the Witwatersrand. The reason for this letter is to request permission for the Grade 1 learners at your school to participate in a research project.

In 1986, Alan Baddeley, a UK-based researcher published a book explaining a new concept "Working Memory". This is like short-term memory but helps us to keep information in mind while we are working on certain tasks. For example, you use working memory to keep a whole sentence in mind so that you can make sense of all the individual words. You also rehearse a telephone number until you have dialled it. These tasks use working memory. Baddeley also reported that there was a relationship between working memory and comprehension, reading and mathematics.

At present there is a test that is used in the United Kingdom to measure working memory capacity in young children. I would like to use it on a group of South African Grade 1 learners together with a short test of reading; spelling and mathematics. I would like to investigate the learners' working memory capacity as well as the relationship (if any) between that capacity and their scholastic abilities. The purpose of the research therefore is to gather data on South African learners and to attempt to replicate the findings between working memory and scholastic ability.

The research will be done as follows:

Permission has been obtained from the Department of Education for the study. If you, having read this letter, also give consent, then each Grade 1 parent will receive a letter of information giving details of the study. Parents, who agree to let their children participate, will have to fill in the consent form and return it to their child's teacher. The parents will then be sent a questionnaire which they will be required to fill in. This questionnaire asks for information about their child. It also asks some questions about the parents, which is optional. Their child will also have to fill in an assent form agreeing to participate.

The information to participate, the information in the questionnaire and the information gathered from the learners is all STRICTLY CONFIDENTIAL and my supervisor, my research assistant and I are the only people who have access to that data. All data will be coded so that the learner's name does not appear on any assessment sheets. The research focus is on group performance so no individual reference is made to a learner.

Once I receive the questionnaires back I, or my research assistant, will arrange with the class teacher to meet with a learner for an hour at your school. The testing will be done outside the classroom in an area of the school that is free from distractions at a time that is suitable for the teacher and the learner. The learner will be asked to answer questions appropriate for his/her age relating to language/memory, spelling, reading and mathematics. These tasks are presented to the learner as “games” and are generally perceived as fun by most children. The total testing time will be about 1 hour per child with breaks in between as deemed necessary. The tasks are designed to be interesting but short.

If the learner does not want to do the testing on a particular day or changes his/her mind about being in the study, they will be allowed to do so with <u>no consequences</u>. You or the parent may also withdraw permission to participate with no consequences should you feel the need to. <u>Participation is voluntary</u>. There are no risks or benefits to participating in this study. Therefore the learner will not be at an advantage for participating in the study neither will he/she be at a disadvantage for not participating.

All the results are grouped – no learner is ever mentioned by name in any written or spoken report. The results are calculated for the group as a whole. Since the present research is part of a much larger study concerning Working Memory, the data will be preserved for later use. However, the learner’s name will not appear on any tests or documents. A report stating the findings of the study will be communicated to your school once the study has been completed.

Should you want more details about the study please contact me at tahiti@icelogic.co.za or you can call me on 083 250 1942 (a/h). A full research proposal is available for your perusal. Please let me know if you would like a copy. Should you decide that your school will participate, could you kindly <u>**indicate your**</u>

decision in writing and forward to me at the following address: 37 North Rd, Linden Ext, 2194.

Sincerely,

Tahiti van Rooyen

Appendix C – letter/consent form to the parent

5 May 2006

Dear Parent,

WORKING MEMORY CAPACITY IN GRADE 1 LEARNERS

My name is Tahiti van Rooyen and I am undertaking the following research as part of my MA Clinical Psychology degree at the University of the Witwatersrand. The reason for this letter is to invite you and your child to participate in the research project.

In 1986, Alan Baddeley, a UK-based researcher published a book explaining a new concept “Working Memory”. This is like short-term memory but helps us to keep information in mind while we are working on certain tasks. For example, you use working memory to keep a whole sentence in mind so that you can make sense of all the individual words. You also rehearse a telephone number until you have dialled it. These tasks use working memory. Baddeley also reported that there was a relationship between working memory and comprehension, reading and maths.

At present there is a test that is used in the United Kingdom to measure working memory capacity in young children. I would like to assess its usefulness for South

African Grade 1 learners together with a short test of reading, spelling and mathematics.

The research will be done as follows:

If, having read this letter of information, you agree to let your child participate, you will have to fill in the consent form and return it to your child's teacher. Your child will also have to fill in an assent form agreeing to participate. You will then be sent a questionnaire which you will be required to fill in. This questionnaire asks for information about your child. It also asks some questions about you, which is optional.

The information is STRICTLY CONFIDENTIAL and my supervisor, my research assistant and I are the only people who have access to the data. All data will be coded so that your child's name does not appear on any assessment sheets. The research focus is on group performance so no individual reference is made to your child. If you and your child agree to participate in the study, I will then arrange to meet with your child for an hour at his/her school.

The testing will be done outside the classroom in an area of the school that is free from distractions. Your child will be asked to answer questions appropriate for his/her age relating to language/memory, spelling, reading and mathematics. These tasks are presented to the child as 'games' and are usually perceived as non-stressful. The total testing time will be about 1 hour and your child will be given a break in between. The tasks are designed to be interesting but short. There are no risks or benefits to participating in this study so your child will not be at an advantage for participating in the study neither will he/she be at a disadvantage for not participating.

If your child does not want to do the testing on the day or changes his/her mind about being in the study, they will be allowed to withdraw from the study with no consequences. You may also withdraw your permission to participate with no consequences. Participation is voluntary.

All the results are grouped – your child will never be mentioned by name in any written or spoken report. The results are calculated for the group as a whole. Since the present research is part of a much larger study concerning Working Memory, the data will be preserved for later use. However, the learner's name will be removed and will not appear on any tests or documents. A report stating the findings of the study will be communicated to the Principal of the school once the study has been completed. Please provide your address should you wish this information to be sent to you as well. If in the course of testing there is reason for concern based on the tests administered and the scores obtained by your child, I would be willing to communicate that to you in confidence. Please indicate your preference on the consent form.

If you are interested, please discuss the study with your child. It is important that you both understand the nature of the study and what will be expected of you before you consent to participate. Then sign below and *return the consent form* to your child's teacher at your earliest convenience. The questionnaire will be mailed to you shortly.

Should you want more details about the study please contact me at tahiti@icelogic.co.za or you can call me on 083 250 1942 (a/h).

Many thanks

Tahiti van Rooyen

✂---

I,________________________________, consent / do not consent to participate in the research study to be conducted by Tahiti van Rooyen and described in the document above. I have discussed the matter with my child and he/she has signed the accompanying letter of assent.

I understand that:

The information gathered is strictly confidential

There are no risks or benefits to my child in participating in this research

I have the right to withdraw permission for my child to participate at any stage of the study with no consequences to either myself of my child

My child has the right to withdraw from the study at any stage with no consequences to himself/herself

My child has the right to refuse to answer questions in the study

Name of Parent: ____

Signature: _________________________ Child's Name: ___________________

Date: _____________________________

Address if you want feedback on the study to be posted to you at home

Should there be reason for concern in any of the tests administered or the scores obtained by your child, would you like to be contacted and informed of the nature of the concern? ____

Appendix D - Biographical Questionnaire

Dear Parent/Guardian,

Thank you for consenting for your child to participate in the study. Please fill in the following questionnaire.

To be filled in by researcher

Group: L1 L2

Research No: ________________________________

....

Learner Information

Name: ____________________________________

Date of Birth: _____________________________________

Gender:

M	F

Language spoken at school: _________________________________

Period of exposure to language used at school: __________________

Language spoken at home: __________________________________

Are any other languages spoken by your child? __________________

Has your child ever experienced neurological or emotional difficulties? Please explain____

____

Has your child ever experienced any learning difficulties?

Please explain____

____

Is your child repeating Grade 1?

Y	N

Parent Information (optional)

Mother's highest level of education: ____________________________________

Father's highest level of education: _____________________________________

Appendix E – Letter of Assent

Dear Grade 1 learner,

My name is Tahiti van Rooyen and I am doing some work on how children remember words, numbers and pictures. I would like to ask you a few questions about remembering, spelling words, reading and counting. These tests help me to understand what things you can remember. The questions are a lot like the things your teacher asks you to do in class.

I will come to your school and we will work there in a quiet place. There are lots of different things to do but we will stop in between so that you can take a break. If you don't feel like doing the tests or you don't feel like answering some of the questions, you just have to tell me and then we will stop. Any of the answers you give me will just be between us. I won't tell anybody else what you said. The questions that I ask you are not harmful or dangerous and they are not going to help you get better at your school work. If you take part in my study it will not affect your school work at all.

If you want to take part in my study and would like me to ask you questions about reading, spelling and counting, then please write your name on the line below.

✂---

I,________________________________, agree to participate in the research study to be conducted by Tahiti van Rooyen and described in the document above.

I understand that:

The information gathered is strictly confidential

There are no risks or benefits to participating in this research

I have the right to withdraw from the study at any stage with no consequences to myself

I have the right to refuse to answer questions in the study

Date: ____________________________________

Appendix F – Ethics clearance certificate

Appendix G - Kolmogorov-Smirnov Test of Normality

Table I: Kolmogorov-Smirnov Test of Normality of all composite scores for the L1 and L2 groups

L1 (n = 30)			L2 (n = 31)		
Variable	**Statistic (D)**	**p-value**	**Variable**	**Statistic (D)**	**p-value**
V-STM	0.13	**ns**	V-STM	0.10	**ns**
V-WM	0.14	**ns**	V-WM	0.13	**ns**
VS-STM	0.08	**ns**	VS-STM	0.10	**ns**
VS-WM	0.11	**ns**	VS-WM	0.16	**ns**
WIAT Comp	0.12	**ns**	WIAT Comp	0.12	**ns**
WIAT Math	0.18	**ns**	WIAT Math	0.13	**ns**
RCPM	0.13	**ns**	RCPM	0.10	**ns**

Key: V-STM = Verbal Short-term Memory, V-WM = Verbal Working Memory, VS-STM = Visuo-spatial Short-term Memory and VS-WM = Visuo-spatial Working Memory, WIAT – Comp = *reading-comprehension,* WIAT- Math = *mathematical ability* and *RCPM* = Raven's Coloured Progressive Matrices.

Note: **ns** = not significant