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The Differential Contributions of Auditory-verbal and Visuospatial Working Memory on Decoding Skills in Children Who Are Poor Decoders

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THE DIFFERENTIAL CONTRIBUTIONS OF AUDITORY-VERBAL AND VISUOSPATIAL WORKING MEMORY ON DECODING SKILLS IN CHILDREN WHO ARE POOR DECODERS

by

Katie Ellen Squires

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Disability Disciplines

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UTAH STATE UNIVERSITY
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ABSTRACT

The Differential Contributions of Auditory-Verbal and Visuospatial Working
Memory on Decoding Skills in Children Who Are Poor Decoders

by

Katie E. Squires, Doctor of Philosophy

Utah State University, 2013

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This study investigated the differential contribution of auditory-verbal and visuospatial working memory (WM) on decoding skills in second- and fifth-grade children identified with poor decoding. Thirty-two second-grade students and 22 fifth-grade students completed measures that assessed simple and complex auditory-verbal and visuospatial memory, phonological awareness, orthographic knowledge, listening comprehension and verbal and nonverbal intelligence.

Bivariate correlations revealed that complex auditory-verbal WM was moderately and significantly correlated to word attack at second grade. The simple auditory-verbal WM measure was moderately and significantly correlated to word identification in fifth grade. The complex visuospatial WM measures were not correlated to word identification or word attack for second-grade students. However, for fifth-grade participants, there was a negative correlation between a complex visuospatial WM measure and word attack and a positive correlation between orthographic knowledge and word identification.

Different types of WM measures predicted word identification and word attack ability in second and fifth graders. We wondered whether the processes involved in visuospatial memory (the visuospatial sketchpad) or auditory-verbal memory (the phonological loop), acting alone, would predict decoding skills. They did not. Similarly, the cognitive control abilities related to executive functions (measured by our complex memory tasks), acting alone, did not predict decoding at either grade. The optimal prediction models for each grade involved various combinations of storage, cognitive control, and retrieval processes. Second graders appeared to rely more on the processes involved in auditory-verbal WM when identifying words, while fifth-grade students relied on the visuospatial domains to identify words. For second-grade students, both complex visuospatial and auditory-verbal WM predicted word attack ability, but by fifth grade, only the visual domains predicted word attack.

This study has implications for training instruction in reading. It was not the individual contributions of auditory-verbal or visuospatial WM that best predicted reading ability in second and fifth grade decoders, but rather, a combination of factors. Training WM in isolation of other skills does not increase reading ability. In fact, for young students, too much WM storage can interfere with learning to decode.

(157 pages)

PUBLIC ABSTRACT

The Differential Contributions of Auditory-Verbal and Visuospatial Working Memory on Decoding Skills in Children Who Are Poor Decoders

by

Katie E. Squires, Doctor of Philosophy

Utah State University, 2013

This study investigated the unique contributions of simple and complex auditory-verbal and visuospatial working memory (WM) in isolation or in conjunction with other skills known to affect decoding such as phonological awareness, orthographic knowledge, and nonverbal and verbal intelligence. Thirty-two second-grade students and 22 fifth-grade students, all identified as poor decoders, participated in this study.

For the second-grade students, a measure of complex auditory-verbal WM was correlated with word attack (reading psuedowords). For fifth-grade participants, there was a negative correlation between a complex visuospatial WM measure and word attack. A measure of simple auditory-verbal WM was correlated to word identification (reading real words) in fifth grade.

Different combinations of WM measures predicted word identification and word attack ability in second and fifth graders. Second graders appeared to rely more on the processes involved in auditory-verbal WM when identifying words, while fifth-grade students relied on the visuospatial domains to identify words. For

second-grade students, both complex visuospatial and auditory-verbal WM predicted word attack ability, but by fifth grade, only the visual domains predicted word attack.

It appears that the storage and attentional control mechanisms in working memory make differential contributions to decoding at second and fifth grade. For second graders, it was a complex auditory-verbal WM measure that required high cognitive control that was most predictive of word identification. The auditory-verbal WM measure that required high cognitive control also was predictive of word attack in second-grade students. The second-grade students were still utilizing the phonological loop to sound out real words, so it makes sense that a measure that requires equal amounts of attentional control and storage would be related to decoding. The complex visuospatial WM measures negatively predicted word attack in these students, suggesting that higher visuospatial capacity was a hindrance to decoding pseudowords. This may have happened because the second-grade students had large visuospatial WM capacities, but they were significantly impaired in their decoding skills. They were not at the stage in their reading development to utilize their visuospatial WM resource efficiently. At this stage in their development, second graders need to be explicitly taught to attend to graphemic and phonemic cues, hold the focus of their attention on critical information for longer periods of time, and then shift their attention back to critical information when it is necessary.

In fifth-grade students, we saw a shift from reliance on auditory-verbal WM to visuospatial WM. It was orthographic knowledge that best predicted word identification in fifth-grade students, suggesting that at this grade level, decoding primarily involves identifying word patterns rather than sounding out words one phoneme at a time. In fact, we saw that fifth-grade students did not attempt to sound out unfamiliar words. This change in the influence of WM on decoding may relate to a curricular change as students go from “learning to read” to “reading to learn.”

Similar to the second-grade students, the visuospatial WM measures negatively predicted word attack scores in the fifth graders. This finding indicates that when there is a large discrepancy between visuospatial WM and decoding abilities, the visuospatial WM actually impedes reading performance. These students may be so dependent on identifying words by sight, that when they encounter a pseudoword not available in their large repertoire of stored representations, they become discouraged and cease trying to decode the word.

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I give all glory to God, who granted me the strength to complete this degree and whom I desire to honor in everything I do.

Katie E. Squires

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CHAPTER I

INTRODUCTION

Many children who struggle to learn to read have their primary deficit within the decoding aspect of reading, as opposed to the comprehension aspect of reading or a combination of both decoding and comprehension (Hoien-Tengesdal & Tonnessen, 2011). When children struggle with reading decoding, there are several underlying mechanisms that may impede their progress. Research suggests that phonological awareness (Boada & Pennington, 2006), orthographic processing (O'Brien, Wolf, Miller, Lovett, & Morris, 2011), vocabulary knowledge (Berends & Reitsma, 2006), working memory (Menghini, Finzi, Carlesimo, & Vicari, 2011), and attention (Facoetti et al., 2006) all contribute to the ability to decode words.

The relationship between working memory (WM) and decoding has been investigated in a number of studies. Many researchers have argued that WM plays an integral role in learning to read (Savage, Lavers, & Pillay, 2007) because it involves the temporary storage and cognitive manipulation of phonological and orthographic information (Baddeley, 2003). Children who are not able to manipulate new phonemes while keeping the old phonemes in mind, a skill required in word decoding, should have difficulty learning to read. Alloway, Gathercole, Kirkwood, and Elliott (2009) have demonstrated that 10 to 15% of young children exhibit poor WM skills. These same researchers found that there was a cumulative effect for WM deficits over time. Older children tend to fall farther and farther behind their typically developing peers even though their WM capacity remains stable over time, so WM may play a larger role in word decoding ability as children mature.

Many studies have been conducted to look at the effects of WM, and there is a consensus that WM contributes to reading ability. However, little is known about the differential contributions of visuospatial and auditory-verbal WM, lower or higher levels of cognitive control, or the effect of age on decoding abilities of children with reading difficulties. Visuospatial and auditory-verbal WM appear to be processed in different areas of the brain. The phonological loop, responsible for processing auditory information, appears to be correlated with word decoding abilities at a young age when children are sounding words out one phoneme at a time. The visuospatial sketchpad, located in the right hemisphere, is thought to be predictive of identifying orthographic patterns in words. Children usually attend to phonemic cues before orthographic cues, so it is expected that auditory-verbal WM would predict reading ability in students at earlier stages of decoding, while visuospatial WM would predict reading in older students who are decoding automatically. To address this gap in the literature, this study assessed the independent and multiple linear relationships between simple and complex visuospatial and auditory-verbal WM and two measures of word decoding in second and fifth graders with poor decoding skills.

CHAPTER II

LITERATURE REVIEW

Working Memory Overview

A generally accepted and influential model of WM proposed by Baddeley and Hitch in 1974 and updated by Baddeley in 2000 describes a storage and retrieval process that involves a visuospatial sketchpad, a phonological loop and an episodic buffer that are interconnected by a central executive system. The visuospatial sketchpad interacts with tasks requiring visual semantics; the episodic buffer interacts with tasks requiring episodic long- term memory; and the phonological loop interacts with tasks requiring language (Baddeley, 2000). The central executive works to coordinate and control a variety of cognitive processes associated with the visuospatial sketchpad, the phonological loop, and the episodic buffer. Although this model was initially proposed as an account of WM in adults, there have been numerous studies with children that imply a developmental improvement in WM as they age (Baddeley, 1986). Memory span increases from four to eight years of age and gradually improves every year after that until leveling off around twelve years of age (Gathercole, 1999). These increases have been attributed to processing efficiency and attentional capacity (cognitive control).

For many years, WM had been assessed with simple span measures in which the participant was required to immediately recall a set of items in their correct serial order. The phonological loop, which is activated for auditory stimuli, was evaluated by having participants recall verbally presented stimuli immediately after hearing the last item in the list. The visuospatial system, which is activated for visual stimuli, was evaluated in a similar manner for stimuli presented visually.

Complex span measures were developed to test the theory that WM involved both storage and manipulation (Unsworth & Engle, 2006) Complex span measures are similar to simple span measures in that participants are required to recall information, but they incorporate a processing activity that occurs before the recall measure. This processing activity interferes with the participant correctly retrieving the stored data. For example, in 1980, Daneman and Carpenter developed a complex span measure that required participants to read a block of sentences one at a time. Participants judged the truthfulness of each sentence immediately after reading it. After a block of sentences was read, participants were asked to recall the last word of each sentence. Complex span measures were designed to more closely mimic the types of processing required in higher-cognitive functions such as reading comprehension, solving mathematical equations, and solving problems.

The data from these types of measures suggests that there is a trade-off between processing (cognitive control) and storage functions of WM. Individuals with reasonably good storage processes but poor cognitive control have fewer problems on simple visuospatial or simple auditory-verbal WM measures because the tasks are minimally affected by interference (Engle, 2010). In other words, because the simple WM measures do not require processing or manipulation of the data before retrieval, individuals with limited cognitive control can still successfully complete the tasks. However, individuals with poorer cognitive control recall less information when they are required to perform WM tasks with higher interference (i.e. complex visuospatial or complex auditory-verbal WM measures) because they make more demands on executive function processes. Therefore, comparison of simple and complex WM tasks can reveal differential contributions of storage and cognitive control processes because the individual differences in WM capacity are not about storage, but they are about storage and cognitive control (Engle & Kane, 2004).

The trade-off between cognitive control and storage may have implications for reading. In order to read efficiently, individuals must be able to automatically connect graphemes to phonemes and instantly recognize the orthographic patterns in multi-letter units. Phonological processing is an auditory skill that is developed in the absence of print. Orthographic processing can be conceptualized as a visually mediated ability to analyze and recognize letters and letter strings (Katzir et al., 2006). Both processes are needed to read fluently. Efficient readers who can decode text effortlessly are left with more capacity to store and maintain information, but poor readers must expend more resources for processing the text and have little left to store or maintain it.

There is some support for the idea that cognitive capacity, as measured by working memory tasks, plays an important role in reading. Daneman and Carpenter's (1980) research on WM was followed by other studies investigating complex span measures over the next thirty years. Many researchers agreed with Daneman and Carpenter and came to the conclusion that complex span measures were more highly correlated with measures of higher order cognition, including reading, than the simple span measures that had been used to assess WM up to that point (Unsworth & Engle, 2007). Because simple and complex span measures shared basic storage and retrieval processes (rehearsal, maintenance, updating), they are highly correlated with each other (Unsworth & Engle, 2007). However, they differ in that complex span measures require more cognitive control processes while the storage processes are occurring. Daneman and Carpenter (1980) argued that it was the inclusion of the processing component that made complex span measures more predictive of activities requiring higher order cognition (such as reading) than their simple counterparts.

However, not everyone agreed with the notion that only complex span measures correlated highly with higher-order cognition. For example, La Pointe and Engle (1990) argued that simple word span measures could predict comprehension as well as complex span measures. In their simple span experiment, college students read a list of words ranging in syllable length from one to four and recalled as many as they could after a set period of time. For the complex span experiment, the students listened to sentences and were presented with a word to be remembered at the end of each sentence. After a specified period of time, they recalled the words that appeared at the end of each sentence. A standardized measure of reading comprehension was used as the dependent measure. La Pointe and Engle demonstrated in their experiment that the reading comprehension was correlated with both simple and complex word span measures. Unsworth and Engle (2007) contended that although simple and complex span tasks measure the same basic processes, they differ in how the processes influence a particular measure. Furthermore, they suggested that other factors such as scoring methods, administration procedures, and age of the participants affect the outcomes created by simple or complex span measures.

Although simple span measures may be able to predict higher-level cognition as accurately as complex span measures, many researchers accept complex span measures as a better index of WM than simple span measures. The question may arise, "Why should we care about the correlation of complex WM measures and decoding when automatic decoding is usually considered to be a lower-level cognitive process?" Indeed, for typical readers, WM is not correlated to word decoding (Hannon, 2013). To shed light on this question, the reader is referred to the information-processing model proposed by Samuels (1987). According to this perspective, fluent decoders automatically recognize words and do not need to allocate much attention to the task. The processing component is bypassed, and the words are stored. In comparison, poor decoders need to allocate so much attention to decoding that they are left with few resources to blend sounds together and recognize them as a word. Although decoding is a lower-level cognitive skill for fluent readers, it is a higher-level cognitive skill for the poor decoder because it requires the child to process the word explicitly before being able to store it.

Each of the components of WM and the simple and complex measures used to assess them will now be described in greater detail.

Phonological Loop

The phonological loop can be divided into two subcomponents, a temporary storage system that holds information, and a second component that acts as a rehearsal system so that the information held in the temporary storage system does not decay (Baddeley, 2003). As suggested by the name, the phonological loop stores information that is presented or can be encoded verbally. Neuroimaging studies of people with deficits in the phonological loop suggest it is located in the left hemisphere of the brain (Salmon et al., 1996). The left temporoparietal brain regions have been shown to play a role in phonological processing during word reading (Hoeft et al., 2007). In fact, intervention studies have shown that as a poor decoder becomes a more proficient reader by participating in phonologically based remediation programs, the occipitotemporal junction (in the left hemisphere) becomes increasingly engaged for reading tasks and the activation patterns in the left hemisphere mimic more closely that which is seen in typical readers (Sandak et al., 2004; Shaywitz et al., 2004).

For over three decades, researchers have noted that poor readers have unusual difficulty with the phonological aspects of learning to read (Wallach, Wallach, Dozier, & Kaplan, 1977). Baddeley (1986) proposed that the phonological loop is especially instrumental in young children targeting word attack skills, and becomes less important as the child begins to rely on other less phonologically based skills. If this hypothesis were true, one would expect the contributions of auditory-verbal WM to be greatest in young children decoding pseudowords, with auditory-verbal WM becoming less predictive as the child matures and reading becomes more automatic. In fact, there is evidence that different aspects of cognitive processing correlate more heavily with either word attack or word identification at different points in time. For example, in a study conducted by Kirby, Parrila, and

Pfeiffer (2003), phonological awareness was highly correlated to word attack skills in kindergarten, but was not so highly correlated by fifth grade. In contrast, by fifth grade, rapid automatized naming (how quickly a child retrieves the name of an item) was more predictive of word reading ability.

Complex span measures that are meant to engage the phonological loop present a verbal processing task before the participant is required to recall specific stimuli. Kane et al. (2004) reviewed three types of verbal complex measures: operation span, reading span, and counting span. In the operation span measure, participants were required to perform a mathematical task and read a word. At the end of the mathematical equations, the participant had to recall the words in the order given. In the reading span measure, participants read a series of sentences followed by a single letter. Some of the sentences made sense, while others did not. The participants had to determine if the sentence made sense as they read them. After reading all the sentences, participants were to recall the letters in order. In the counting span measure, participants had to count the number of dark blue circles in a display and verbally announce the number. The display disappeared and either a new display or the same display appeared. If it was the same display, the participant had to recall all the numbers of dark blue circles that appeared before the duplicate display appeared.

Visuospatial Sketchpad

This component of WM integrates spatial and visual information so that it can be temporarily stored and manipulated (Baddeley, 2003). The visuospatial sketchpad stores information that is presented or can be encoded visually. The visuospatial sketchpad is represented in the right hemisphere, specifically in areas associated with visual and motor activities and language perception and processing (Baddeley, 2000). Interestingly, there is converging evidence regarding the neural signature of dyslexia showing that neurobiological anomalies in dyslexia are mainly focused in the posterior left hemisphere, specifically when processing words and pseudowords, with the right-hemisphere posterior regions and inferior regions in both hemispheres serving in compensatory roles by mediating phonological performance in dyslexic readers (Pugh et al., 2000a, 2000b). In other words, other areas of the brain that are not typically used in reading intervene to assist the reader in unlocking the code for reading.

While there is evidence from the neuroimaging literature concerning the brain activation patterns of poor decoders, there is a notable absence of studies that use behavioral measures to explain this phenomenon. For example, Swanson and Jerman (2007) examined the role of WM on reading growth in children with reading disabilities utilizing only phonological WM measures.

Researchers have developed tasks to measure visuospatial WM, but they have not been extensively used to predict reading skills. Kane et al. (2004) discussed three types of complex span tasks used to measure visuospatial WM: rotation span, symmetry span, and navigation span. In rotation span measures, the participant looked at a letter (G,R, or F), that was rotated one of eight ways, decided whether the letter was normal or mirror-reversed, and then viewed a short or long arrow. At the conclusion of the processing task, the participant had to recall the order of arrows for the series. For the processing portion of the symmetry span measure, participants had to decide whether a square matrix composed of black cubes in an 8 x 8 design was symmetrical along its vertical axis. This was followed by a brief red square display. When the processing component was complete, the participants had to recall, in order, the location of the red squares. In the navigation span, participants viewed one of two uppercase outlined letters (E, H) that were marked with a starting point. They had to begin at the starting point and trace the outline of the letter all the way around to get back to the starting point. They had to decide if the ending point was on the top of the letter or the bottom of the letter. The letter disappeared and a ball navigated across the screen. At the end of the processing measure, the participant had to recall the direction of the ball's journey for the series.

Frijters et al. (2011) suggested that because most of the focus has been on phonological awareness and rapid naming, many cognitive and neuropsychological constructs related to visual WM have been ignored as they relate to reading.

Episodic Buffer

The episodic buffer binds information together from a number of sources into larger chunks of information that can be stored more efficiently (Baddeley, 2003). The job of the episodic buffer is to integrate information across memory subsystems and allow those subsystems to interact with long-term memory. It appears that the episodic buffer integrates auditory-verbal and visuospatial information to optimize working memory performance, but cognitive control is needed to keep the items from being destroyed by competing stimuli (Baddeley, Allen, & Hitch, 2010). The episodic buffer has limited capacity and appears to be controlled by the central executive system (Baddeley, 2000). Episodes are retrieved from the episodic buffer through conscious awareness (Baddeley, 2000).

Although it is quite likely that the episodic buffer is located in numerous areas of the brain, fMRI studies indicate involvement of the right frontal lobes. Participants showed greater right frontal activation when presented with verbal and visuospatial integrated information as opposed to unintegrated information (Prabhakaran, Narayanan, Zhao, & Gabriel, 2000). The unintegrated information activated posterior regions in the brain normally implicated in verbal and visuospatial working memory tasks.

Central Executive

The central executive works in tandem with the visuospatial sketchpad, phonological loop, and episodic buffer to provide attentional control of WM. Executive processes, such as attention, have been argued to be a principal factor in determining individual differences in WM (Baddeley, 2003). Recall that Unsworth and Engle suggested that simple and complex span tasks measure the same basic processes, but that they differ in how those processes influenced a particular task. The processes that share the variance between simple and complex span tasks are housed in the central executive. Unsworth and Engle (2007) propose that this common variance is what is responsible for predicting higher order cognitive tasks.

Engle (2010) further argued that the core of individual differences in WM capacity is the ability to have the cognitive control necessary to attend to the task. Simple WM tasks, which only demand storage, require minimal cognitive control. Complex WM tasks, which demand both processing and storage, require higher levels of cognitive control. The more interference created in the task increases the level of cognitive control necessary to successfully complete the task. In other words, more cognitive control is necessary when an individual has to process or manipulate stimuli while simultaneously holding other stimuli in memory. Even within complex tasks, there are different levels of cognitive control. Complex tasks that demand processing and storage require moderate levels of cognitive control. Complex tasks that demand processing, decision making, and storage require high levels of cognitive control.

Unsworth and Engle (2007) proposed that individuals with low WM capacities are more vulnerable to the effects of interference with storage and retrieval mechanisms that comes from having to perform multiple cognitive processes during a task. For example, they found that when individuals with low WM capacity participated in a span task that required them to solve an operation and then remember a letter, they had difficulty retrieving the appropriate letter if it was not the first one in the sequence. They were unable to inhibit previous representations, so they searched through the emerging list and items from previous lists. On the other hand, individuals with high WM capacities were able to inhibit the activation of items from previous lists, so they could search the emerging lists for the required information. These individuals with high WM capacities used their cognitive control to successfully complete the task. Thus, Engle equated WM capacity with higher levels of cognitive control. He proposed that it was cognitive control, rather than storage, that developed in the high WM capacity individuals.

Domain-Specific vs. Domain-General Processes

Naturally, the question is raised that if the phonological loop, visuospatial sketchpad, and episodic buffer have storage and control components, and the central executive provides the executive processes necessary to coordinate those components, how much do the various aspects of processing (storage or control) contribute to complex measures such as reading? There is no direct answer to this question. Some researchers argue that processing and storage are not correlated to performance on complex measures; some claim a negative correlation; while others show a positive correlation. For example, Unsworth, Redick, Heitz, Broadway, and Engle (2009) found that processing time and storage were negatively correlated, a discovery that was in line with Daneman and Carpenter's (1980) finding that processing and storage compete for limited resources. In Unsworth et al. (2009) participants between the ages of 18 and 35 were asked to complete computerized versions of three types of complex span measures (operation, reading, and symmetry). The researchers collected processing speed, processing accuracy, and percentage of data correctly recalled from storage. The results revealed that processing accuracy and time were negatively correlated at -.49, while processing accuracy and storage recall were positively correlated at .61. This finding also supports Towse, Hitch, and Hutton (1998) who suggested that time spent processing takes away from time spent rehearsing, and therefore, the items that decay are lost and cannot be restored. Furthermore, Unsworth's team discovered that processing accuracy and processing time did not provide the same index of processing efficiency, with accuracy providing unique information over and beyond the contributions of speed and storage. Finally, they discovered that after controlling for processing performance, storage was related to higher-order cognitive performance. They determined that complex span measures rely on many processes that relate to higher-order cognitive measures. However, they studied the young adult population, so their findings may not generalize to elementary students.

Kane et al. (2004) studied a population of young adults using a latent variable approach to examine whether auditory-verbal and visuospatial WM capacity reflected a domain general construct. Three complex span tasks, each designed to measure auditory-verbal and visuospatial WM, three simple span tasks, designed to measure simple auditory-verbal and visuospatial memory, as well as tests of verbal and spatial reasoning and general fluid intelligence were administered to participants. The span tasks were the same, with the exception of the inclusion of a processing component in the complex span tasks. A path model for confirmatory factor analysis revealed the complex span WM measures reflected a domain general factor, whereas the simple span measures were much more domain specific. These findings suggest that while domain specific storage and rehearsal processes contribute to WM performance, the domain general aspect of WM drives the correlations between general cognitive ability measures and WM span.

Age Differences in WM Performance

There are age differences in children's performance on WM measures. At issue is whether improvements on WM tasks result from changes in the size of the memory store or increased proficiency at using the processes required for WM. Baddeley (1986) found that auditory-verbal WM is more highly correlated with cognitive skills in the younger grades than the older grades. This may occur because children do not develop the second component of the phonological loop, the rehearsal component, until after the age of seven (Hitch & Towse, 1995). The rehearsal component is what keeps items in an active state and prevents them decaying from memory.

In an important study of this issue, Cowan, AuBuchon, Gilchrist, Ricker, and Saults (2011) investigated differences in visual WM at three ages (grades 1-2, grades 6-7, and adults). Participants were instructed to attend to a specific stimulus (circles) and to ignore all other stimuli (triangles). The circles and triangles appeared in a grid in different colors and locations. After a series had been presented, the participants to recall where a particular probe appeared. This measure was presented under three different conditions. In one condition, the participants were asked to provide a verbal response during the visual encoding that was irrelevant to the task. Another condition required the participants to name the color of the stimulus item when it was presented. The third condition did not control for verbal encoding or rehearsal processes. Older children differed from younger children in that they were able to hold more items in WM, and the adults held more items in WM than the older children.

These results suggested that visual WM does increase during a person's lifespan. These developmental changes cannot be explained by the ability to encode stimuli verbally as the age difference remained whether the verbal encoding and rehearsal processes were uncontrolled, encouraged through color naming during item presentation, or discouraged through the repetition of an irrelevant word during item presentation. Furthermore, attentional processes cannot explain these results, as the young participants favored the more-relevant stimuli over the less-relevant stimuli to the same degree as the older children and adults, while holding fewer items in WM. Cowan et al. (2011) suggested that the increase in visuospatial WM could be accounted for by a basic growth in capacity. This finding would suggest that older elementary school children would demonstrate a larger visual-spatial WM than younger children. Nevo and Breznitz (2013) suggested that although research has shown that auditory-verbal and visuospatial WM improve over time, the pinnacle of performance is achieved at different ages on different components and measures of the WM system.

The next section of the dissertation examines the relationships between the components of WM and decoding ability.

Information Processing Models of Reading

Researchers have proposed multiple models of processing in word reading. The dual-route theory of processing proposed by Coltheart, Rastle, Perry, Langdon, and Ziegler (2001) is based on the premise that there are two pathways leading to word recognition. The lexical pathway leads to real word identification while the sublexical (phonological) pathway results in pseudoword decoding (word attack). This theory was originally designed to explain visual presentation of stimuli, but has since been expanded to include auditory presentation as well.

Many researchers believe that children must acquire both automatic recognition of real words and the ability to decode pseudowords at the single word reading level (Coltheart, 2005; Ehri, 1999; Farrington-Flint, Coyne, Stiller, & Heath, 2008). In fact, the ability to read pseudowords has been shown to differentiate good readers from poor ones (Stanovich, 2000). Pseudowords are only similar to real words in the sense that they share phonological and orthographic representation. They do not share lexical, grammatical, or semantic information. We may expect that the phonological loop would be more involved in processing pseudowords and words that are easily sounded out (i.e. nap, cat, stop) whereas the visuospatial sketchpad may become more stimulated for words that depend on identifying letter strings and processing them by units instead of individual phonemes (i.e. fought, night, and session).

According to the dual-route theory, selective reading skills can be impaired (Griffiths & Snowling, 2002). A reader may be able to process previously encountered words using the lexical route, while trying unsuccessfully to read pseudowords via the nonlexical route. However, because this model does not simulate learning (Coltheart et al., 2001) it cannot address how deficits in reading-related cognitive skills such as WM affect reading performance.

An alternate theory, a connectionist model proposed by Seidenberg and McClelland, (1989) describes a shared pathway for pseudowords and real words.

They argued that any differences observed between pseudowords and real words reflect not separate pathways, but how strongly orthography, phonology, and semantics are stimulated. Griffiths and Snowling (2002) provided support for the connectionist model when they discovered that the level of severity of a phonological impairment determined the extent of a nonword reading deficit whereas print exposure (orthography) influenced the extent of exception word (i.e. island, busy, sovereign, colonel) reading deficits.

Neuroimaging studies have been conducted in an effort to determine whether words and pseudowords share processing pathways (Cibelli, 2012). However, they have lent support to both schools of thought, so it seems that there are no definitive answers to whether pseudowords and real words are processed similarly.

Working Memory Deficiencies and Decoding Difficulties

Although WM by itself does not offer a complete model of reading, it does contribute to the skills needed to be a fluent reader because it is central to language comprehension and production (Weismer, Evans, & Hesketh, 1999). In a study conducted by Reiter, Tucha, and Lange (2005) 42 fifth-grade children with dyslexia (a reading disability affecting decoding but not comprehension) were assessed with two measures of WM and showed deficits in both verbal and visual domains. The dyslexic group performed significantly worse than the typical group on the digit span backwards task (an auditory-verbal test of WM) with an effect size of .541. They also performed worse than the typical group on a visuospatial WM task that required them to recall the number of corners on a rectangular figure after it was briefly displayed on a computer screen with an effect size of 1.059. Reiter et al. (2005) proposed that children with dyslexia have impairments in a variety of functions that cause weak WM skills in both the verbal and visual domains.

Beneventi, Tonnessen, Ersland, and Hugdahl (2010) used fMRI measurements to show that 13-year-old children with dyslexia had deficits in WM not seen in typical readers. Dyslexics and age-matched typical controls performed verbal 0-, 1-, and 2-back tasks. The dyslexics did not differ from the controls on the 0-back task, but were significantly impaired compared to the controls on the 1- and 2-back tasks.

The brain activation patterns for the dyslexics mirrored that of the typical readers, which indicated that the two groups were using the same general WM cortical network when solving verbal WM tasks. However, even though the overall activation patterns were similar, the control group showed significantly more activation than the dyslexic group in the prefrontal and parietal cortices and the cerebellum suggesting that the areas were less sensitive to increasing WM demands in the dyslexic group. The prefrontal and parietal cortices are involved in the planning and execution of movements and coactivation of these two regions have been observed across a wide variety of measures, including those that engage WM components (Bunge, Hazeltine, Scanlon, Rosen, & Gabrieli, 2002). Although traditionally the cerebellum has been viewed as a motor mechanism, there is a growing body of evidence to suggest there is cerebellar involvement in cognitive and language functions (Leiner, Leiner, & Dow, 1993). These areas are also associated with WM processes such as continuous memory updating and temporal order memory. Moreover, individuals with dyslexia showed increased activity in the right anterior middle frontal gyrus (Bunge et al., 2002). Research conducted by Price et al. (1994) illuminates the significance of these results. They used a PET scan to record brain activity during periods of reading aloud, silent reading, and deciding whether a presented word was a real word or pseudoword. It was during this last task that the middle frontal gyrus was activated. They suggested the readers were trying to employ a phonological strategy to make the lexical decision. Beneventi et al. (2010) concluded that a WM deficit in dyslexia is supported and it may exacerbate reading impairment.

Yanai and Maekawa (2011) administered visual n-back memory tasks to Japanese ninth-grade boys who had IQs higher than 80 but scored more than two grades lower on a reading assessment. In this study, numbers, hirogana characters, kanji characters, and random figures were presented visually, and participants were asked to recall if a certain stimuli appeared in the sequence zero to three times before the end of the sequence. Hirogana and kanji characters are symbolic, which invites linguistic processing (requiring the phonological loop), whereas the random figures could not be processed linguistically (requiring the visuospatial sketchpad). There were large correlations (ranging from .59 to .78) between 1 and 2-back hirogana, kanji, and random figures as well as 2-back numbers. Three-back numbers, hiragana characters, and kanji characters were also highly correlated with reading (ranging from .68 to .72). The results from this study suggest that both auditory-verbal and visuospatial WM are related to decoding ability in adolescent poor readers.

In summary, both visuospatial and auditory-verbal WM measures have predicted decoding skills in readers with dyslexia with moderate to large effects. The children in the studies that were reviewed ranged from ages nine through 13. It is unknown if visuospatial or auditory-verbal WM are more predictive of decoding nonwords versus real words in poor decoders because the three reviewed studies did not investigate these differences.

Working Memory Intervention Studies

Frijters et al. (2011) recently presented a study in which they investigated the contribution of eight neurocognitive processes (phonological awareness, oral language skills, phonological memory, visual-motor processes, verbal comprehension, perceptual organization, freedom from distractibility, and processing speed) to predict how responsive children with reading disabilities would be to an intervention program. They discovered that even after they controlled for phonological awareness and rapid naming (two of the most studied constructs), the other constructs did predict reading outcomes with medium to high correlations. Furthermore, the model provided a better classification system between children who responded well to intervention and those who were treatment-resistant.

Missing from this investigation was the direct contribution of visuospatial WM and the impact on words versus pseudowords. Although there was a visual component included as a predictor, it was a visual-motor component, not a visuospatial construct. It has been suggested that visuospatial WM is a component in orthographic knowledge, and as stated earlier, there are studies revealing orthographic knowledge to be a contributor to reading ability.

Recently, Melby-Lervag and Hulme (2012) conducted a systematic meta-analysis to determine if WM training programs impacted abilities such as decoding. They investigated 23 studies and coded them for age, training dosage, design type, type of control group, learner status, and intervention type. Included in intervention types were packaged, computerized programs such as CogMed, Cognifit, and Memory Booster, researcher developed computerized WM programs, and N-back training tasks. In general, memory training was effective for improving performance on WM measures. Studies of memory training with children 10 years and younger yielded large, significant effect sizes (*d*=1.41). For children older than ten years, the effect size of the treatment effect, while significant, was not as large (*d*=.26). The training effects on visuospatial WM were similar for both age groups. For younger children, the effect size for improvements in visuospatial WM after training was .46, and for older children it was .45. Both of these effect sizes were statistically significant.

Melby-Lervag and Hulme (2012) also compared pretest and posttest gains on word decoding after memory training. Across seven studies, the mean effect size for transfer to reading decoding was not significant (*d*=.13), although the 95% confidence interval ranged from -.17 to .42. This represents a large variance in effect sizes among the seven studies. Upon closer examination, there was no difference in the ages of participants in the studies reporting the highest effect sizes versus the studies reporting the lowest effect sizes. Participants ranging from the ages of 10 to 25 were represented in both. However, the four studies with the highest effect sizes combined word identification and word attack. On the other hand, the studies with the lowest effect sizes included a study that assessed WM effects on both types of decoding, and two studies featured real word decoding in the studies reporting the lowest effect sizes. This discrepancy in types of decoding ability examined may have impacted the size of the effects.

Research Questions

In summary, existing research suggests that:

1. There is a relationship between auditory-verbal and visuospatial WM and decoding ability
2. These relationships have been measured by simple and complex WM measures.
3. Auditory-verbal and visuospatial WM are developmental in nature, but we don't know if they develop at the same rates or have the same influences on decoding ability.
4. Real words and pseudowords share phonological information, but whether they share the same processing pathway is unknown.
5. Poor decoders tend to demonstrate low WM abilities in both the auditory-verbal and visuospatial domains, but we do not know whether

the processes associated with one domain or the other play a larger role in reading.

The research questions this study proposes to answer are:

1. How well do auditory-verbal WM measures predict word identification and word attack for young and old children who are poor decoders?
2. How well do visuospatial WM measures predict word identification and word attack for young and old children who are poor decoders?
3. For young and old children, how well do the visuospatial WM measures predict word identification and word attack over and above the contributions of the auditory-verbal WM measures?
4. For young and old children who are poor decoders, how well do the auditory-verbal WM measures predict word identification and word attack over and above the contributions of visuospatial WM measures?
5. For children who are poor decoders, how well do the complex auditory-verbal memory measures predict reading ability over the simple auditory-verbal memory measure controlling for verbal intelligence or phonological awareness?
6. For children who are poor decoders, how well does a phonological awareness measure predict reading ability over a simple auditory-

verbal WM measure controlling for verbal intelligence or complex auditory-verbal WM measures?

7. For children who are poor decoders, how well does the complex visuospatial WM measure predict reading ability over a simple visuospatial WM measure controlling for nonverbal intelligence or orthographic knowledge?

8. For children who are poor decoders, how well does orthographic knowledge predict reading ability over a simple visuospatial WM measure controlling for nonverbal intelligence or complex visuospatial WM measures?

CHAPTER III

METHODS

Participants and Screening Measure

Permission to conduct research was secured from the literacy coordinator, superintendent, and principals of a large school district in Northern Utah. Students from sixteen elementary schools participated in this study. Parents were informed about a screening for word decoding ability through a letter disseminated by the teachers and given a time range for when the screening would occur. Unless parents chose to not have their child(ren) involved, all second- and fifth-grade students in the schools were screened for decoding ability with the Test of Silent Word Reading Fluency (TOSWRF; Mather, Hammill, Allen, & Roberts, 2004).

The TOSWRF assesses the ability to segment letter strings into words. Children have 3 minutes to segment as many words as possible from a text containing sentences that are presented with no spaces between any of the words. This test yields raw scores, standard scores, percentiles, and age and grade equivalents. Alternate forms reliability ranges from .73 to .87. This measure was chosen for a number of reasons. First, this measure taxes both auditory-verbal and visuospatial memory. The participant is required to select appropriate units of print from the page to form words thus taxing visuospatial memory. Because sound units are mapped on to the visual units, the participant must accurately decode using auditory-verbal WM. Secondly, this measure allows entire classrooms of children to be screened at one time, thereby limiting the intrusions in each classroom.

The first author and two trained undergraduate research assistants conducted the class-wide screenings over a three-week time period. The first author and a trained assistant scored the protocols. Of the more than 2,200 students that participated in the screening, 137 second-grade and 83 fifth-grade students placed in the bottom quartile on this assessment and qualified for further analysis of their decoding skills.

Qualification Measures

Teachers sent letters to the parents of the students scoring in the bottom quartile on the TOSWRF inviting their children to participate in a further examination of their decoding skills with the Word Identification and Word Attack subtests of the Woodcock Reading Mastery Test - III (Woodcock, 2011). These subtests require the participant to read a list of words or pseudowords until they reach a ceiling performance. The test-retest reliability coefficient of the word identification is .95 for students in second grade and .92 for students in fifth grade. The test-retest reliability coefficient of the word attack subtest is .89 for students in second grade and .88 for students in fifth grade.

Please see Tables 1 and 2 for the range, means, and standard deviations of the standard scores on all the standardized tests. These figures serve to illustrate that the children who participated in this study were significantly impaired in their decoding ability of words and pseudowords. The mean for these subtests is 100 with a standard deviation of 15. The children in this study were about 1.5 standard deviations below the mean of their typically achieving peers. For second graders in this district, the mean range of scores on the TOSWRF was 15 points, with the average score of the lowest class being a score of 98 and the average score of the highest class being a score of 113. For fifth graders in this district, the range of scores on the TOSWRF was 12 points (98 – 110).

Seventy-seven second-grade students and 57 fifth-grade students returned permission forms to participate in the Woodcock Reading Tests and their parents filled out a brief demographic and history form.

Students were invited to participate in the study if they met the following conditions: they were either monolingual in English or starting speaking English in preschool, had standard scores of 85 or below on at least one of the reading subtests, if both scores were not below 85, the other score had to be below 90, had no history of hearing loss, had intelligible speech, and no had no history of a serious psychiatric or neurological illness. The parents of these students who met the inclusion criteria were approached to ask permission to enroll their children in the study to determine the role of verbal and visual WM on decoding skills in these children who were poor decoders. After administering the tests, children were dropped if their nonverbal IQ score was less than 75. Fifty-four children (32 second graders and 22 fifth graders) were ultimately selected to participate in the study.

Of the 54 participants, 20 were female and 34 were male. The majority of participants spoke English as their only language, were Caucasian, came from homes where at least one parent received some college education, and paid for lunches. (See Table 3 for participant characteristics.)

Table 1

Range, Mean, and Standard Deviation for Grade 2 Standard Scores[a] and Chronological Age

Variable	Min	Max	Mean	Std. Deviation
Age in months	89	101	95.88	3.51
Word ID	63	87	78.56	6.27
Word Attack	61	88	76.22	6.60
Verbal intelligence	66	123	98.28	14.63
Nonverbal intelligence	77	122	94.91	11.75
Understanding Spoken Par.	2	14	8.28	3.44
Elision	3	14	8.41	2.63
Orthographic Knowledge	0	64	38.47	17.30
Nonword Repetition	4	10	7.34	1.47
Leiter-Forward	1	18	9.78	4.68
WJ Auditory WM	61	127	95.97	18.07
Leiter-Reverse	2	15	8.56	3.79
Competing Lang. Proc.	0	26	8.84	5.89
Visual Processing	15	37	27.63	6.10

[a]Only raw scores are available for the Orthographic Knowledge, Competing Lang. Processing, and Visual Processing Measure

Table 2

Range, Mean, and Standard Deviation for Grade 5 Standard Scores[a] and Chronological Age

Variable	Min	Max	Mean	Std. Deviation
Age in months	126	149	134.23	4.50
Word ID	62	86	76.27	7.77
Word Attack	21	87	70.68	12.96
Verbal intelligence	72	114	94.05	13.76
Nonverbal intelligence	80	115	92.64	9.73
Understanding Spoken Par.	1	13	9.41	3.07
Elision subtest	3	11	7.59	2.36
Orthographic Knowledge	29	96	60.86	15.23
Nonword Repetition	5	12	7.73	1.75
Leiter-Forward	6	18	11.36	3.55
WJ Auditory WM	55	103	88.27	13.87
Leiter-Reverse	4	15	10.68	2.66
Competing Lang. Proc.	5	31	15.05	5.98
Visual Processing	20	40	33.09	5.55

[a]Only raw scores are available for the Orthographic Knowledge, Competing Lang. Processing, and Visual Processing Measure

Table 3

Participant Characteristics

Characteristics	*n*	Percentage
Gender		
Males	34	63%
Females	20	37%
Grade		
Second	32	59%
Fifth	22	41%
Ethnicity		
Caucasian	48	89%
Caucasian/American Indian	2	4%
Latino	2	4%
Latino/Caucasian	1	2%
Black/African American	1	2%
Language(s) spoken		
English	52	96%
English/Spanish	2	4%
Highest level of education achieved by parent		
High school	8	15%
Some college	17	31%
Associate's degree	5	9%
Bachelor's degree	12	22%
Graduate degree	8	15%
Prefer not to answer	4	8%
Lunch		
Paid	22	41%
Reduced	9	17%
Free	19	35%
Prefer not to answer	4	8%

Materials and Procedures

Students enrolled in the WM study were evaluated with standardized, nationally normed tests and experimental measures. All testing took place in a quiet room in the school in two separate sessions held no longer than two weeks apart, with each session lasting approximately 40 minutes in order to accommodate the participant's attention spans and schedules. Participants were given their choice of small toys, pencils, or books at the end of each session. The first author and an undergraduate research assistant trained by the first author collected the data, and the first author scored all data. The Institutional Review Board at Utah State University approved all procedures before data collection began.

Three measures were selected for each WM domain (auditory-verbal and visuospatial), each offering a different level of cognitive control and processing demands. The measures that required the participant to immediately retrieve information were called simple (auditory-verbal or visuospatial) WM measures. These measures required the lowest demand of cognitive control because the participant was not asked to process any information other than the stimuli that were to be remembered. For the auditory-verbal measure, participants heard a pseudoword and repeated it. For the visuospatial measure, the participants viewed a sequence of pictures and pointed to the order in which they were shown.

Two measures in each domain were considered to be complex WM measures; however, one placed moderate demands on storage and cognitive control while the other placed high demands on storage and cognitive control. For the measures requiring moderate demands on cognitive control, the participant had to listen to a string of letters and words, organize them semantically, and repeat them back (the auditory-verbal measure) or view a sequence of pictures, organize them, and point to them in the reverse order (the visuospatial measure).

Measures requiring the highest amount of cognitive control required the participants to make multiple decisions between being presented with the information to be remembered and recalling that information. The auditory-verbal measure required the participant to listen to lists of sentences, verify the truth of each sentence after it was presented, and then remember the last word of the sentences in the list in the order that they were presented in. The visuospatial measure required participants to view colored Xs on a matrix, identify the color of each X after it was presented, and then point to the location of each X on the matrix in the order that they appeared.

Measures

Low Demands on Cognitive Control

Nonword Repetition Measure: This subtest of the Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999) was used as a simple auditory-verbal memory measure to assess the phonological loop. It correlates with phonological memory at .65. Children heard prerecorded nonwords at either one, two, three, or four syllable lengths and had to repeat them. The mean of this subset is 10 with a standard deviation of 3. The test-retest reliability for this subtest is .75 for children between the ages of 8 and 17.

Leiter-Forward Measure: This subtest from the Leiter International Performance Scale-Revised (Roid & Miller, 1997) is a measure of simple visuospatial memory. For this measure, the participant watched as the examiner demonstrated a pattern by pointing to pictures in a particular order. The participant repeated the pattern as shown. Because this subtest only required participant to store information (as opposed to manipulate and store), this assessment measured simple visuospatial WM. The mean of this subtest is 10 with a standard deviation of 3. The forward memory subtest has an internal consistency reliability coefficient of .71 for the younger children and .82 for older children.

Moderate Demands on Cognitive Control

Woodcock-Johnson Auditory WM Subtest: Used as a complex auditory WM measure, this subtest of the Woodcock-Johnson Tests of Cognitive Abilities-III (Woodcock, McGrew, & Mather, 2001) required the student to repeat randomly dictated words and numbers with the words first and then the numbers in the order they were heard. For example, if the student heard “apple, 9, shoe,” he/she would repeat back, “apple, shoe, 9.” Trial blocks became progressively longer as the experiment progressed. A ceiling was reached when the participant was unable to correctly recall three items in a series. The mean of this subtest is 100 with a standard deviation of 15. The reliability coefficient for participants at eight years of age is .90 and .86 for participants 11 years of age.

Reverse Memory: This subtest from the Leiter International Performance Scale-Revised (Roid & Miller, 1997) is a measure of complex visuospatial WM. For the reverse memory measure, participants viewed an increasingly difficult pattern demonstrated by the examiner and indicated the reverse of the pattern. This measure required processing and storage, so it was considered a complex WM measure. The mean of these subtests is 10 with a standard deviation of 3. The reverse memory subtest has an internal consistency reliability coefficient of .82 for children ages 8 – 10 and .85 for children ages 11 – 15.

Higher Demand on Cognitive Control

The Auditory-verbal WM Measure: Competing Language Processing Measure-Modified: (See Appendix A). This assessment was adapted from the original Competing Language Processing Measure (Gaulin & Campbell, 1994) for a research study by Magimairaj and Montgomery (2012). Participants had to listen to recorded groups of short sentences, presented in blocks of two, three, four, five, or six. Immediately after hearing each sentence, the participant judged the validity of the sentence as true or false. After the block of sentences was presented, the participant provided the last word of each sentence in the group. The number of words recalled by the participant determined the raw score. A total of 40 points was possible. All sentence blocks were given. Cronbach's coefficient of reliability was .73.

Visual WM Measure: Visual Information Processing Measure: (See Appendix B). In this assessment, participants viewed a progressive series of colored X's in a 16 block matrix. Just two X's appeared initially (one right after the other), and an X was added to each block until there were six X's in the set. The X's disappeared after two seconds and the participant had to non-verbally identify the color of the X by touching a matching color card. At the culmination of the set, the participant had to point to where the X's were located in the matrix. There were 40 points possible. All blocks of X's were shown. Intra-rater reliability for this measure is 99.4% and inter-rater reliability is 98.9% (Hoffman & Gillam, 2004).

Intelligence

Kaufman Brief Intelligence Test 2 (Kaufman & Kaufman, 2004): This test is a memory-free measure that provides a means to assess nonverbal and verbal intelligence. The Verbal Scale assesses crystallized ability, while the Matrices subtest assesses fluid thinking. Participants demonstrate expressive language skills by solving riddles using one word and they demonstrate receptive language ability by pointing to a picture that matches a given term. In the matrices subtest, participants have to figure out a relationship or rule for a set of pictures or patterns. The Kaufman Brief Intelligence Test eliminates the issues of using a measure of general intelligence that may use constructs that are too highly correlated to provide unique information about the contributions of IQ. The mean of this test is 100 with a standard deviation of 15. For children up to age 12 in the normed sample, the test-retest reliability for the verbal portion was .85 and the nonverbal portion was .69.

Phonological Awareness

Comprehensive Test of Phonological Processing, Elision Subtest: (Wagner et al., 1999). This measure required participants to listen to a word and then repeat it back without a syllable or a phoneme. For example, the child heard “pancake” and then had to say the word without saying “pan” or the child heard “meet” and had to say the word without saying the /t/ sound. The mean of this subtest is 10 with a standard deviation of 3. The test-retest reliability for this subtest is .79 for children between the ages of 8 and 17.

Orthographic Knowledge

Orthographic Choice Measure: In the orthographic choice measure (Olson, Forsberg, Wise & Rack, 1994), participants viewed pairs of letter strings that sounded alike (e.g., take-taik) and identified which word in the pair was spelled correctly. Both words sounded the same when decoded, so differences in phonological decoding ability cannot be the only explanation for whether the student is able to correctly identify the word. Testing ceased after five incorrect identifications. It was possible to obtain a raw score of 80 points.

Language Comprehension

Understanding Spoken Paragraphs subtest of the Clinical Evaluation of Language Fundamentals, Fourth ed. (Semel, Wiig, & Secord, 2003): This measure was given to differentiate children with dyslexia from garden-variety poor readers by assessing listening comprehension. If children have listening comprehension scores within the average range but exhibit poor decoding skills, they can be classified as having dyslexia. If both listening comprehension and decoding are impaired, they are considered a garden-variety poor reader. In this subtest, participants listened to three short stories read by the examiner and then answered open-ended questions. The mean of this subtest is 10 with a standard deviation of 3. Test-retest reliability is .62 to .74 for children 7 – 12 years of age.

Anticipated Results

Based on the review of literature, I anticipated that the findings would reveal the following scenarios:

1. There would be strong correlation of auditory-verbal WM to word attack at the second grade that decreased by fifth grade.

   This hypothesis was based on Baddeley's work (1986) with the phonological loop that suggested it was especially instrumental in young children who are targeting word attack skills and becomes less important as they begin to rely on less phonologically based skills. Readers have to possess good phonological awareness to decode a pseudoword because pseudowords can only be identified through their phonemic properties.

2. There would be moderate correlations of auditory-verbal WM to word identification at second grade that decreased by fifth grade.

   This hypothesis was based on Baddeley's work with the phonological loop and the knowledge that beginning readers are presented with words that are easily decodable. As readers mature, they are presented with words that require orthographic knowledge in addition to phonological awareness.

3. There would be small correlations between visuospatial WM and word identification at the second grade level that increased by the fifth grade.

   This hypothesis was based on Cowan and others' research (2011) that suggests visuospatial WM capacity increases during the lifespan and the knowledge that orthographic patterns become identifiable in words in late elementary.

CHAPTER IV

RESULTS

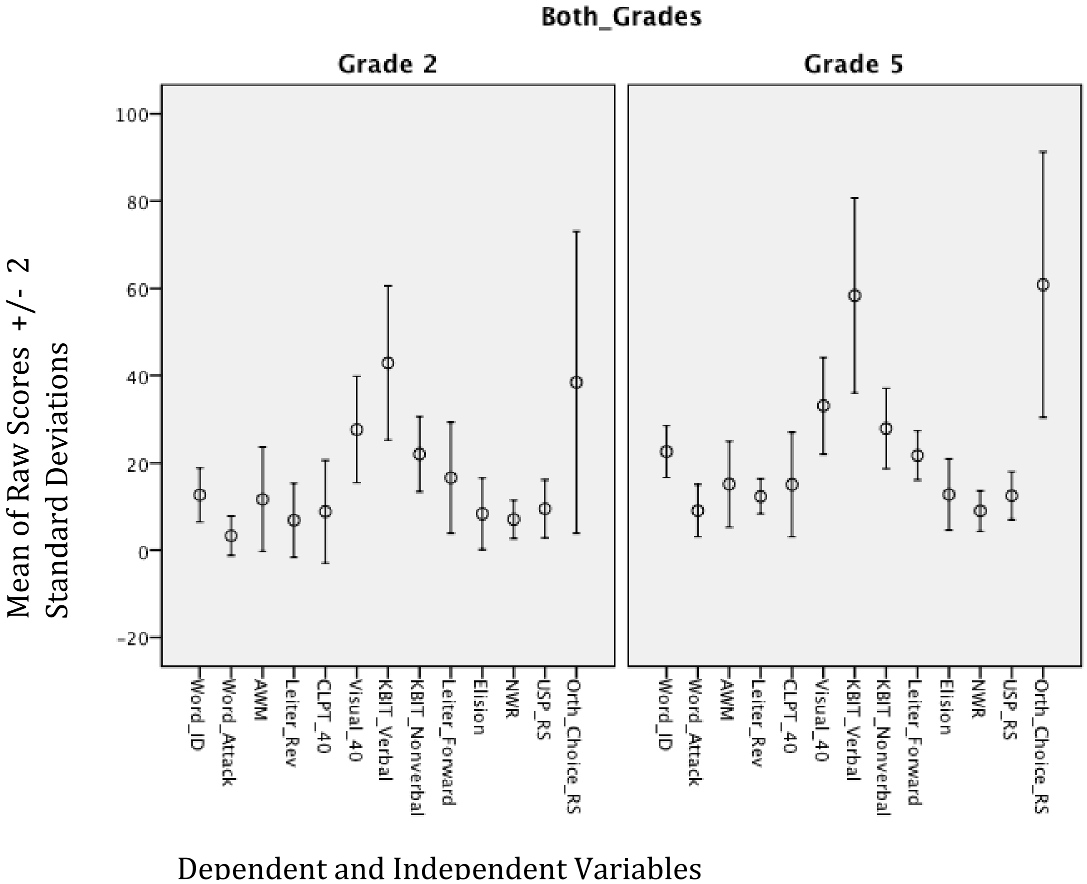
This study was designed to answer questions regarding the differential contributions of verbal and visual WM on word attack and word identification for children who are poor decoders in both the second and fifth grades. Further analyses were conducted to discover if other measures of verbal and nonverbal measures of intelligence, orthographic knowledge, or phonological awareness added any predictive value. It was hypothesized that auditory-verbal WM would be predictive of word identification and word attack, particularly at second grade, and would wane in importance by fifth grade. Visuospatial WM was hypothesized to be more highly correlated with word identification at fifth grade when orthographic knowledge became a factor in word reading. For each research question, an analysis was run. The first two research questions will be answered with correlational statistics while the remaining questions will be answered with hierarchical multiple regressions using word identification and word attack scores as the dependent variables.

Descriptive Data

The mean, standard deviations, and minimum and maximum scores for all independent (predictor) variables and the dependent variables are presented in Tables 1 and 2.

Independent-samples *t*-tests were conducted to evaluate the difference between the means of the second-grade students and the fifth-grade students on the word identification and word attack measures, the complex auditory-verbal and visuospatial WM measures, the simple auditory-verbal and visuospatial WM measures, the verbal and nonverbal intelligence measures, the phonological awareness measure, and the orthographic knowledge measure. Levene's Test for Equality of Variances was used to validate the assumption of normality. Two measures, the Leiter-Reverse and the Leiter-Forward, were significant (F=13.259, p=.001; F=4.320, p=.043), so equal variances could not be assumed. For the other ten measures, the Levene's test was insignificant, indicating equal variances could be assumed. All measures were significant for equality of means between the two grade levels, meaning that the group means of the second graders were statistically and significantly different than the group means of the fifth graders on the test measures. The large and significant t values indicate that students in grade five performed higher on all measures than students in grade two. Figure 1 shows the distributions for the two grade levels. Table 4 displays the t values and significance for all measures.

Seventy-two percent of the second-grade participants and 86% of the fifth-grade participants exhibited poor decoding skills in the absence of poor comprehension skills or low intelligence. As such, these children would be considered to have dyslexia.



Word_ID (Word Identification test); Word Attack; AWM (Woodcock Johnson's Auditory Working Memory test); Leiter_Reverse; CLPT_40 (Competing Language Processing Task/Measure); Visual_40 (Visual Processing Task/Measure); KBIT_Verbal (Kaufman Brief Intelligence Test-2, verbal subtest); KBIT_Nonverbal (Kaufman Brief Intelligence Test-2, nonverbal subtest); Leiter_Forward; Elision (Elision subtest of the Comprehensive Test of Phonological Processing); NWR (Nonword repetition subtest of the Comprehensive Test of Phonological Processing) USP (Understanding Spoken Paragraphs subtest of the CELF-4); Orth_Choice (Orthographic Choice Task)

Figure 1

Means with error bars representing approximately 95% of the scores (2 standard deviations) for all the dependent and independent variables.

Table 4

t-Test Values and Cohen's d Values for all Dependent and Independent Variables Comparing the Means for Second Grade Students with the Means of Fifth Grade Students

Measure	*t*-test value, *p* value, Cohen's *d*
Word identification	*t*(52)=11.743, *p*=.000, *d*=.32
Word Attack	*t*(52)=8.099, *p*=.000, *d*=.54
Verbal intelligence	*t*(52)=5.667, *p*=.000, *d*=.30
Nonverbal intelligence	*t*(52)=4.785, *p*=.000, *d*=.21
Understanding Spoken Para.	*t*(52)=3.546, *p*=.001, *d*=1.00
Elision	*t*(52)=3.903, *p*=.000, *d*=.33
Orthographic Choice	*t*(52)=4.902, *p*=.000, *d*=1.37
Nonword Repetition	*t*(52)=3.106, *p*=.003, *d*=.24
Leiter-Forward	*t*(45.780)=4.016, *p*=.000, *d*=.38
WJ Auditory WM	*t*(52)=2.254, *p*=.028, *d*=.48
Leiter-Reverse	*t*(47.168)=6.313, *p*=.000, *d*=.65
Competing Language Processing Measure	*t*(52)=3.780, *p*=.000, *d*=1.05
Visual Processing Measure	*t*(52)=3.353, *p*=.001, *d*=.94

Research Questions and Results

Research Question 1: How well do the complex auditory-verbal WM measures predict word identification and word attack for young and old children who are poor decoders?

Second Grade

Correlation coefficients were computed among the two dependent variables (word identification and word attack), the two complex auditory-verbal WM measures (Woodcock-Johnson's Auditory WM test, The Competing Language Processing Measure), the phonological awareness measure (Elision), and the simple auditory-verbal WM measure (Nonword Repetition) for the second-grade participants. The results of the correlational analyses presented in Table 5 show that 7 of the 15 correlations were statistically significant and were greater than or equal to .35. The two dependent measures were largely and significantly correlated with each other (r = .665, *p* = .000). Word attack was moderately and significantly correlated with the Competing Language Processing Measure (r = .452, *p* = .009). The two complex auditory-verbal WM measures (Competing Language Processing Measure and Woodcock-Johnson's Auditory WM Test) were moderately and significantly correlated with each other (r = .377, *p* = .033). The Competing Language Processing Measure was highly correlated with the Elision measure (r = .557, *p*= .001). The nonword repetition measure (a simple auditory-verbal WM measure) was highly correlated to the two complex auditory-verbal WM measures (Woodcock-Johnson's auditory WM measure and Competing Language Processing Measure) (r = .496, *p* = .004; r = .504, *p* = .003, respectively) and moderately correlated to the phonological awareness measure (r = .440 , *p* = .012).

In general, the results suggest that students with decoding difficulties who performed well on nonword repetition measures (a simple auditory-verbal WM measure) also performed well on the complex auditory-verbal WM measures and the phonological awareness measure. Students who performed well on a complex auditory-verbal memory measure that required the participant to make a semantic judgment regarding the truthfulness of a statement before retrieving the last word of the statement (high cognitive control) performed better on word attack. However, the two complex auditory-verbal measures were not related to word identification (see Figure 2).

Table 5

Correlations Between Word Identification, Word Attack, and the Four Tests Measuring a Component of Auditory-Verbal Memory at Grade 2 (n=32)

		Word ID	Word Attack	WJ AWM	CLPT	Elision	NWR
Word ID	Pearson Correlation	1					
	Sig. (2-tailed)						
Word Attack	Pearson Correlation	.665**	1				
	Sig. (2-tailed)	.000					
WJ AWM	Pearson Correlation	-.004	.337	1			
	Sig. (2-tailed)	.981	.059				
CLPT	Pearson Correlation	.161	.452**	.377*	1		
	Sig. (2-tailed)	.380	.009	.033			
Elision	Pearson Correlation	.123	.213	.248	.557**	1	
	Sig. (2-tailed)	.501	.242	.171	.001		
NWR	Pearson Correlation	.079	.251	.496**	.504**	.440*	1
	Sig. (2-tailed)	.667	.166	.004	.003	.012	

** Correlation is significant at the .01 level (2-tailed).
* Correlation is significant at the .05 level (2-tailed).

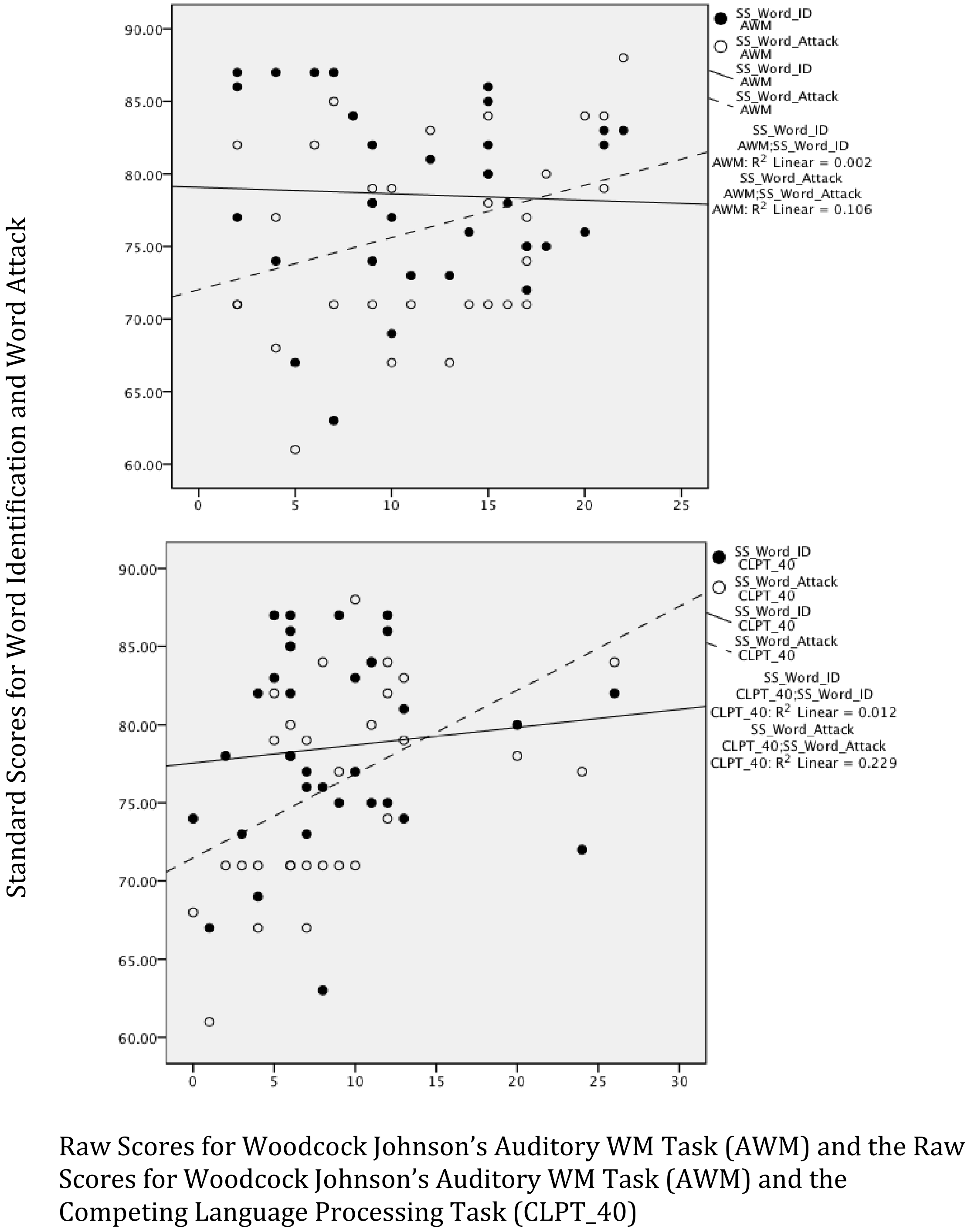


Figure 2

Scatterplots showing trend lines and correlations between reading scores and Woodcock Johnson's Auditory WM Task at grade 2 and the Competing Language Processing Task at grade 2.

Fifth Grade

For fifth-grade students, correlation coefficients were computed among the two dependent variables, the two complex auditory-verbal WM measures, the simple auditory-verbal WM measure, and the phonological awareness measure. The results of the correlational analyses presented in Table 6 show that 2 of the 15 correlations were statistically significant and were greater than or equal to .45.

Table 6

Correlations between Word Identification, Word Attack, and the Four Tests Measuring a Component of Auditory-Verbal Memory at Grade 5 (n=22)

		Word ID	Word Attack	WJ AWM	CLPT	Elision	NWR
Word ID	Pearson Correlation	1					
	Sig. (2-tailed)						
Word Attack	Pearson Correlation	.478[a]	1				
	Sig. (2-tailed)	.025					
WJ AWM	Pearson Correlation	-.310	-.279	1			
	Sig. (2-tailed)	.161	.209				
CLPT	Pearson Correlation	.174	.216	-.179	1		
	Sig. (2-tailed)	.438	.334	.424			
Elision	Pearson Correlation	.148	.204	-.230	.246	1	
	Sig. (2-tailed)	.510	.362	.303	.269		
NWR	Pearson Correlation	.568[aa]	.247	-.348	-.062	-.180	1
	Sig. (2-tailed)	.006	.269	.112	.786	.422	

[aa] Correlation is significant at the .01 level (2-tailed).
[a] Correlation is significant at the .05 level (2-tailed).

Word identification and word attack were moderately and significantly correlated (*r* = .478, *p* = .025). Word identification was highly and significantly correlated to the Nonword Repetition measure (*r* = .568, *p* = .006). There were no significant correlations with Word Attack. In general, the complex auditory-verbal WM measures and the phonological awareness measure were not correlated with reading decoding at fifth grade, see Figure 3.

To summarize, complex auditory-verbal WM did not predict word identification scores for either group of participants and predicted word attack scores only for students in second grade.

Research Question 2: How well do the complex visuospatial WM measures predict word identification and word attack for young and old children who are poor decoders?

Second Grade

Correlation coefficients were computed among the two dependent variables (word identification and word attack) and the four visuospatial memory measures (Leiter-Reverse, Visual Processing Measure, Orthographic Choice measure, and Leiter-Forward) for second-grade participants. The results of the correlational analyses presented in Table 7 show that 4 of the 15 correlations were statistically significant and were greater than or equal to .40. Word identification was highly and significantly correlated with word attack (*r* = .665, *p* = .000). The two Leiter subtests were moderately and significantly correlated (*r* = .409, *p* = .020) and both of those subtests were moderately and significantly correlated to the Visual

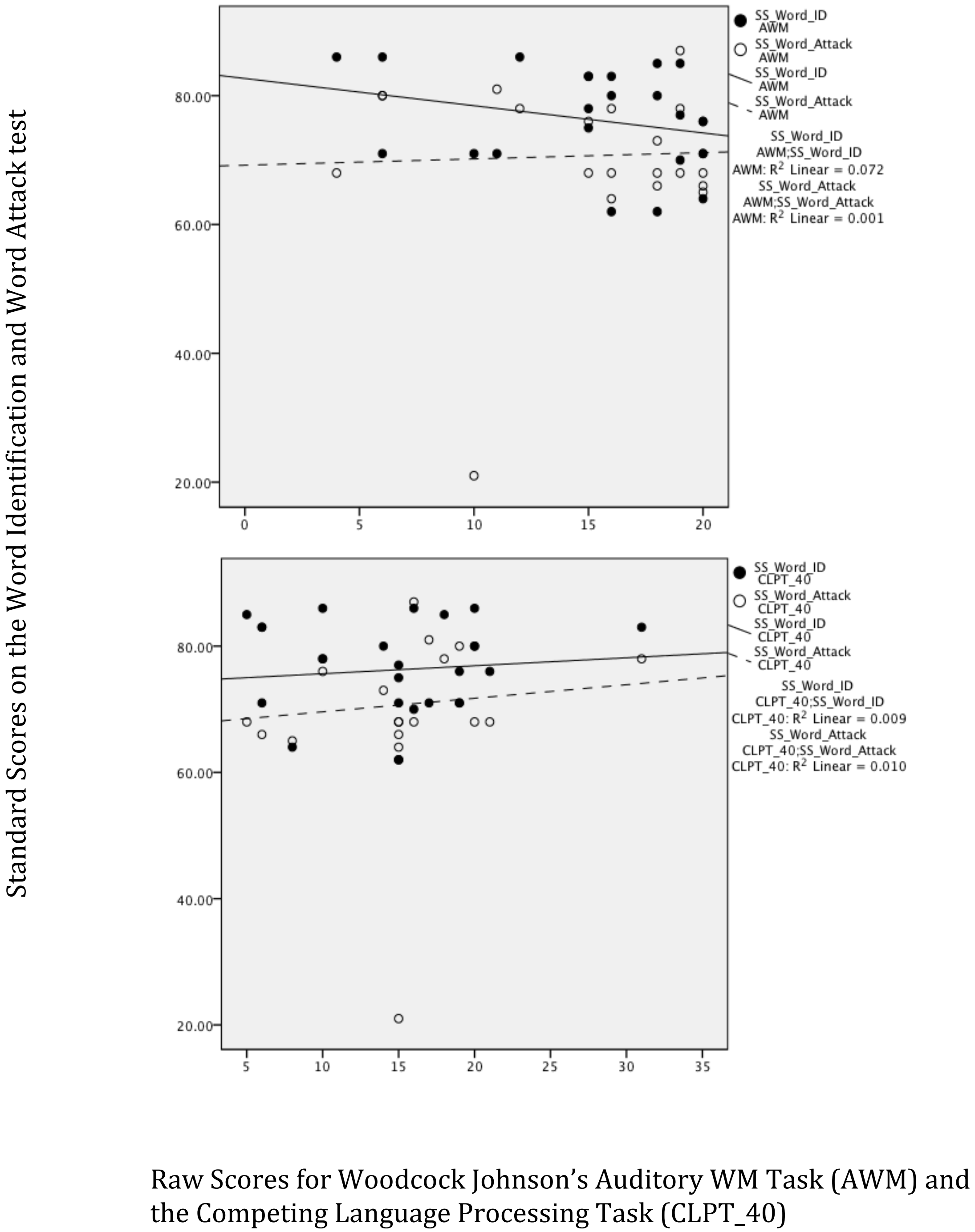


Figure 3

Scatterplots showing trend lines and correlations between reading scores and Woodcock Johnson's Auditory WM Task at grade 5 and the Competing Language Processing Task at grade 5.

Processing Measure (a complex visuospatial WM measure requiring high cognitive control). The Leiter Forward (a simple visuospatial WM measure) was correlated at r = .406, p = .021 to the Visual Processing Measure and the Leiter Reverse (a complex visual WM measure requiring moderate cognitive control) was correlated at r = .439, p = .012 to the same measure. The correlations of word identification and word attack with the visual measures were low and insignificant. In general, second-grade students who performed well on the simple visuospatial WM measures also performed well on the complex visuospatial WM measures, but their performance was not related to their reading ability, see Figure 4.

Table 7

Correlations Between Word Identification, Word Attack, and the Four Tests Measuring a Component of Visuospatial Memory at Grade 2 (n=32)

		Word ID	Word Attack	Leiter Reverse	Visual Processing Measure	Leiter Forward	Orthographic Choice
Word ID	Pearson Correlation	1					
	Sig. (2-tailed)						
Word Attack	Pearson Correlation	.665**	1				
	Sig. (2-tailed)	.000					
Leiter Reverse	Pearson Correlation	-.213	-.118	1			
	Sig. (2-tailed)	.242	.519				
Visual Processing Measure	Pearson Correlation	-.202	.222	.439*	1		
	Sig. (2-tailed)	.268	.222	.012			
Leiter Forward	Pearson Correlation	-.299	.033	.409*	.406*	1	
	Sig. (2-tailed)	.097	.858	.020	.021		
Orthographic Choice	Pearson Correlation	.165	.324	.015	.301	.116	1
	Sig. (2-tailed)	.366	.070	.935	.094	.528	

** Correlation is significant at the .01 level (2-tailed).
* Correlation is significant at the .05 level (2-tailed).

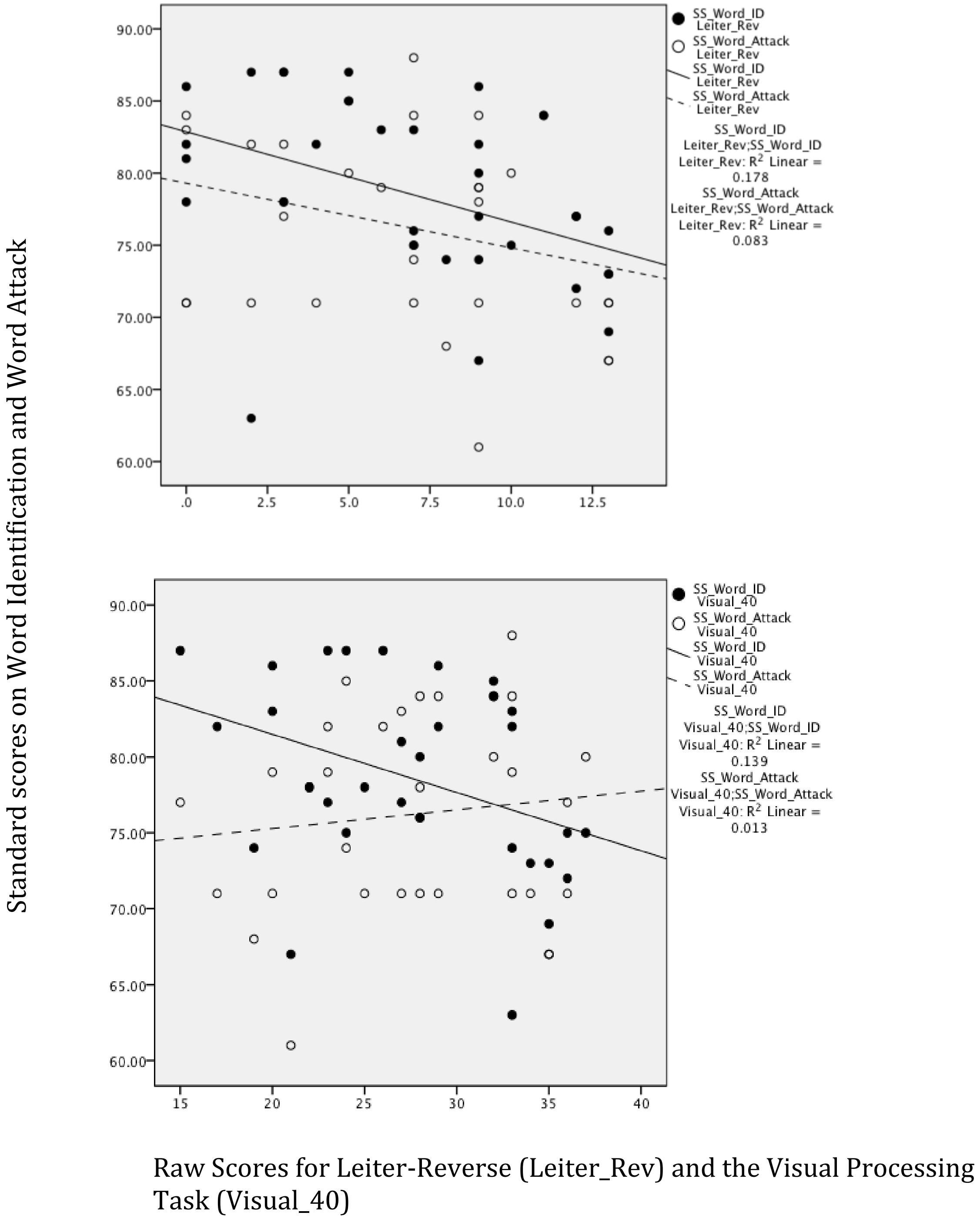


Figure 4

Scatterplots showing trend lines and correlations between reading scores and Leiter-Reverse at grade 2 and the Visual Processing Task at grade 2.

Fifth Grade

Correlation coefficients were computed for fifth-grade students among the two dependent variables, the two complex visuospatial WM measures, the simple visuospatial WM measure, and the orthographic knowledge measure. The results of the correlational analyses presented in Table 8 show that 3 of the 15 correlations were statistically significant and were greater than or equal to .45. The correlations between word identification and word attack were significant and moderate

Table 8

Correlations between Word Identification, Word Attack, and the Four Tests Measuring a Component of Visuospatial Memory at Grade 5 (n=22)

		Word ID	Word Attack	Leiter Reverse	Visual Processing Measure	Leiter Forward	Orthographic Choice
Word ID	Pearson Correlation	1					
	Sig. (2-tailed)						
Word Attack	Pearson Correlation	.478[a]	1				
	Sig. (2-tailed)	.025					
Leiter Reverse	Pearson Correlation	-.358	-.487[a]	1			
	Sig. (2-tailed)	.102	.022				
Visual Processing Measure	Pearson Correlation	-.196	-.069	.347	1		
	Sig. (2-tailed)	.383	.760	.113			
Leiter Forward	Pearson Correlation	.127	-.162	.401	.353	1	
	Sig. (2-tailed)	.573	.472	.064	.107		
Orthographic Choice	Pearson Correlation	.468[a]	.011	.006	-.151	-.038	1
	Sig. (2-tailed)	.028	.963	.978	.503	.865	

[a] Correlation is significant at the .05 level (2-tailed).

in size (r = .478, *p* = .025). The Orthographic Choice measure was moderately and significantly correlated with word identification (r = .468, *p* = .028). No other visual measures were significantly correlated with word identification. The Leiter-Reverse measure (a complex visuospatial WM measure requiring moderate cognitive control) was significantly and negatively correlated with word attack (r = -.487, *p* = .022) suggesting that the higher the fifth-grade students performed on the visuospatial complex measure, the poorer they performed on word attack. In general, visual measures were not indicative of reading performance at fifth grade, see Figure 5.

In summary, complex visuospatial WM measures did not predict word identification for either group of students and negatively predicted word attack for fifth-grade participants.

The next two research questions were investigated to determine if there was shared variance between auditory-verbal and visuospatial WM. If the cognitive capacity (storage plus attentional control) between the two types of WM is the same, any differences between the two WM measures could be attributed to a particular WM domain.

Research Question 3: For young and old children who are poor decoders, how well do the complex visuospatial WM measures predict word identification over and above the contributions of the complex auditory-verbal WM measures?

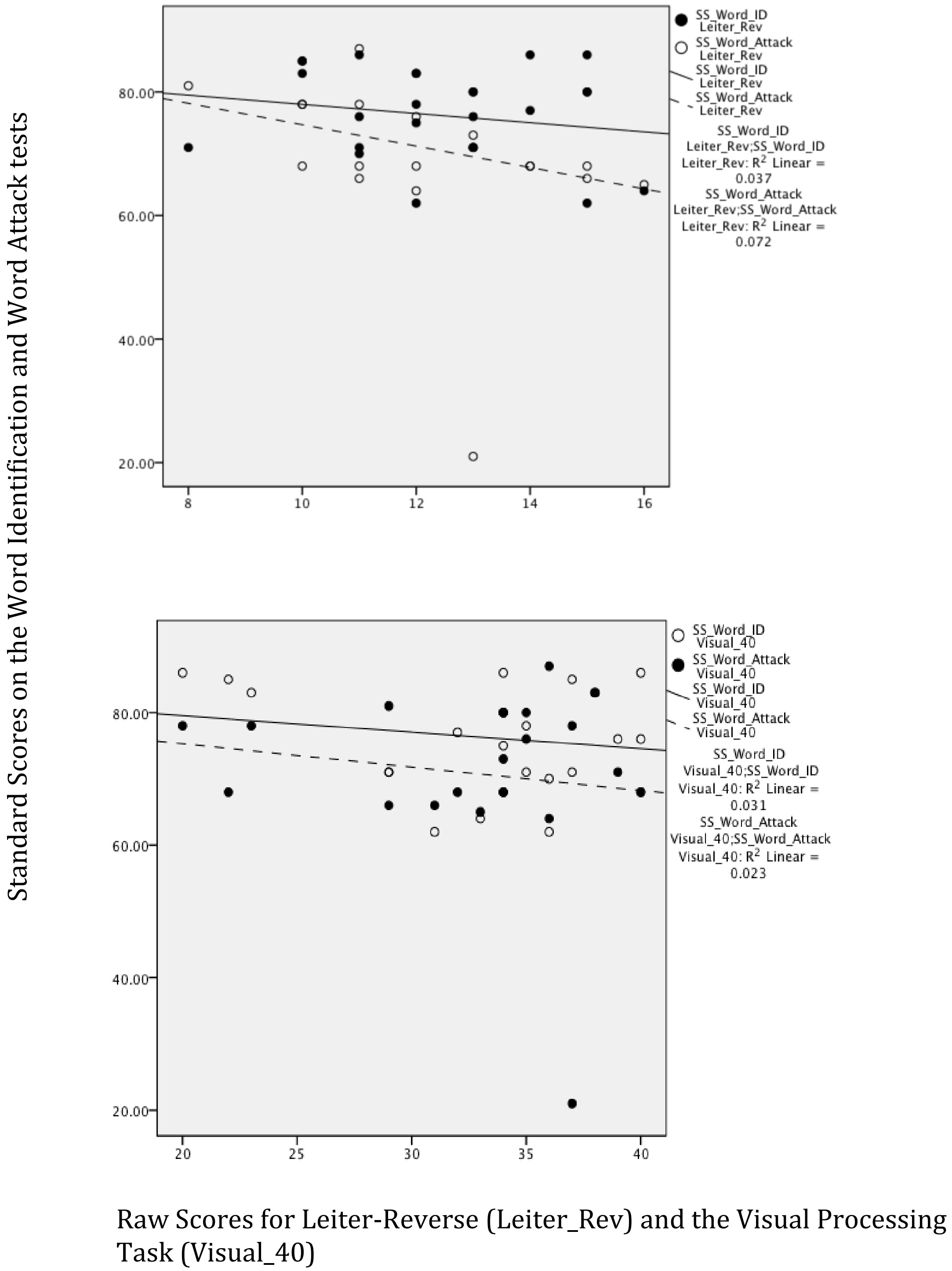


Figure 5

Scatterplots showing trend lines and correlations between reading scores and Leiter-Reverse at grade 5 and the Visual Processing Task at grade 5.

Word Identification

Complex visuospatial WM vs. complex auditory-verbal WM. A hierarchical multiple regression analyses was conducted to explore the relationship of predictor variables to the criterion variable. The predictors were the scores on the word identification measure, and the control variables were the two complex auditory-verbal WM measures and the two complex visuospatial WM measures. First, the control variables of Woodcock-Johnson's Auditory WM measure and the Competing Language Processing Measure were entered in the equation. The squared multiple correlation for the equation was $R^2 = .019$ for second grade and $R^2 = .074$ for fifth grade, see Table 9. This model was not significant for either grade level (see Table 10), and within this model, there were no significant individual contributors for either grade, see Table 11.

Table 9

Regression Models to Predict Word Identification

Model	*R*	*R*^{2}	Adjusted *R*^{2}	Std. Error	ΔR2	*F* change	*df*1	*df*2	Sig. *F* change
Second grade									
1	.139	.019	-.048	6.42233	.019	.288	2	29	.752
2	.516	.266	.157	5.75797	.247	4.539	2	27	.020
Fifth grade									
1	.273	.074	-.023	7.86064	.074	.764	2	19	.480
2	.379	.143	-.058	7.99416	.069	.685	2	17	.517

Model 1: Competing Language Processing Measure and Woodcock Johnson WM Measure

Model 2: Competing Language Processing Measure, Woodcock Johnson WM Measure and Leiter-Reverse and Visual Processing Measure

In the second model, the predictor variables of Leiter-Reverse and the Visual Processing Measure were entered into the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .247$ for second grade and $\Delta R^2 = .069$ for fifth grade. Adding the complex visuospatial WM measures improved the prediction of word identification for second grade but not enough to make the model significant, F(4,27) = 2.448, *p* = .070. Within this model, there were no significant individual contributors for either grade. The second regression equation was not significant for fifth grade, F(4,17) = .712, *p* = .595.

Table 10

ANOVA

Model		Sum of Squares	*df*	Mean Square	*F*	Sig
Second grade						
1	Regression	23.731	2	11.866	.288	.752
	Residual	1196.144	29	41.246		
	Total	1219.875	31			
2	Regression	324.712	4	81.178	2.448	.070
	Residual	895.163	27	33.154		
	Total	1219.875	31			
Fifth grade						
1	Regression	94.360	2	47.180	.764	.480
	Residual	1174.003	19	61.790		
	Total	1268.364	21			
2	Regression	181.951	4	45.488	.712	.595
	Residual	1086.413	17	63.907		
	Total	1268.364	21			

Dependent Variable: Standard Scores on Word Identification
Predictors for Model 1: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory Task
Predictors for Model 2: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory Task, Leiter-Reverse, Visual Processing Task

Overall, the full regression equation explained 27% of the variance for second grade and 14% of the variance for fifth grade. Based on these results, although the complex auditory-verbal WM measures do not account for a significant amount of the variance on their own for either grade level, the visual WM measures appear to offer a little additional predictive power for second-grade readers, but not enough to make the model significant.

Word Attack

Complex visuospatial WM vs. complex auditory-verbal WM. Another hierarchical multiple regression analysis was run to answer the same research question of whether visual WM measures predicted reading ability over and above

Table 11

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Identification

Model	Slope	Intercept	Std. Error	*t*	Sig.
Second Grade					
1 Woodcock-Johnson Auditory WM	-.101	78.388	.209	-.485	.632
Competing Lang. Processing Measure	.152		.212	.723	.475
2 Woodcock-Johnson Auditory WM	.082	88.846	.202	.405	.688
Competing Lang. Processing Measure	.217		.201	1.083	.288
Leiter-Reverse	-.384		.281	-1.367	.183
Visual Processing Measure	-.381		.224	-1.701	.100
Fifth Grade					
1 Woodcock-Johnson Auditory WM	-.408	81.466	.354	-1.155	.262
Competing Lang. Processing Measure	.066		.292	.225	.824
2 Woodcock-Johnson Auditory WM	-.459	97.240	.363	-1.265	.223
Competing Lang. Processing Measure	.076		.300	.252	.804
Leiter-Reverse	-.686		.937	-.733	.474
Visual Processing Measure	-.202		.339	-.597	.558

the contributions of auditory WM measures, but this time with word attack as the dependent variable. First, the control variables of complex auditory-verbal WM measures were entered into the regression equation. Results showed that the squared multiple correlation for the equation was $R^2 = .253$ for second grade and $R^2 = .013$ for fifth grade, see Table 12. This model was significant for second grade but not for fifth, see Table 13. Furthermore, within this model for second grade, the Competing Language Processing Measure, $\beta = .465$, emerged as the strongest predictor of word attack, see Table 14.

In the second model, the predictor variables of visual WM measures were entered into the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .084$ for second grade and $\Delta R^2 = .074$ for fifth grade. This second model was significant for second grade, $F(4,27) = 3.444$, $p = .021$, but not for fifth, $F(4,17) = .402$, $p = .804$. Within the second model for second grade the Competing Language Processing Measure, $\beta = .431$, again emerged as a significant predictor of word attack.

For both regression models, the Competing Language Processing Measure, a complex auditory-verbal WM measure requiring high cognitive control, was the most predictive of word attack ability. However, it was only predictive for the second-grade participants. Complex visuospatial WM measures offered no additional predictive power over the complex auditory-verbal WM measures. Overall, the full regression equation explained 34% of the variance in word attack for second grade and 9% of the variance in word attack for fifth grade. Based on these results, complex auditory-verbal WM measures predicted second grader's

Table 12

Regression Models to Predict Word Attack

Model	*R*	R^2	Adjusted R^2	Std. Error	ΔR2	*F* change	*df*1	*df*2	Sig. *F* change
Second grade									
1	.503	.253	.202	5.89424	.253	4.921	2	29	.014
2	.581	.338	.240	5.75280	.084	1.722	2	27	.198
Fifth grade									
1	.114	.013	-.091	13.53181	.013	.125	2	19	.883
2	.294	.087	-.128	13.76242	.074	.684	2	17	.518

Model 1: Competing Language Processing Measure and Woodcock Johnson WM Measure
Model 2: Competing Language Processing Measure, Woodcock Johnson WM Measure and Leiter-Reverse and Visual Processing Measure

Table 13

ANOVA

Model		Sum of Squares	*df*	Mean Square	*F*	Sig
Second grade						
1	Regression	341.950	2	170.975	4.921	.014
	Residual	1007.519	29	34.742		
	Total	1349.469	31			
2	Regression	455.910	4	113.978	3.444	.021
	Residual	893.558	27	33.095		
	Total	1349.469	31			
Fifth grade						
1	Regression	45.684	2	22.842	.125	.883
	Residual	3479.088	19	183.110		
	Total	3524.773	21			
2	Regression	304.902	4	76.225	.402	.804
	Residual	3219.871	17	189.404		
	Total	3524.773	21			

Dependent Variable: Standard Scores on Word Attack
Predictors for Model 1: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory Task
Predictors for Model 2: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory Task, Leiter-Reverse, Visual Processing Task

Table 14

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Attack

Model	Slope	Intercept	Std. Error	*t*	Sig.
Second Grade					
1 Woodcock-Johnson Auditory WM	.187	69.933	.191	.975	.338
Competing Lang. Processing Measure	.465		.194	2.394	.023
2 Woodcock-Johnson Auditory WM	.231	72.705	.201	1.148	.261
Competing Lang. Processing Measure	.431		.201	2.149	.041
Leiter-Reverse	-.461		.281	-1.642	.112
Visual Processing Measure	.007		.224	.029	.977
Fifth Grade					
1 Woodcock-Johnson Auditory WM	.149	64.856	.609	.245	.809
Competing Lang. Processing Measure	.237		.502	.472	.642
2 Woodcock-Johnson Auditory WM	.052	91.378	.625	.084	.934
Competing Lang. Processing Measure	.230		.517	.444	.663
Leiter-Reverse	-1.507		1.613	-.934	.363
Visual Processing Measure	-.193		.584	-.330	.745

word attack ability, but not fifth grader's word attack ability. Complex visuospatial WM measures did not predict word attack over and above the contributions of complex auditory-verbal WM measures at either grade level.

Research Question 4: For young and old children who are poor decoders, how well do the complex auditory-verbal WM measures predict word identification and word attack over and above the contributions of complex visuospatial WM measures?

Word Identification

Complex auditory-verbal WM vs. complex visuospatial WM. The dependent variable in this hierarchical regression was the standard scores of the word identification measure. The independent variables were entered into the equation in two steps. First, the control variables of the two complex visuospatial WM measures (Leiter-Reverse and Visual Processing Measure) were entered in the equation. Results showed that the squared multiple correlation for the equation was $R^2 = .222$ for second grade and $R^2 = .051$ for fifth grade, see Table 15. This model was significant for second grade, see Table 16. Within this model, there were no significant individual predictors for either grade level, see Table 17.

In the second model, the predictor variables of auditory-verbal WM measures were entered into the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .044$ for second grade and $\Delta R^2 = .093$ for fifth grade. This model was not significant for either grade level, $F(4,27) = 2.448$, $p = .070$; $F(4,17) = .712$, $p = .595$; respectively, and no individual contributors emerged as a significant predictor in this model.

Overall, the full regression equation explained 27% of the variance for second grade and 14% of the variance for fifth grade. Based on these results, the complex auditory-verbal WM measures appeared to offer no predictive power beyond the complex visuospatial WM measures for word identification ability in second- or fifth-grade students. Furthermore, the complex visuospatial WM measures only predicted word identification at second grade.

Word Attack

Complex auditory-verbal WM vs. complex visuospatial WM. Another hierarchical multiple regression analysis was run to answer the same research question of whether complex auditory-verbal WM measures predicted reading

Table 15

Regression Models to Predict Word Identification

Model	R	R^2	Adjusted R^2	Std. Error	ΔR2	F change	df1	df2	Sig. F change
Second grade									
1	.471	.222	.168	5.72095	.222	4.136	2	29	.026
2	.516	.266	.157	5.75797	.044	.814	2	27	.454
Fifth grade									
1	.225	.051	-.049	7.96066	.051	.507	2	19	.610
2	.379	.143	-.058	7.99416	.093	.921	2	17	.417

Model 1: Visual Processing Measure, Leiter-Reverse
Model 2: Visual Processing Measure, Leiter-Reverse, Competing Language Processing Measure, and Woodcock-Johnson Auditory WM Measure

Table 16

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig
Second Grade		270.726	2	135.363	4.136	.026
1	Regression	949.149	29	32.729		
	Residual	1219.875	31			
	Total					
2	Regression	324.712	4	81.178	2.448	.070
	Residual	895.163	27	33.154		
	Total	1219.875	31			
Fifth Grade		64.295	2	32.147	.507	.610
1	Regression	1204.069	19	63.372		
	Residual	1268.364	21			
	Total					
2	Regression	181.951	4	45.488	.712	.595
	Residual	1086.413	17	63.907		
	Total	1268.364	21			

Dependent Variable: Standard Scores on Word Identification
Predictors for Model 1: Visual Processing Task, Leiter-Reverse
Predictors for Model 2: Visual Processing Task, Leiter-Reverse, Competing Language Processing Task, and Woodcock Johnson's Auditory Working Memory Task

Table 17

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Identification

Model	Slope	Intercept	Std. Error	*t*	Sig.
Second Grade					
1 Leiter-Reverse	-.475	88.421	.270	-1.758	.089
Visual Processing Measure	-.239		.187	-1.273	.213
2 Leiter-Reverse	-.384	88.846	.281	-1.367	.183
Visual Processing Measure	-.381		.224	-1.701	.100
Woodcock-Johnson Auditory WM	.082		.202	.405	.688
Competing Lang. Processing Measure	.217		.201	1.083	.288
Fifth Grade					
1 Leiter-Reverse	-.573	89.153	.922	-.622	.541
Visual Processing Measure	-.176		.334	-.527	.604
2 Leiter-Reverse	-.686	97.240	.937	-.733	.474
Visual Processing Measure	-.202		.339	-.597	.558
Woodcock-Johnson Auditory WM	-.459		.363	-1.265	.223
Competing Lang. Processing Measure	.076		.300	.252	.804

ability over and above the contributions of complex visuospatial WM measures,but this time with word attack as the dependent variable. Results showed that the squared multiple correlation for the equation was $R^2 = .155$, for second grade and $R^2 = .076$ for fifth grade, see Table 18. This first regression equation was not significant for either grade level, see Table 19. However, the Leiter-Reverse measure emerged as a significant negative predictor, $\beta = -.653$, to the second grade word attack scores, see Table 20. The higher the participants scored on the Leiter-Reverse (a complex visuospatial WM measure requiring moderate cognitive control), the worse they scored on the word attack.

Table 18

Regression Models to Predict Word Attack

Model	*R*	R^2	Adjusted R^2	Std. Error	ΔR2	*F* change	*df*1	*df*2	Sig. *F* change
Second grade									
1	.393	.155	.096	6.27231	.155	2.651	2	29	.088
2	.581	.338	.240	5.75280	.183	3.737	2	27	.037
Fifth grade									
1	.276	.076	-.021	13.09323	.076	.780	2	19	.472
2	.294	.087	-.128	13.76242	.011	.099	2	17	.907

Model 1: Visual Processing Measure, Leiter-Reverse
Model 2: Visual Processing Measure, Leiter-Reverse, Competing Language Processing Measure, and Woodcock-Johnson Auditory WM Measure

Table 19

ANOVA

Model		Sum of Squares	*df*	Mean Square	*F*	Sig
Second grade						
1	Regression	208.556	2	104.278	2.651	.088
	Residual	1140.913	29	39.342		
	Total	1349.469	31			
1	Regression	455.910	4	113.978	3.444	.021
	Residual	893.558	27	33.095		
	Total	1349.469	31			
Fifth grade						
1	Regression	267.554	2	133.777	.780	.472
	Residual	3257.219	19	171.433		
	Total	3524.773	21			
2	Regression	304.902	4	76.225	.402	.804
	Residual	3219.871	17	189.404		
	Total	3524.773	21			

Dependent Variable: Standard Scores on Word Attack
Predictors for Model 1: Visual Processing Task, Leiter-Reverse
Predictors for Model 2: Visual Processing Task, Leiter-Reverse, Competing Language Processing Task, and Woodcock Johnson’s Auditory Working Memory Task

For the second model, the predictor variables of complex auditory-verbal WM measures were entered into the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .183$ for second-grade and $\Delta R^2 = .011$ for fifth grade. This model was significant for second graders, but not for fifth, $F(4,27) = 3.444$, $p = .021$; $F(4, 17) = .402$, $p = .804$, respectively. The Competing Language Processing Measure, β = .431, emerged as a significant predictor in this second model for word attack in second-grade participants.

Overall, the full regression equation explained 34% of the variance for second grade and 9% of the variance for fifth grade. For second-grade participants, the complex auditory-verbal WM measure did predict word attack over and above the contributions of the complex visuospatial WM measures. However, for fifth-grade participants, neither regression equation predicted the word attack scores.

Table 20

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Attack

Model	Slope	Intercept	Std. Error	*t*	Sig.
Second Grade					
1 Leiter-Reverse	-.653	71.796	.296	-2.203	.036
Visual Processing Measure	.322		.206	1.569	.128
2 Leiter-Reverse	-.461	72.705	.281	-1.642	.112
Visual Processing Measure	.007		.224	.029	.977
Woodcock-Johnson Auditory WM	.231		.201	1.148	.261
Competing Lang. Processing Measure	.431		.201	2.149	.041
Fifth Grade					
1 Leiter-Reverse	-1.584	95.275	1.516	-1.045	.309
Visual Processing Measure	-.154		.549	-.280	.783
2 Leiter-Reverse	-1.507	1.613	-.234	-.934	.363
Visual Processing Measure	-.193	.584	-.083	-.330	.745
Woodcock-Johnson Auditory WM	.052	.625	.020	.084	.934
Competing Lang. Processing Measure	.230	.517	.106	.444	.663

Research Question 5: For children who are poor decoders, how well do the complex auditory-verbal WM measures predict reading ability over the simple auditory-verbal WM measure controlling for verbal intelligence or phonological awareness ability?

Word Identification

Simple vs. complex auditory-verbal WM. To answer this question, the independent variables were entered into the hierarchical regression equation in four steps. First, the control variable of verbal intelligence was entered in the equation. Results showed that the squared multiple correlation for the equation was $R^2 = .046$ for second grade and $R^2 = .025$ for fifth grade, see Table 21. The regression model with just verbal intelligence as a predictor of word identification was not significant for either second- or fifth-grade participants, see Table 22.

In the second model a predictor variable, the simple auditory-verbal WM measure (nonword repetition), was entered into the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .000$ for second grade and $\Delta R^2 = .437$ for fifth grade. This model was not significant for second grade, $F(2,29) = .697$, $p = .506$, but it was significant for fifth grade, $F(2,19) = 8.158$, $p = .003$. Within this model for fifth-grade participants, the simple auditory-verbal memory measure, the nonword repetition measure, $\beta = .671$ was a significant predictor, see Table 23.

In the third model, the predictor variable of the general phonological awareness measure (Elision) was added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .006$ for second grade and $\Delta R^2 = .069$ for fifth grade. Although this regression equation was not significant for second grade, F(3,28) = .514, $p = .676$, it was significant for fifth grade, F(3,18) 6.796, $p = .003$. Within the fifth grade regression model, nonword repetition, $\beta = 2.386$, emerged as the strongest predictor of word identification.

In the fourth model, the complex auditory-verbal WM measures were added to the equation. Results showed that the change in the squared multiple correlation

Table 21

Regression Models to Predict Word Identification

Model	*R*	R^2	Adjusted R^2	Std. Error	ΔR2	*F* change	*df*1	*df*2	Sig. *F* change
Second grade									
1	.214	.046	.014	6.22872	.046	1.443	1	30	.239
2	.214	.046	-.020	6.33518	.000	.000	1	29	.991
3	.229	.052	-.049	6.42579	.006	.188	1	28	.668
4	.278	.077	-.100	6.57952	.025	.353	2	26	.706
Fifth grade									
1	.157	.025	-.024	7.86487	.025	.505	1	20	.486
2	.680	.462	.405	5.99282	.437	15.447	1	19	.003
3	.729	.531	.453	5.74815	.069	2.652	1	18	.003
4	.741	.549	.408	5.98185	.018	.311	2	16	.017

Model 1: Verbal intelligence
Model 2: Verbal intelligence, Nonword repetition
Model 3: Verbal intelligence, Nonword repetition, Elision
Model 4: Verbal intelligence, Nonword repetition, Elision, Woodcock-Johnson auditory WM, Competing Language Processing Measure

Table 22

ANOVA

Model		Sum of Squares	*df*	Mean Square	*F*	Sig
Second grade						
1	Regression	55.968	1	55.968	1.443	.239
	Residual	1163.907	30	38.797		
	Total	1219.875	31			
2	Regression	55.973	2	27.986	.697	.506
	Residual	1163.902	29	40.135		
	Total	1219.875	31			
3	Regression	63.732	3	21.244	.514	.676
	Residual	1156.143	28	41.291		
	Total	1219.875	31			
4	Regression	94.332	5	18.866	.436	.819
	Residual	1125.543	26	43.290		
	Total	1219.875	31			
Fifth grade						
1	Regression	31.239	1	31.239	.505	.486
	Residual	1237.125	20	61.856		
	Total	1268.364	21			
2	Regression	585.999	2	293.000	8.158	.003
	Residual	682.364	19	35.914		
	Total	1268.364	21			
3	Regression	673.621	3	224.540	6.796	.003
	Residual	594.742	18	33.041		
	Total	1268.364	21			
4	Regression	695.842	5	139.168	3.889	.017
	Residual	572.521	16	35.783		
	Total	1268.364	21			

Dependent Variable: Standard Scores on Word Identification
Predictors for Model 1: Verbal intelligence
Predictors for Model 2: Verbal intelligence, Nonword Repetition
Predictors for Model 3: Verbal intelligence, Nonword Repetition, Elision
Predictors for Model 4: Verbal intelligence, Nonword Repetition, Elision, Woodcock Johnson's Auditory Working Memory Task, Competing Language Processing Task

Table 23

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Identification

Model	Slope	Intercept	Std. Error	*t*	Sig.
Second Grade					
1 Verbal intelligence	.152	72.049	.126	1.201	.239
2 Verbal intelligence	.152	72.075	.133	1.144	.262
Nonword repetition	-.006		.536	-.011	.991
3 Verbal intelligence	.167	71.904	.139	1.199	.240
Nonword repetition	.094		.590	.159	.875
Elision	-.140		.323	-.433	.668
4 Verbal intelligence	.182	71.998	.152	1.193	.244
Nonword repetition	.239		.691	.346	.732
Elision	-.200		.358	-.557	.582
Woodcock-Johnson Auditory WM	-.187		.238	-.785	.440
Competing Lang Processing Measure	.103		.270	.382	.705
Fifth Grade					
1 Verbal intelligence	.109	69.894	.154	.711	.486
2 Verbal intelligence	.029	54.437	.119	.242	.811
Nonword repetition	2.239		.570	3.930	.001
3 Verbal intelligence	.047	45.537	.115	.408	.688
Nonword repetition	2.386		.554	4.308	.000
Elision	.511		.314	1.628	.121
4 Verbal intelligence	.081	37.384	.127	.639	.532
Nonword repetition	2.507		.626	4.004	.001
Elision	.522		.351	1.487	.157
Woodcock-Johnson Auditory WM	.163		.311	.524	.608
Competing Lang Processing Measure	.163		.238	.686	.502

for this equation was $\Delta R^2 = .025$ for second grade and $\Delta R^2 = .018$ for fifth grade. Again, while the regression equation was not significant for second grade, F(5,26) = .436, $p = .819$, it was significant for fifth grade F(5,16) = 3.889, $p = .017$. The nonword repetition measure, $\beta = 2.507$, emerged as a significant predictor.

Overall, the full regression equation explained only 8% of the variance for second grade but 55% of the variance for fifth grade. It was the simple auditory-verbal memory measure, the nonword repetition measure, which best predicted word identification for fifth-grade participants. However, nonword repetition did not predict word identification for second-grade participants.

Word Attack

Simple vs. complex auditory-verbal WM. The same question was asked of word attack ability. "How well do the complex auditory-verbal WM measures predict word attack ability over the simple auditory-verbal WM measure controlling for verbal intelligence or a general phonological awareness measure?" To answer this question, the independent variables were entered into the hierarchical regression equation in four steps. First, the control variable of vocabulary intelligence was entered in the equation. Results showed that the squared multiple correlation for the equation was $R^2 = .129$ for second grade and $R^2 = .022$ for fifth grade, see Table 24. This model was significant for the second-grade participants, but not for fifth, suggesting that verbal intelligence is significantly correlated to word attack in younger students, see Table 25.

In the second model, the simple auditory-verbal memory measure was entered into the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .027$ for second grade and $\Delta R^2 = .038$ for fifth grade. This equation was not significant for either grade, $F(2,29) = 2.682$; $p = .085$; $F(2,19) = .610$, $p = .554$; respectively. Neither the verbal intelligence nor the simple auditory-verbal memory measure emerged as a significant predictor of word attack for either grade in this regression equation, see Table 26.

In the third model, the predictor variable of the general phonological awareness measure was added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .001$ for second grade and $\Delta R^2 = .001$ for fifth grade. This regression equation was not significant for second grade, $F(3, 28) = 1.736$, $p = .182$ or for fifth grade $F(3,18) = .391$, $p = .761$. None of the three predictors emerged as significant.

In the fourth model, the complex auditory-verbal WM measures were added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .142$ for second grade and $\Delta R^2 = .059$ for fifth grade. Although the overall equation was not significant for either grade level, $F(5,26) = 2.220$, $p = .083$; $F(5,16) = .437$, $p = .816$, respectively, the Competing Language Processing Measure (a complex auditory-verbal WM measure requiring high cognitive control) did emerge in the second grade equation as a significant predictor of word attack ($\beta = .518$).

Overall, the full regression equation explained 30% of the variance for second grade and 12% of the variance for fifth grade. These results suggest that verbal intelligence predicts word attack in young students, but the combination of verbal intelligence, simple auditory-verbal WM, and phonological awareness was not a significant predictor. The complex auditory-verbal WM measure that required the participants to make a semantic decision while holding words in memory predicted word attack in second-grade participants, but the contribution of that predictor alone was not enough to make the regression model significant. Therefore, complex auditory-verbal WM measures do not predict word attack over and above the contributions of simple auditory-verbal WM, verbal intelligence, or phonological awareness for either grade level.

Research Question 6: For children who are poor decoders, how well does phonological awareness predict reading ability over the auditory-verbal WM measures controlling for verbal intelligence?

Table 24

Regression Models to Predict Word Attack

Model	*R*	R^2	Adjusted R^2	Std. Error	ΔR2	*F* change	*df*1	*df*2	Sig. *F* change
Second grade									
1	.359	.129	.100	6.26017	.129	4.434	1	30	.044
2	.395	.156	.098	6.26661	.027	.938	1	29	.341
3	.396	.157	.066	6.37470	.001	.025	1	28	.876
4	.547	.299	.164	6.03089	.142	2.642	2	26	.090
Fifth grade									
1	.149	.022	-.027	13.12652	.022	.457	1	20	.507
2	.246	.060	-.039	13.20333	.038	.768	1	19	.392
3	.247	.061	-.095	13.55889	.001	.017	1	18	.899
4	.347	.120	-.155	13.92286	.059	.536	2	16	.595

Model 1: Verbal intelligence
Model 2: Verbal intelligence, Nonword repetition
Model 3: Verbal intelligence, Nonword repetition, Elision
Model 4: Verbal intelligence, Nonword repetition, Elision, Woodcock-Johnson auditory WM, Competing Language Processing Measure

Table 25

ANOVA

Model		Sum of Squares	*df*	Mean Square	*F*	Sig
Second grade						
1	Regression	173.776	1	173.776	4.434	.044
	Residual	1175.693	30	39.190		
	Total	1349.469	31			
2	Regression	210.627	2	105.314	2.682	.085
	Residual	1138.841	29	39.270		
	Total	1349.469	31			
3	Regression	211.637	3	70.546	1.736	.182
	Residual	1137.832	28	40.637		
	Total	1349.469	31			
4	Regression	403.805	5	80.761	2.220	.083
	Residual	945.664	26	36.372		
	Total	1349.469	31			
Fifth grade						
1	Regression	78.660	1	78.660	.457	.507
	Residual	3446.113	20	172.306		
	Total	3524.773	21			
2	Regression	212.542	2	106.271	.610	.554
	Residual	3312.230	19	174.328		
	Total	3524.773	21			
3	Regression	215.591	3	71.864	.391	.761
	Residual	3309.182	18	183.843		
	Total	3524.773	21			
4	Regression	423.236	5	84.647	.437	.816
	Residual	3101.537	16	193.846		
	Total	3524.773	21			

Dependent Variable: Standard Scores on Word Attack
Predictors for Model 1: Verbal intelligence
Predictors for Model 2: Verbal intelligence, Nonword Repetition
Predictors for Model 3: Verbal intelligence, Nonword Repetition, Elision
Predictors for Model 4: Verbal intelligence, Nonword Repetition, Elision, Woodcock Johnson's Auditory Working Memory Task, Competing Language Processing Task

Table 26

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Attack

Model	Slope	Intercept	Std. Error	T	Sig.
Second Grade					
1 Verbal intelligence	.267	64.742	.127	2.106	.044
2 Verbal intelligence	.234	62.533	.132	1.781	.085
Nonword repetition	.513		.530	.969	.341
3 Verbal intelligence	.240	62.471	.138	1.736	.094
Nonword repetition	.549		.585	.938	.356
Elision	-.050		.320	-.158	.876
4 Verbal intelligence	.134	66.889	.140	.962	.345
Nonword repetition	-.040		.634	-.062	.951
Elision	-.308		.328	-.937	.357
Woodcock-Johnson Auditory WM	.157		.218	.719	.478
Competing Lang Processing Measure	.518		.247	2.096	.046
Fifth Grade					
1 Verbal intelligence	.173	60.560	.257	.676	.507
2 Verbal intelligence	.134	52.966	.262	.511	.615
Nonword repetition	1.100		1.255	.876	.392
3 Verbal intelligence	.137	51.306	.270	.508	.618
Nonword repetition	1.127		1.307	.863	.400
Elision	.095		.740	.129	.899
4 Verbal intelligence	.242	24.293	.296	.818	.425
Nonword repetition	1.582		1.457	1.086	.294
Elision	.190		.817	.233	.819
Woodcock-Johnson Auditory WM	.602		.724	.831	.418
Competing Lang Processing Measure	.431		.553	.778	.448

Word Identification

Phonological awareness vs. auditory-verbal WM. To answer this question, the independent variables were entered into the hierarchical regression equation in four steps. First, the control variables of auditory-verbal WM were entered in the equation. Results showed that the squared multiple correlation for the equation was $R^2 = .019$ for second grade and $R^2 = .074$ for fifth grade, see Table 27. This model was not significant for either grade level, see Table 28.

In the second model, verbal intelligence was entered into the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .045$ for second grade and $\Delta R^2 = .016$ for fifth grade. This equation was not significant for either grade, $F(3,28) = .643$, $p = .594$; $F(3,18) = .595$, $p = .627$; respectively. No significant individual contributors emerged, see Table 29.

In the third model, the simple auditory-verbal memory predictor variable (nonword repetition) was added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .002$ for second grade and $\Delta R^2 = .396$ for fifth grade. This regression equation was not significant for second grade, $F(4,27) = .479$, $p = .751$, but it was for fifth grade, $F(4,17) = 4.023$, $p = .018$, with the simple auditory-verbal memory measure, $\beta = 2.266$, emerging as a significant contributor to the equation.

In the fourth model, the phonological awareness measure was added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .011$ for second grade and $\Delta R^2 = .062$ for fifth grade. Although the overall equation was not significant for second grade, $F(5,26) = .436$, $p = .819$, it was significant for fifth grade, $F(5,16) = 3.889$, $p = .017$. The simple auditory-verbal WM measure, $\beta = 2.507$, emerged in the fifth grade equation as a significant predictor of word identification.

Overall, the full regression equation explained 8% of the variance for second grade and 55% of the variance for fifth grade. Phonological awareness did not have predictive powers above auditory WM, verbal simple memory, or verbal intelligence. This model was not a good predictor for second grade word identification. For fifth-grade participants, the simple auditory-verbal WM measure provided the best predictor of word identification.

Table 27

Regression Models to Predict Word Identification

Model	*R*	R^2	Adjusted R^2	Std. Error	ΔR2	*F* change	*df*1	*df*2	Sig. *F* change
Second grade									
1	.139	.019	-.048	6.42233	.019	.288	2	29	.752
2	.254	.064	-.036	6.38414	.045	1.348	1	28	.255
3	.258	.066	-.072	6.49498	.002	.052	1	27	.821
4	.278	.077	-.100	6.57952	.011	.311	1	26	.582
Fifth grade									
1	.273	.074	-.023	7.86064	.074	.764	2	19	.480
2	.300	.090	-.061	8.00685	.016	.312	1	18	.583
3	.697	.486	.365	6.19110	.396	13.107	1	17	.002
4	.741	.549	.408	5.98185	.062	2.210	1	16	.157

Model 1: Competing Language Processing Measure and Woodcock-Johnson Auditory WM
Model 2: Competing Language Processing Measure, Woodcock-Johnson Auditory WM, and Verbal intelligence
Model 3: Competing Language Processing Measure, Woodcock-Johnson Auditory WM, Verbal intelligence, and Nonword Repetition Measure
Model 4: Competing Language Processing Measure, Woodcock-Johnson Auditory WM, Verbal intelligence, Nonword Repetition Measure, and Elision measure

Table 28

ANOVA

Model		Sum of Squares	*df*	Mean Square	*F*	Sig
Second grade						
1	Regression	23.731	2	11.866	.288	.752
	Residual	1196.144	29	41.246		
	Total	1219.875	31			
2	Regression	78.672	3	26.224	.643	.594
	Residual	1141.203	28	40.757		
	Total	1219.875	31			
3	Regression	80.885	4	20.221	.479	.751
	Residual	1138.990	27	42.185		
	Total	1219.875	31			
4	Regression	94.332	5	18.866	.436	.819
	Residual	1125.543	26	43.290		
	Total	1219.875	31			
Fifth grade						
1	Regression	94.360	2	47.180	.764	.480
	Residual	1174.003	19	61.790		
	Total	1268.364	21			
2	Regression	114.389	3	38.130	.595	.627
	Residual	1153.975	18	64.110		
	Total	1268.364	21			
3	Regression	616.759	4	154.190	4.023	.018
	Residual	651.605	17	38.330		
	Total	1268.364	21			
4	Regression	695.842	5	139.168	3.889	.017
	Residual	572.521	16	35.783		
	Total	1268.364	21			

Dependent Variable: Standard Scores on Word Identification
Predictors for Model 1: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory
Predictors for Model 2: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory, Verbal Intelligence
Predictors for Model 3: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory, Verbal Intelligence, Nonword Repetition
Predictors for Model 4: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory, Verbal Intelligence, Nonword Repetition, Elision

Table 29

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Identification

Model	Slope	Intercept	Std. Error	*t*	Sig.
Second Grade					
1 Woodcock-Johnson Auditory WM	-.101	78.388	.209	-.485	.632
Competing Lang Processing Measure	.153		.212	.723	.475
2 Woodcock-Johnson Auditory WM	-.157	72.500	.213	-.739	.466
Competing Lang Processing Measure	.067		.223	.299	.767
Verbal intelligence	.170		.147	1.161	.255
3 Woodcock-Johnson Auditory WM	-.178	71.807	.234	-.759	.454
Competing Lang Processing Measure	.045		.246	.184	.856
Verbal intelligence	.171		.149	1.148	.261
Nonword repetition	.152		.665	.229	.821
4 Woodcock-Johnson Auditory WM	-.187	71.998	.238	-.785	.440
Competing Lang Processing Measure	.103		.270	.382	.705
Verbal intelligence	.182		.152	1.193	.244
Nonword repetition	.239		.691	.346	.732
Elision	-.200		.358	-.557	.582
Fifth Grade					
1 Woodcock-Johnson Auditory WM	-.408	81.466	.354	-1.155	.262
Competing Lang Processing Measure	.066		.292	.225	.824
2 Woodcock-Johnson Auditory WM	-.352	74.275	.374	-.941	.359
Competing Lang Processing Measure	.121		.313	.387	.704
Verbal intelligence	.094		.169	.559	.583
3 Woodcock-Johnson Auditory WM	.025	48.716	.307	.083	.935
Competing Lang Processing Measure	.215		.243	.881	.390
Verbal intelligence	.061		.131	.466	.647
Nonword repetition	2.266		.626	3.620	.002
4 Woodcock-Johnson Auditory WM	.163	37.384	.311	.524	.608
Competing Lang Processing Measure	.163		.238	.686	.502
Verbal intelligence	.081		.127	.639	.532
Nonword repetition	2.507		.626	4.004	.001
Elision	.522		.351	1.487	.157

Word Attack

Phonological awareness vs. auditory-verbal WM. The same question was asked of word attack. First, the auditory WM measures were entered in the equation. Results showed that the squared multiple correlation for the equation was $R^2 = .253$ for second grade and $R^2 = .013$ for fifth grade, see Table 30. The regression model with just verbal WM measures as the predictors of word attack was significant for second grade but not for fifth-grade participants, see Table 31. Within the model for second grade, the Competing Language Processing Measure, $\beta = .465$, was the strongest predictor of word attack, see Table 32.

In the second model, verbal intelligence was entered into the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .020$ for second grade and $\Delta R^2 = .042$ for fifth grade. This model was significant for second grade, $F(3,28) = 3.512$, $p = .028$, but it was not significant for fifth grade, $F(3,18) = .350$, $p = .790$. There were no significant predictors in this model for either grade level.

In the third model, the predictor variable of simple auditory-verbal memory was added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .002$ for second grade and $\Delta R^2 = .062$ for fifth grade. This regression equation was not significant for second grade, $F(4,27) = 2.567$, $p = .061$ or for fifth grade, $F(4,17) = .564$, $p = .692$. No individual predictors emerged as significant.

In the fourth model, the phonological awareness measure was added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .024$ for second grade and $\Delta R^2 = .003$ for fifth grade. The regression equation was not significant for second grade, $F(5,26) = 2.220$, $p = .083$, or for fifth grade, $F(5,16) = .437$, $p = .816$. Even though the model was not significant, the Competing Language Processing Measure, $\beta = .518$, emerged as a significant predictor of word attack at second grade.

Overall, the full regression equation explained 30% of the variance for second grade and 12% of the variance for fifth grade. Phonological awareness was not predictive of word attack above the contributions of complex auditory-verbal WM, simple auditory-verbal WM, or verbal intelligence for either grade level.

Table 30

Regression Models to Predict Word Attack

Model	*R*	R^2	Adjusted R^2	Std. Error	ΔR2	*F* change	*df*1	*df*2	Sig. *F* change
Second grade									
1	.503	.253	.202	5.89424	.253	4.921	2	29	.014
2	.523	.273	.196	5.91759	.020	.772	1	28	.387
3	.525	.276	.168	6.01734	.002	.079	1	27	.780
4	.547	.299	.164	6.03089	.024	.879	1	26	.357
Fifth grade									
1	.114	.013	-.091	13.53181	.013	.125	2	19	.883
2	.235	.055	-.120	13.60283	.042	.802	1	18	.382
3	.342	.117	-.091	13.52996	.062	1.194	1	17	.290
4	.347	.120	-.155	13.92286	.003	.054	1	16	.819

Model 1: Competing Language Processing Measure and Woodcock-Johnson Auditory WM

Model 2: Competing Language Processing Measure, Woodcock-Johnson Auditory WM, and Verbal intelligence

Model 3: Competing Language Processing Measure, Woodcock-Johnson Auditory WM, Verbal intelligence, and Nonword Repetition Measure

Model 4: Competing Language Processing Measure, Woodcock-Johnson Auditory WM, Verbal intelligence, Nonword Repetition Measure, and Elision measure

Table 31

ANOVA

Model		Sum of Squares	*df*	Mean Square	*F*	Sig
Second grade						
1	Regression	341.950	2	170.975	4.921	.014
	Residual	1007.519	29	34.742		
	Total	1349.469	31			
2	Regression	368.969	3	122.990	3.512	.028
	Residual	980.500	28	35.018		
	Total	1349.469	31			
3	Regression	371.842	4	92.961	2.567	.061
	Residual	977.627	27	36.208		
	Total	1349.469	31			
4	Regression	403.805	5	80.761	2.220	.083
	Residual	945.664	26	36.372		
	Total	1349.469	31			
Fifth grade						
1	Regression	45.684	2	22.842	.125	.883
	Residual	3479.088	19	183.110		
	Total	3524.773	21			
2	Regression	194.109	3	64.703	.350	.790
	Residual	3330.664	18	185.037		
	Total	3524.773	21			
3	Regression	412.754	4	103.189	.564	.692
	Residual	3112.019	17	183.060		
	Total	3524.773	21			
4	Regression	423.236	5	84.647	.437	.816
	Residual	3101.537	16	193.846		
	Total	3524.773	21			

Dependent Variable: Standard Scores on Word Attack
Predictors for Model 1: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory
Predictors for Model 2: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory, Verbal Intelligence
Predictors for Model 3: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory, Verbal Intelligence, Nonword Repetition
Predictors for Model 4: Competing Language Processing Task, Woodcock Johnson's Auditory Working Memory, Verbal Intelligence, Nonword Repetition, Elision

Table 32

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Attack

Model	Slope	Intercept	Std. Error	*t*	Sig.
Second Grade					
1 Woodcock-Johnson Auditory WM	.187	69.933	.191	.975	.338
Competing Lang Processing Measure	.465		.194	2.394	.023
2 Woodcock-Johnson Auditory WM	.147	65.804	.197	.745	.462
Competing Lang Processing Measure	.404		.207	1.955	.061
Verbal intelligence	.119		.136	.878	.387
3 Woodcock-Johnson Auditory WM	.170	66.594	.217	.785	.439
Competing Lang Processing Measure	.429		.228	1.884	.070
Verbal intelligence	.118		.138	.855	.400
Nonword repetition	-.174		.616	-.282	.780
4 Woodcock-Johnson Auditory WM	.157	66.889	.218	.719	.478
Competing Lang Processing Measure	.518		.247	2.096	.046
Verbal intelligence	.134		.140	.962	.345
Nonword repetition	-.040		.634	-.062	.951
Elision	-.308		.328	-.937	.357
Fifth Grade					
1 Woodcock-Johnson Auditory WM	.149	64.856	.609	.245	.809
Competing Lang Processing Measure	.237		.502	.472	.642
2 Woodcock-Johnson Auditory WM	.303	45.280	.635	.477	.639
Competing Lang Processing Measure	.388		.532	.729	.476
Verbal intelligence	.257		.287	.896	.382
3 Woodcock-Johnson Auditory WM	.552	28.419	.672	.821	.423
Competing Lang Processing Measure	.449		.532	.844	.410
Verbal intelligence	.235		.286	.821	.423
Nonword repetition	1.495		1.368	1.093	.290
4 Woodcock-Johnson Auditory WM	.602	24.293	.724	.831	.418
Competing Lang Processing Measure	.431		.553	.778	.448
Verbal intelligence	.242		.296	.818	.425
Nonword repetition	1.582		1.457	1.086	.294
Elision	.190		.817	.233	.819

Research Question 7: For children who are poor decoders, how well does the complex visuospatial WM measure predict reading ability over the simple visuospatial WM measure controlling for nonverbal intelligence or orthographic knowledge?

Word Identification

Complex vs. simple visuospatial WM measures. For this research question, the dependent variable was the standard score on the word identification measure, and the independent variables were entered into the equation in four steps. First, the control variable of nonverbal intelligence was entered in the equation. Results showed that the squared multiple correlation for the equation was $R^2 = .070$ for second grade and $R^2 = .022$ for fifth grade, see Table 33. This model was not significant for either grade, see Table 34.

In the second model, the predictor variable of Leiter-Forward, the simple, simple visuospatial WM measure, was entered into the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .230$ for second grade and $\Delta R^2 = .010$ for fifth grade. This model was significant for the second grade participants, $F(2,29) = 6.211$, $p = .006$, with the Leiter-Forward (the simple visuospatial memory measure), $\beta = -.473$, emerging as a significant predictor, see Table 35. However the correlation was negative, indicating that roughly for every half point earned on the Leiter-Forward, word identification decreased by one point. This model was not significant for fifth grade, $F(2,19) = .313$, $p = .735$.

In the third model, the predictor variable of orthographic knowledge was added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .002$ for second grade and $\Delta R^2 = .318$ for fifth grade. This model was significant for second grade, $F(3,28) = 4.028$, $p = .017$, as well as fifth grade, $F(3,18) = 3.232$, $p = .047$. For second grade, the Leiter-Forward, $\beta = -.467$, continued to significantly and negatively predict word identification. For fifth grade, the orthographic measure, $\beta = .293$, emerged as a predictor of word identification.

Table 33

Regression Models to Predict Word Identification

Model	*R*	R^2	Adjusted R^2	Std. Error	ΔR2	*F* change	*df*1	*df*2	Sig. *F* change
Second grade									
1	.265	.070	.039	6.14823	.070	2.271	1	30	.142
2	.548	.300	.252	5.42679	.230	9.507	1	29	.004
3	.549	.301	.227	5.51656	.002	.064	1	28	.802
4	.591	.349	.223	5.52791	.047	.943	2	26	.403
Fifth grade									
1	.150	.022	-.027	7.87400	.022	.458	1	20	.507
2	.179	.032	-.070	8.03901	.010	.187	1	19	.670
3	.592	.350	.242	6.76741	.318	8.811	1	18	.008
4	.660	.435	.259	6.69060	.085	1.208	2	16	.325

Model 1: Nonverbal intelligence
Model 2: Nonverbal intelligence and Leiter-Forward
Model 3: Nonverbal intelligence, Leiter-Forward, and Orthographic knowledge
Model 4: Nonverbal intelligence, Leiter-Forward, Orthographic knowledge, and Visual Processing Measure and Leiter-Reverse

Table 34

ANOVA

Model		Sum of Squares	*df*	Mean Square	*F*	Sig
Second grade						
1	Regression	85.852	1	85.852	2.271	.142
	Residual	1134.023	30	37.801		
	Total	1219.875	31			
2	Regression	365.824	2	182.912	6.211	.006
	Residual	854.051	29	29.450		
	Total	1219.875	31			
3	Regression	367.768	3	122.589	4.028	.017
	Residual	852.107	28	30.432		
	Total	1219.875	31			
4	Regression	425.371	5	85.074	2.784	.038
	Residual	794.504	26	30.558		
	Total	1219.875	31			
Fifth grade						
1	Regression	28.366	1	28.366	.458	.507
	Residual	1239.998	20	62.000		
	Total	1268.364	21			
2	Regression	40.475	2	20.238	.313	.735
	Residual	1227.888	19	64.626		
	Total	1268.364	21			
3	Regression	444.002	3	148.001	3.232	.047
	Residual	824.361	18	45.798		
	Total	1268.364	21			
4	Regression	552.139	5	110.428	2.467	.077
	Residual	716.225	16	44.764		
	Total	1268.364	21			

Dependent Variable: Standard Scores on Word Identification
Predictors for Model 1: Nonverbal intelligence
Predictors for Model 2: Nonverbal intelligence, Leiter-Forward
Predictors for Model 3: Nonverbal intelligence, Leiter-Forward, Orthographic Knowledge
Predictors for Model 4: Nonverbal intelligence, Leiter-Forward, Orthographic Knowledge, Visual Processing Task, Leiter-Reverse

Table 35

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Identification

Model	Slope	Intercept	Std. Error	*t*	Sig.
Second Grade					
1 Nonverbal intelligence	-.386	87.061	.256	-1.507	.142
2 Nonverbal intelligence	-.334	93.761	.227	-1.473	.151
Leiter-Forward	-.473		.153	-3.083	.004
3 Nonverbal intelligence	-.353	94.679	.243	-1.455	.157
Leiter-Forward	-.467		.158	-2.964	.006
Orthographic knowledge	-.015		.061	-.253	.802
4 Nonverbal intelligence	-.271	96.511	.264	-1.027	.314
Leiter-Forward	-.356		.178	-2.003	.056
Orthographic knowledge	.006		.063	.093	.926
Visual Processing Measure	-.180		.199	-.906	.373
Leiter-Reverse	-.190		.298	-.638	.529
Fifth grade					
1 Nonverbal intelligence	-.252	83.313	.373	-.676	.507
2 Nonverbal intelligence	-.236	77.010	.383	-.617	.544
Leiter-Forward	.269		.622	.433	.670
3 Nonverbal intelligence	-.056	52.195	.328	-.170	.867
Leiter-Forward	.359		.525	.683	.503
Orthographic knowledge	.293		.099	2.968	.008
4 Nonverbal intelligence	-.133	63.859	.344	-.387	.704
Leiter-Forward	.741		.583	1.271	.222
Orthographic knowledge	.287		.098	2.922	.010
Visual Processing Measure	-.099		.304	-.326	.749
Leiter-Reverse	-1.151		.852	-1.351	.196

In the fourth model, the complex visuospatial WM measures (Leiter-Reverse and Visual Processing Measure) were added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .047$ for second grade and $\Delta R^2 = .085$ for fifth grade. This regression equation was significant for second grade, F(5,26) = 2.784, $p = .038$ but not for fifth grade, F(5,16) = 2.467, $p = .077$. Oddly enough, no individual predictors emerged at the second grade level to significantly impact word reading ability, but orthographic knowledge, β = .287, did emerge as a significant predictor at fifth grade.

Overall, the full regression equation explained 35% of the variance for second grade and 44% of the variance for fifth grade. When all things were considered, simple visuospatial WM was the greatest predictor of word identification at second grade and orthographic knowledge was the greatest predictor of word identification at fifth grade. Complex visuospatial WM measures did not contribute to word identification over and above the contributions of simple visuospatial WM, nonverbal intelligence, or orthographic knowledge.

Word Attack

Complex vs. simple visuospatial WM measures. The same question was asked of word attack. To answer this question, the independent variables were entered into the equation in four steps. First, the control variable of nonverbal intelligence was entered in the equation. Results showed that the squared multiple correlation for the equation was $R^2 = .239$ for second grade and $R^2 = .009$ for fifth grade, see Table 36. Nonverbal intelligence was significant and predictive of word attack for second grade students, but it was not predictive for fifth-grade students, see Table 37.

In the second model, the Leiter-Forward, a simple visuospatial WM measure, was entered into the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .008$ for second grade and $\Delta R^2 = .007$ for fifth grade. This model was significant for second-grade students, $F(2,29) = 4.743$, $p = .017$ but not for fifth-grade students, $F(2,19) = .154$, $p = .859$. Within the second grade model, the nonverbal intelligence, β = -.737, emerged as the strongest predictor of word attack, although it was negatively correlated, meaning that the better the participant did on the nonverbal measure, the worse score they attained on the word attack measure, see Table 38.

Table 36

Regression Models to Predict Word Attack

Model	*R*	R^2	Adjusted R^2	Std. Error	ΔR2	*F* change	*df*1	*df*2	Sig. *F* change
Second grade									
1	.489	.239	.213	5.85144	.239	9.413	1	30	.005
2	.496	.246	.195	5.92147	.008	.295	1	29	.591
3	.505	.255	.175	5.99391	.008	.303	1	28	.586
4	.542	.299	.164	6.03104	.045	.828	2	26	.448
Fifth grade									
1	.096	.009	-.040	13.21415	.009	.186	1	20	.671
2	.126	.016	-.088	13.51154	.007	.129	1	19	.723
3	.433	.187	.052	12.61692	.171	3.790	1	18	.067
4	.493	.243	.006	12.91477	.056	.590	2	16	.566

Model 1: Nonverbal intelligence
Model 2: Nonverbal intelligence and Leiter-Forward
Model 3: Nonverbal intelligence, Leiter-Forward, and Orthographic knowledge
Model 4: Nonverbal intelligence, Leiter-Forward, Orthographic knowledge, Visual Processing Measure and Leiter-Reverse

In the third model, the predictor variable of orthographic knowledge was added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .008$ for second graders and $\Delta R^2 = .171$ for fifth graders. This model was significant for second graders, $F(3,28) = 3.187$, $p = .039$, but not for fifth graders, $F(3,18) = 1.381$, $p = .281$. Within the second grade model the nonverbal intelligence, $\beta = -.692$, was the strongest significant predictor of word attack, although it was still negatively correlated.

In the fourth model, the complex visuospatial WM measures were added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .045$ for second grade and $\Delta R^2 = .056$ for fifth grade. This model was not significant for second grade, $F(5,26) = 2.220$, $p = .083$, nor was it significant for fifth grade, $F(5,16) = 1.027$, $p = .435$. However, for second grade, the nonverbal intelligence, $\beta = -.598$, was still a significant predictor, albeit negative, of word attack.

Overall, the full regression equation explained 55% of the variance for second grade and 24% of the variance for fifth grade. In general, nonverbal intelligence predicted word attack for second-grade students. There was not a significant predictor for fifth grade word attack. Complex visuospatial WM measures did not have predictive power over simple visuospatial WM measures, nonverbal intelligence, or orthographic knowledge at either grade level.

Research Question 8: For children who are poor decoders, how well does orthographic knowledge predict reading ability over simple and complex visuospatial WM measures controlling for nonverbal intelligence?

Table 37

ANOVA

Model		Sum of Squares	*df*	Mean Square	*F*	Sig
Second grade						
1	Regression	322.287	1	322.287	9.413	.005
	Residual	1027.182	30	34.239		
	Total	1349.469	31			
2	Regression	332.619	2	166.309	4.743	.017
	Residual	1016.850	29	35.064		
	Total	1349.469	31			
3	Regression	343.513	3	114.504	3.187	.039
	Residual	1005.956	28	35.927		
	Total	1349.469	31			
4	Regression	403.761	5	80.752	2.220	.083
	Residual	945.708	26	36.373		
	Total	1349.469	31			
Fifth grade						
1	Regression	32.496	1	32.496	.186	.671
	Residual	3492.277	20	174.614		
	Total	3524.773	21			
2	Regression	56.099	2	28.050	.154	.859
	Residual	3468.673	19	182.562		
	Total	3524.773	21			
3	Regression	659.415	3	219.805	1.381	.281
	Residual	2865.358	18	159.187		
	Total	3524.773	21			
4	Regression	856.112	5	171.222	1.027	.435
	Residual	2668.660	16	166.791		
	Total	3524.773	21			

Dependent Variable: Standard Scores on Word Attack
Predictors for Model 1: Nonverbal intelligence
Predictors for Model 2: Nonverbal intelligence, Leiter-Forward
Predictors for Model 3: Nonverbal intelligence, Leiter-Forward, Orthographic Knowledge
Predictors for Model 4: Nonverbal intelligence, Leiter-Forward, Orthographic Knowledge, Visual Processing Task, Leiter-Reverse

Table 38

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Attack

Model	Slope	Intercept	Std. Error	*t*	Sig.
Second Grade					
1 Nonverbal intelligence	-.747	92.685	.244	-3.068	.005
2 Nonverbal intelligence	-.737	93.972	.247	-2.983	.006
Leiter-Forward	-.091		.167	-.543	.591
3 Nonverbal intelligence	-.692	91.798	.264	-2.265	.014
Leiter-Forward	-.105		.171	-.611	.546
Orthographic knowledge	.036		.066	.551	.586
4 Nonverbal intelligence	-.598	85.837	.288	-2.073	.048
Leiter-Forward	-.116		.194	-.600	.553
Orthographic knowledge	.019		.069	.268	.790
Visual Processing Measure	.250		.217	1.150	.261
Leiter-Reverse	-.310		.325	-.952	.350
Fifth grade					
1 Nonverbal intelligence	.270	63.147	.626	.431	.671
2 Nonverbal intelligence	.248	71.946	.643	.385	.704
Leiter-Forward	-.376		1.046	-.360	.723
3 Nonverbal intelligence	.468	41.602	.611	.766	.453
Leiter-Forward	-.267		.979	-.273	.788
Orthographic knowledge	.359		.184	1.947	.067
4 Nonverbal intelligence	.352	57.288	.664	.530	.603
Leiter-Forward	.236		1.125	.210	.836
Orthographic knowledge	.352		.190	1.854	.082
Visual Processing Measure	-.099		.587	-.169	.868
Leiter-Reverse	-1.598		1.644	-.972	.346

Word Identification

Predictive power of orthographic knowledge. For this final research question, the dependent variable was the standard score on the word identification measure. The independent variables were entered into the equation in four steps. First, the complex visuospatial WM measures (Leiter-Reverse and Visual Processing

Measure) were entered in the equation. Results showed that the squared multiple correlation for the equation was $R^2 = .222$ for second grade and $R^2 = .051$ for fifth grade, see Table 39. This model was significant for second grade, but not for fifth, see Table 40. Within the second grade model, the two complex visuospatial WM measures combined predicted word identification, but neither of the complex visuospatial WM measures alone significantly predicted word reading ability.

In the second model, nonverbal intelligence was entered into the equation. Results showed that the change in the squared multiple correlation for this equation

Table 39

Regression Models to Predict Word Identification

Model	*R*	*R*²	Adjusted *R*²	Std. Error	ΔR2	*F* change	*df*1	*df*2	Sig. *F* change
Second grade									
1	.471	.222	.168	5.72095	.222	4.136	2	29	.026
2	.498	.248	.168	5.72321	.026	.977	1	28	.331
3	.590	.348	.252	5.42548	.100	4.157	1	27	.051
4	.591	.349	.223	5.52791	.000	.009	1	26	.926
Fifth grade									
1	.225	.051	-.049	7.96066	.051	.507	2	19	.610
2	.285	.081	-.072	8.04731	.030	.593	1	18	.451
3	.366	.134	-.070	8.03870	.053	1.039	1	17	.322
4	.660	.435	.259	6.69060	.301	8.541	1	16	.010

Model 1: Visual Processing Measure and Leiter-Reverse
Model 2: Visual Processing Measure, Leiter-Reverse, and Nonverbal intelligence
Model 3: Visual Processing Measure, Leiter-Reverse, Nonverbal intelligence, and Leiter-Forward
Model 4: Visual Processing Measure, Leiter-Reverse, Nonverbal intelligence, Leiter-Forward, and Orthographic knowledge

was $\Delta R^2 = .026$ for second grade and $\Delta R^2 = .030$ for fifth grade. This model was significant for the second-grade participants, $F(3,28) = 3.081$, $p = .044$, but no individual variable emerged as a significant predictor, see Table 41. This model was not significant for fifth graders, $F(3,18) = .529$, $p = .668$.

In the third model, the predictor variable of simple visuospatial WM (Leiter-Forward) was added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .100$ for second grade and $\Delta R^2 = .053$ for fifth grade. This model was significant for second grade, $F(4,27) = 3.610$, $p = .018$, but not for fifth grade, $F(4,17) = .657$, $p = .630$. There were no individual variables that emerged as significant predictors.

In the fourth model, the orthographic knowledge WM measure was added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .000$ for second grade and $\Delta R^2 = .301$ for fifth grade. Similar to models 2 and 3, the regression equation for model 4 was significant for second grade, $F(5,26) = 2.784$, $p = .038$, but not for fifth grade, $F(5,16) = 2.467$, $p = .077$. Oddly enough, no individual predictors emerged at the second grade level to significantly impact word reading ability, but orthographic knowledge, $\beta = .287$, did emerge as a significant predictor at fifth grade.

Overall, the full regression equation explained 35% of the variance for second grade and 44% of the variance for fifth grade. When all things were considered, simple visuospatial WM was the greatest predictor of word identification at second grade and orthographic knowledge was the greatest predictor of word identification at fifth grade.

Table 40

ANOVA

Model		Sum of Squares	*df*	Mean Square	*F*	Sig
Second grade						
1	Regression	270.726	2	135.363	4.136	.026
	Residual	949.149	29	32.729		
	Total	1219.875	31			
2	Regression	302.733	3	100.911	3.081	.044
	Residual	917.142	28	32.755		
	Total	1219.875	31			
3	Regression	425.106	4	106.277	3.610	.018
	Residual	794.769	27	29.436		
	Total	1219.875	31			
4	Regression	425.371	5	85.074	2.784	.038
	Residual	794.769	26	30.558		
	Total	1219.875	31			
Fifth grade		64.295	2	32.147	.507	.610
1	Regression	1204.069	19	63.372		
	Residual	1268.364	21			
	Total					
2	Regression	102.698	3	34.233	.529	.668
	Residual	1165.666	18	64.759		
	Total	1268.364	21			
3	Regression	169.811	4	42.453	.657	.630
	Residual	1098.553	17	64.621		
	Total	1268.364	21			
4	Regression	552.139	5	110.428	2.467	.077
	Residual	716.225	16	44.764		
	Total	1268.364	21			

Dependent Variable: Standard Scores on Word Identification
Predictors for Model 1: Visual Processing Task, Leiter-Reverse
Predictors for Model 2: Visual Processing Task, Leiter-Reverse, Nonverbal intelligence
Predictors for Model 3: Visual Processing Task, Leiter-Reverse, Nonverbal intelligence, Leiter-Forward
Predictors for Model 4: Visual Processing Task, Leiter-Reverse, Nonverbal intelligence, Leiter-Forward, Orthographic Knowledge

Orthographic knowledge did predict word identification over and above the contributions of nonverbal intelligence, complex visuospatial WM measures, and a simple visuospatial WM measure for fifth-grade participants.

Word Attack

Predictive power of orthographic knowledge. The same question was asked of word attack. To answer this question, the independent variables were entered into the equation in four steps. First, the complex visuospatial WM measures (Leiter-Reverse, Visual Processing Measure) were entered in the equation. Results showed that the squared multiple correlation for the equation was $R^2 = .155$ for second grade and $R^2 = .076$ for fifth grade, see Table 42. This model was not significant for either grade, see Table 43. However, a complex visuospatial WM measure requiring moderate cognitive control was predictive of word attack for second-grade students, but not for fifth-grade students. Specifically, the Leiter-Reverse, $\beta = -.653$, negatively and significantly predicted word attack scores, see Table 44. This means for every point earned in the Leiter-Reverse measure, the word attack scores decreased by nearly seven tenths of a point.

In the second model, nonverbal intelligence was entered into the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .133$ for second grade and $\Delta R^2 = .003$ for fifth grade. This model was significant for second-grade students, $F(3,28) = 3.770$, $p = .022$, but not for fifth-grade students, $F(3,18) = .513$, $p = .678$. Within the second grade model, the nonverbal intelligence, $\beta = -.614$, emerged as the strongest predictor of psuedoword

Table 41

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Identification

Model	Slope	Intercept	Std. Error	*t*	Sig.
Second Grade					
1 Leiter-Reverse	-.475	88.421	.270	-1.758	.089
Visual Processing Measure	-.239		.187	-1.273	.213
2 Leiter-Reverse	-.353	94.336	.297	-1.188	.245
Visual Processing Measure	-.277		.191	-1.445	.160
Nonverbal intelligence	-.259		.262	-.989	.331
3 Leiter-Reverse	-.191	96.752	.293	-.651	.521
Visual Processing Measure	-.175		.188	-.932	.359
Nonverbal intelligence	-.278		.248	-1.120	.272
Leiter-Forward	-.356		.174	-2.039	.051
4 Leiter-Reverse	-.190	96.511	.298	-.638	.529
Visual Processing Measure	-.180		.199	-.906	.373
Nonverbal intelligence	-.271		.264	-1.027	.314
Leiter-Forward	-.356		.178	-2.003	.056
Orthographic Knowledge	.006		.063	.093	.926
Fifth Grade					
1 Leiter-Reverse	-.573	89.153	.922	-.622	.541
Visual Processing Measure	-.176		.334	-.527	.604
2 Leiter-Reverse	-.813	98.399	.983	-.828	.419
Visual Processing Measure	-.101		.351	-.288	.777
Nonverbal intelligence	-.314		.408	-.770	.451
3 Leiter-Reverse	-1.107	88.784	1.023	-1.082	.294
Visual Processing Measure	-.197		.363	-.543	.594
Nonverbal intelligence	-.282		.409	-.689	.500
Leiter-Forward	.714		.700	1.019	.322
4 Leiter-Reverse	-1.151	63.859	.852	-1.351	.196
Visual Processing Measure	-.099		.304	-.326	.749
Nonverbal intelligence	-.133		.344	-.387	.704
Leiter-Forward	.741		.583	1.271	.222
Orthographic Knowledge	.287		.098	2.922	.010

decoding, although it was negatively correlated, meaning that the better the participant did on the nonverbal measure, the worse score they attained on the word attack measure.

In the third model the simple visuospatial WM measure (Leiter-Forward) was added to the equation. Results showed that the change in the squared multiple correlation for this equation was ΔR^2 = .010 for second grade and ΔR^2 = .002 for fifth grade. This model was significant for second grade, F(4,27) = 2.855, *p* = .043, but not for fifth grade, F(4,17) = .371, *p* = .826. Within the second grade model the nonverbal intelligence, β = -.620, was the strongest significant predictor of word attack, although it was still negatively correlated.

Table 42

Regression Models to Predict Word Attack

Model	*R*	*R*^{2}	Adjusted *R*^{2}	Std. Error	ΔR2	*F* change	*df*1	*df*2	Sig. *F* change
Second grade									
1	.393	.155	.096	6.27231	.155	2.651	2	29	.088
2	.536	.288	.211	5.85901	.133	5.236	1	28	.030
3	.545	.297	.193	5.92649	.010	.366	1	27	.550
4	.547	.299	.164	6.03104	.002	.072	1	26	.790
Fifth grade									
1	.276	.076	-.021	13.09323	.076	.780	2	19	.472
2	.281	.079	-.075	13.43116	.003	.056	1	18	.816
3	.283	.080	-.136	13.80901	.002	.028	1	17	.868
4	.493	.243	.006	12.91477	.163	3.436	1	16	.082

Model 1: Visual Processing Measure and Leiter-Reverse
Model 2: Visual Processing Measure, Leiter-Reverse, and Nonverbal intelligence
Model 3: Visual Processing Measure, Leiter-Reverse, Nonverbal intelligence, and Leiter-Forward
Model 4: Visual Processing Measure, Leiter-Reverse, Nonverbal intelligence, Leiter-Forward, and Orthographic knowledge

In the fourth model the measure of orthographic knowledge was added to the equation. Results showed that the change in the squared multiple correlation for this equation was $\Delta R^2 = .002$ for second grade and $\Delta R^2 = .163$ for fifth grade. This model was not significant for second grade, $F(5,26) = 2.220$, $p = .083$, nor was it significant for fifth grade, $F(5,16) = 1.027$, $p = .435$. However, for second grade, the nonverbal intelligence, $\beta = -.598$, was still a significant predictor, albeit negative, of word attack.

Overall, the full regression equation explained 30% of the variance for second grade and 24% of the variance for fifth grade. In general, nonverbal intelligence was the most predictive for word attack for second grade students. Orthographic knowledge did not contribute any predictive value to either grade level over and above the contributions made by nonverbal intelligence or visuospatial WM measures.

Summary of Results

The contributions of complex auditory-verbal and visuospatial WM on decoding skills were examined in second- and fifth-grade students who were poor decoders. Complex auditory-verbal WM predicted word attack for second graders. Furthermore, complex auditory-verbal WM measures predicted word attack above the contributions of the complex visuospatial WM measures. Neither complex auditory-verbal nor visuospatial WM measures were predictive of word identification for second graders.

Table 43

ANOVA

Model		Sum of Squares	*df*	Mean Square	*F*	Sig
Second grade						
1	Regression	208.556	2	104.278	2.651	.088
	Residual	1140.913	29	39.342		
	Total	1349.469	31			
2	Regression	388.286	3	129.429	3.770	.022
	Residual	961.183	28	34.328		
	Total	1349.469	31			
3	Regression	401.139	4	100.285	2.855	.043
	Residual	948.330	27	35.123		
	Total	1349.469	31			
4	Regression	403.761	5	80.752	2.220	.083
	Residual	945.708	26	36.373		
	Total	1349.469	31			
Fifth grade						
1	Regression	267.554	2	133.777	.780	.472
	Residual	3257.219	19	171.433		
	Total	3524.773	21			
2	Regression	277.643	3	92.548	.513	.678
	Residual	3247.129	18	180.396		
	Total	3524.773	21			
3	Regression	283.066	4	70.767	.371	.826
	Residual	3241.707	17	190.689		
	Total	3524.773	21			
4	Regression	856.112	5	171.222	1.027	.435
	Residual	2668.660	16	166.791		
	Total	3524.773	21			

Dependent Variable: Standard Scores on Word Attack
Predictors for Model 1: Visual Processing Task, Leiter-Reverse
Predictors for Model 2: Visual Processing Task, Leiter-Reverse, Nonverbal intelligence
Predictors for Model 3: Visual Processing Task, Leiter-Reverse, Nonverbal intelligence, Leiter-Forward
Predictors for Model 4: Visual Processing Task, Leiter-Reverse, Nonverbal intelligence, Leiter-Forward, Orthographic Knowledge

Table 44

Slope, Intercept, and Significance of Individual Coefficients to Predict Word Attack

Model	Slope	Intercept	Std. Error	*t*	Sig.
Second Grade					
1 Leiter-Reverse	-.653	71.796	.296	-2.203	.036
Visual Processing Measure	.322		.206	1.569	.128
2 Leiter-Reverse	-.363	85.813	.304	-1.195	.242
Visual Processing Measure	.232		.196	1.186	.246
Nonverbal intelligence	-.614		.268	-2.288	.030
3 Leiter-Reverse	-.311	86.596	.320	-.972	.340
Visual Processing Measure	.265		.206	1.291	.208
Nonverbal intelligence	-.620		.271	-2.284	.030
Leiter-Forward	-.115		.191	-.605	.550
4 Leiter-Reverse	-.310	85.837	.325	-.952	.350
Visual Processing Measure	.250		.217	1.150	.261
Nonverbal intelligence	-.598		.288	-2.073	.048
Leiter-Forward	-.116		.194	-.600	.553
Orthographic Knowledge	.019		.069	.268	.790
Fifth Grade					
1 Leiter-Reverse	-1.584	95.275	1.516	-1.045	.309
Visual Processing Measure	-.154		.549	-.280	.783
2 Leiter-Reverse	-1.461	90.536	1.640	-.891	.385
Visual Processing Measure	-.192		.586	-.328	.747
Nonverbal intelligence	.161		.681	.236	.816
3 Leiter-Reverse	-1.544	87.803	1.757	-.879	.392
Visual Processing Measure	-.219		.624	-.352	.729
Nonverbal intelligence	.170		.702	.242	.811
Leiter-Forward	.203		1.203	.169	.868
4 Leiter-Reverse	-1.598	57.288	1.644	-.972	.346
Visual Processing Measure	-.099		.587	-.169	.868
Nonverbal intelligence	.352		.664	.530	.603
Leiter-Forward	.236		1.125	.210	.836
Orthographic Knowledge	.352		.190	1.854	.082

For fifth graders, a complex visuospatial WM measure was negatively correlated with word identification, and neither of the complex WM measures predicted word attack.

Because the complex measures of WM were not good predictors of word attack and word identification for both grades, further analyses were conducted to consider the influences of simple measures of WM, phonological awareness, orthographic knowledge, and verbal and nonverbal intelligence.

For second graders who were poor decoders, the complex auditory-verbal WM measure requiring the highest amount of cognitive control (the Competing Language Processing Measure), consistently predicted word identification and word attack skills regardless of the order that it was entered into the hierarchical regression models. This complex auditory-verbal WM measure contributed the most to the finding that auditory-verbal WM was more predictive of reading decoding than visuospatial WM. Considering just the visuospatial contributions to word decoding, the two complex visuospatial WM measures (the Visual Processing Measure and Leiter-Reverse) along with the simple visuospatial WM measure (Leiter-Forward) were negative predictors of word identification. The Leiter-Reverse also negatively and significantly predicted word attack. Across multiple models, nonverbal IQ also had a negative relationship to word attack performance. Taken together, these results suggest that measures requiring higher degrees of auditory-verbal cognitive control were positive predictors of word decoding in second graders, while visual problem-solving and visuospatial storage were negatively related to decoding.

For fifth-grade students who were poor decoders, it was the simple auditory-verbal WM measure (nonword repetition), a storage only measure that predicted word identification over and above the complex auditory-verbal WM measures, verbal intelligence, and phonological awareness. Orthographic knowledge also predicted word identification over and above the other visuospatial WM measures and nonverbal intelligence. The complex visuospatial WM measure that required moderate cognitive control, the Leiter-Reverse, was negatively correlated to word attack. Taken together, these findings suggest that it was not the measures that demanded moderate or high cognitive control that positively and significantly predicted word identification and word attack for fifth-grade students who were poor decoders. The storage only auditory-verbal WM measure and the general measure of orthographic knowledge lent the most predictive powers to reading ability to this grade level.

CHAPTER V

DISCUSSION

This study proposed to answer a series of research questions regarding the differential contributions of visuospatial and auditory-verbal WM to decoding skills in children who were poor decoders. It was hypothesized that there would be significant correlations between auditory-verbal WM and decoding ability in word attack, and to a lesser extent, in word identification for poor decoders in second grade and that the relationships between these measures and decoding would be insignificant by fifth grade. This hypothesis was driven by studies in which the phonological loop was highly correlated to decoding ability in young readers but became less predictive in older readers. It was also hypothesized that there would be small correlations between complex visuospatial WM and word identification at second grade that would become stronger by fifth grade. This hypothesis was driven by studies in which older students had larger visuospatial WM capacities than younger students.

The Contributions of Complex Auditory-verbal and Visuospatial WM

The first two research questions this study proposed to answer were how well complex auditory-verbal and visuospatial WM measures predicted word identification and word attack reading ability for young and old children who are poor decoders. To answer this question, bivariate correlation coefficients were run between the word attack and word identification measures and the two complex auditory-verbal WM and visuospatial WM measures for each grade level.

Results revealed that even though word identification and word attack measures were highly correlated, there were differences in the measures that predicted reading ability. For example, the Competing Language Processing Measure (the index of high cognitive control) predicted word attack at second grade, but it did not predict word identification at second grade. One explanation to account for this discrepancy could lie in the nature of the measure. The Competing Language Processing Measure required high cognitive control, in which the student had to process a semantic statement while holding words in mind. This measure may be very similar to figuring out a pseudoword – in that a student has to hold one option in mind while sorting through other possibilities of what the word might be. Furthermore, the complex auditory-verbal WM measure did not predict word attack at fifth grade. This finding was in line with previously reviewed research that stated the phonological loop held less predictive powers as students matured.

There were no significant correlations between word identification and complex auditory-verbal WM at either grade level. Although it was expected that auditory-verbal WM would be correlated to word identification, especially at second grade, one explanation for this finding is found by examining Tables 2 and 3. While the second grade mean for word identification was approximately 1.5 standard deviations below the mean for a typical sample, the mean for the standardized auditory-verbal WM measure was within the average range. The fifth grade statistics tell a similar story. This sample of poor decoders did not exhibit low auditory-verbal WM skills, which is contrary to what many others (i.e. Beneventi et al., 2010; Reiter et al., 2005) have found in their research. Recall that Reiter et al.

(2005) found that fifth-grade children with dyslexia performed significantly poorer on a digit span backwards task than their typically-developing peers. Beneventi et al. (2010) also demonstrated that in their sample of 13-year-old children with dyslexia, the children performed worse than their typically-developing peers on 1- and 2-back verbal tasks. In both of these studies, the complex auditory-verbal WM measures that were employed required moderate degrees of cognitive control.

The visuospatial WM measures were not correlated with word identification at either grade level. This finding was surprising, until Tables 2 and 3 were consulted. Again, although the participants in both grades scored approximately 1.5 standard deviations below the mean on word attack, their scores on the Leiter-Reverse (the standardized visual complex memory measure) were well within the average range. The sample of poor decoders in this study did not demonstrate poor visual WM, contrary to what other researchers have found (i.e. Reiter et al., 2005; Yanai & Maekawa, 2011).

Reiter et al. (2005) used a complex visuospatial WM measure requiring moderate cognitive control with their fifth-grade participants. The students viewed a rectangular figure on a computer screen for a brief amount of time after which the figure disappeared and the students had to recall the number of corners on the figure. Yanai and Maekawa's (2011) measure of complex visuospatial WM was a visual n-back task. Both groups of researchers found that their complex visuospatial WM measures requiring moderate cognitive control were predictive of reading ability in poor decoders.

A complex visuospatial WM measure requiring moderate cognitive control (Leiter-Reverse) was not correlated with word attack at second grade, but it was negatively correlated at fifth grade. Again, this finding is surprising. It was not expected that higher performance on a complex visuospatial WM measure would lead to poorer word attack. However, it has been shown that individuals with dyslexia use the right hemisphere (where the visuospatial sketchpad is located) to compensate for deficits in the left hemisphere (where the phonological loop is located). In light of those findings, it makes sense that people who struggle to decode words may have developed their visuospatial WM to compensate for their inability to decode phonologically. When they are presented with a pseudoword, they activate their visuospatial WM, trying to compare the new word with one for which they have stored a visual representation. At second grade, they have very few representations with which to compare the pseudoword, so they are not negatively impacted by their visuospatial WM. By fifth grade, they have many more representations stored, so it becomes a larger chore to try to figure out what the pseudoword says.

Complex Auditory-Verbal vs. Complex Visuospatial WM

The third question this study proposed to answer was how well the complex visuospatial WM measures predicted word identification and word attack ability over and above the contributions of the complex auditory-verbal WM measures in second- and fifth-grade students.

To address this question, a multiple hierarchical regression analysis was run. In the first model, the two complex auditory-verbal WM measures were entered

Competing Language Processing Measure and Woodcock Johnson's Auditory WM Measure, and found to not have any significant predictive value on word identification. When the two complex visuospatial WM measures were entered (Leiter-Reverse and Visual Processing Measure), the measures improved the predictive value of the model for second-grade students' word identification, but not enough to make the model with all four factors significant. This finding did not pertain to fifth graders. In general, this model was not a good explanation for what was predicting word identification in either second- or fifth-grade students.

When the dependent variable was changed to word attack scores, the two complex auditory-verbal WM measures significantly predicted how well second graders performed on the word attack measure. The Competing Language Processing Measure emerged as a significant predictor. When the two complex visuospatial WM measures were added, the model remained significant for second grade, but there was no significant change in R^2 values, suggesting that the addition of the two complex visuospatial WM measures was not the reason the model remained significant. In fact, the Competing Language Processing Measure remained the significant individual predictor of word attack for second graders. This model was a good predictor of word attack scores for second-grade students, primarily because the Competing Language Processing Measure was it. Neither model was predictive of word attack in fifth grade. In fact, the full regression equation was a poor predictor of both word identification and word attack for fifth grade poor decoders.

The fourth question was the reverse of the third question. That is, how well did the complex auditory-verbal WM measures predict word identification and word attack over and above the contributions of complex visuospatial WM measures for poor decoders in second and fifth grade.

When the two complex visuospatial WM measures (Leiter-Reverse and Visual Processing Measure) were regressed on word identification scores, the model was significant for second grade but not for fifth. However, neither visuospatial WM measure emerged as a significant predictor, suggesting that they both equally influenced word reading ability. When the two complex auditory-verbal WM measures (Competing Language Processing Measure and Woodcock Johnson's Auditory WM Measure) were added to the equation, the R^2 did not change significantly and the model was not significant. This suggests that the complex auditory-verbal WM measures did not have any predictive value above the two complex visuospatial WM measures. Neither model was significant for fifth grade.

When word attack scores were used as the dependent variable, the two complex visuospatial WM measures predicted decoding ability for second-grade students with the Leiter-Reverse emerging as a significant predictor. However, the Leiter-Reverse was negatively associated with word attack scores, suggesting that the more competent the child was with using visuospatial WM, the poorer the child performed on word attack. When the complex auditory-verbal WM measures were added, the R^2 significantly changed for the second-grade participants indicating that the addition of the complex auditory-verbal WM measures added significant prediction to the model. The model containing the four complex WM measures was significant for second grade and the Competing Language Processing Measure emerged as an individual significant predictor for second grade. There were no contributors to word attack for fifth-grade students.

The Role of Individual Measures and Cognitive Control

The next set of questions were designed to evaluate the predictive power of simple and complex WM measures independently or in combination with variables such as intelligence, phonological awareness or orthographic awareness that are known to contribute to decoding. The fifth research question sought to identify how well the complex auditory-verbal memory measures predicted reading ability over the simple auditory-verbal WM measure controlling for verbal intelligence or phonological awareness.

When verbal intelligence was regressed on word identification, there were no significant findings for second- or fifth-grade students. When nonword repetition (a low cognitive control measure) was added to the regression equation, it changed the R^2 and became a significant predictor of word reading ability for fifth-grade students. The model also became significant. With the addition of the phonological awareness measure, the model remained significant as a predictor of word identification, but the R^2 did not change. This indicates that it was not the addition of the phonological awareness measure that caused the model to remain significant. In fact, the nonword repetition measure continued to be the individual significant predictor for reading ability. Finally, when the two complex auditory-verbal WM measures were added to the regression equation, the model remained significant, however, the R^2 did not change. The nonword repetition measure continued to be the significant predictor of word identification. This is interesting because it was the simple auditory-verbal WM measure that was driving the predictive value, not the complex auditory-verbal WM measures.

Recall that LaPointe and Engle (1990) argued that simple and complex measures could predict higher order cognitive processes equally well. This was not the case for this sample of poor decoders. However, bear in mind that although these readers were poor decoders, they did not have poor WM skills. It could be the case that, for these poor readers, manipulation and storage was not the issue. The nonword repetition measure does not require manipulation, only storage. Very little cognitive control is needed to be successful when the task only requires verbatim repetition. However, it could be the case that the second-grade students were actually victims of their own success. Elman (1993) suggested that in order to successfully learn a concept, restricted capacity (cognitive control plus storage) may be necessary. Although his research is based on findings obtained with artificial neural network models of learning, he argued that when children are undergoing early periods of learning, they may benefit from having a limited working memory that slowly develops as the child matures. In having this restricted capacity, the child is limited in the input he or she is able to receive and learning can be focused on only the areas that will lay the foundation for future success. The negative predictive value of several second grade measures (Leiter-Forward, Leiter-Reverse, and Nonverbal intelligence) on both word identification and word attack lend support to Elman's theory.

None of the four models were predictive of reading ability at second grade. In fact, this full model explained only 8% of the variance. It is very interesting that the combination of variables that least predicted word identification in second grade (the Competing Language Processing Measure, the Woodcock Johnson's Auditory WM Measure, verbal intelligence, nonword repetition, and phonological awareness) was the combination that best predicted word identification in fifth grade. This phenomenon cannot be casually attributed to an increased capacity in the auditory-verbal domain because both groups exhibited scores within the average range on the auditory-verbal WM measures. It may be that the fifth-grade students become more adept at using their complex auditory-verbal WM, simple auditory-verbal WM, verbal intelligence, and phonological awareness to identify words than second-grade students.

When verbal intelligence was regressed on word attack, it had predictive value for second grade, indicating that the better the children performed on the verbal intelligence measure, the better their performance was on word attack. When nonword repetition was added to the equation, there were no significant changes in R^2, and the model did not become significant. In light of the findings for word identification measures, this was an unexpected finding. The same story was repeated when the phonological awareness measure was added to the equation. When the two complex auditory-verbal WM measures were added, the model did not become significant, but the Competing Language Processing Measure became a significant predictor within the model for both second- and fifth-grade participants.

Because phonological awareness is critical for learning to read in an alphabetic writing system, the sixth question this study proposed was to determine if a phonological awareness measure predicted reading ability over a simple auditory-verbal WM measure when verbal intelligence and complex auditory-verbal WM measures were controlled. In short, phonological awareness did not predict either word identification or word attack scores above and beyond the contributions of simple auditory-verbal WM measures, complex auditory-verbal WM measures, or verbal intelligence at either grade level. This finding was a bit surprising because phonological awareness is often credited as a large contributor to reading ability.

We then turned our attention to cognitive control in visuospatial WM measures. The seventh question was posed regarding the ability of complex visuospatial WM measures to predict reading ability over the simple visuospatial WM measure controlling for nonverbal intelligence and orthographic knowledge.

Nonverbal intelligence had no predictive value on word identification for either second- or fifth-grade participants. When a simple visuospatial WM measure (the Leiter-Forward) was added to the regression equation, the R^2 became significant as well as the model for the second-grade students. However, the Leiter-Forward had a negative β value, indicating that higher performance on this measure was related to lower performance on the word identification measure. It was interesting that this simple visuospatial WM measure would be negatively correlated to word identification measures in second grade, when the simple auditory-verbal WM measure was so positively predictive of word identification measures in fifth grade. This potentially points to a domain specific WM model.

When orthographic knowledge was added to the regression equation, the R^2 value changed significantly for fifth grade and orthographic knowledge emerged as a significant predictor of word identification. While this model was significant for both second and fifth grade, there were no individual predictors that emerged from this model. Orthographic knowledge continued to be a significant contributor to word identification for fifth-grade students. The contribution of orthographic knowledge for fifth grade but not second is not that unexpected. Orthography builds on phonology, so naturally it would have more predictive value with older students.

Complex visuospatial WM measures offered no additional contributions to word identification for either grade level beyond the predictors already discussed. This model predicted word identification ability for second-grade students, explaining 35% of the variance.

When word attack became the dependent variable, nonverbal intelligence became a significant predictor for second-grade participants. The nonverbal intelligence had a negative β, indicating that the better the participant performed on the nonverbal measure, the worse he or she performed on word attack. When the Leiter-Forward was added to the regression equation, the model remained significant for second grade, but there was no change in R^2. In fact, nonverbal intelligence remained the strongest predictor, and it still remained negative. Adding orthographic knowledge to the model did not change the significance of the model nor did it change what variable contributed the most to the dependent variable.

Finally, the two complex visuospatial WM measures (Leiter-Reverse, Visual Processing Measure) were added to the model. Again, the significance of the model did not change, and nonverbal intelligence remained negatively, but significantly, predictive of word attack ability for second-grade students. For second-grade students, nonverbal intelligence was the individual variable that lent the most predictive power to word attack, accounting for 55% of the variance, but it was not a positive predictor. A possible explanation for this phenomenon is that students who are poor decoders have had to become very good at figuring out nonverbal matrices but because pseudowords can only be figured out phonologically, they are not able to use their visuospatial memory strength to help them unlock the code. Even though none of the individual equations or the whole regression model predicted word attack in fifth-grade students, this model was still tied for the best fit for predicting word attack performance, accounting for 25% of the variance.

Finally, the issue of whether orthographic knowledge predicted word identification and word attack above and beyond the contributions of nonverbal intelligence, simple visuospatial WM, and complex visuospatial WM was addressed. For second-grade participants, orthographic knowledge did not offer any additional contributions toward word identification above and beyond those made by the complex and simple visuospatial WM measures and nonverbal intelligence. However, for fifth-grade participants, orthographic knowledge did have predictive powers above the other contributors toward word identification. The discrepancy between second grade and fifth grade was not unexpected. In fact, it was hypothesized that visuospatial measures would be more predictive of word identification at the older grade level.

Orthographic knowledge did not predict word attack skills at either grade level. This was an expected finding. Orthographic knowledge is expected to only predict words that would be in the student's repertoire.

Implications for Intervention

Many companies advertise programs designed to increase WM skills and they claim religious adherence to their program will result in better academic skills, including reading. However, in this study, children were poor decoders in spite of having WM skills within the average range. Furthermore, the second-grade students were negatively impacted in both word identification and word attack by their simple and complex visuospatial WM. The better the second graders performed on simple and complex visuospatial WM measures, the worse they performed on measures of decoding. Fifth-grade students were also negatively impacted on word attack. The better fifth graders performed on a measure of complex visuospatial WM, the worse they performed on a measure of word attack. It appears that possessing a high WM capacity is not the answer to successfully learning to read, and may, in fact, interfere with learning to decode, especially in the early stages. However, many programs designed to train WM have high visuospatial components. Such programs should be used with caution. Reading intervention needs to encompass good instruction in many different areas, as putting "all in the eggs in the WM basket" is not going to create better decoders.

Limitations and Future Research

The study, though well-conducted and tightly controlled, is not without limitations. Although many studies that were reviewed pointed to WM, specifically the domains of auditory-verbal and visuospatial, as predictors of word decoding ability, the fact is that the best models only predicted 35% of the variance for word identification in second grade, 34% of the variance for second grade word attack, 55% of the variance for fifth grade word identification, and 24% of the variance for fifth grade word attack. This indicates that there are many other contributors to decoding ability that are left unaccounted. WM is only part of the equation. Future research should investigate other constructs that may also contribute to reading ability.

There are a number of reasons that can be offered as possible explanations for the discrepancies between the poor WM found in numerous studies with poor decoders and the good WM displayed in this particular sample of poor decoders. The reviewed studies included children fifth grade and older, whereas the current study also included children in second grade. Perhaps the current sample of students was not as influenced by WM because they were younger and less vulnerable to the effects of WM on decoding. WM capacity (storage and attentional control) increases during childhood and moves toward stable or consistent performance attained at approximately 12 years of age. The differences could have occurred because the task used to measure auditory-verbal and visuospatial WM were not the same between the reviewed studies and the current study. Other researchers used n-back tasks and digit span backwards tasks to assess complex

WM skills, whereas this study utilized different types of tasks requiring varying levels of cognitive control.

Finally, within the fifth grade sample, there was one participant who scored considerably lower than the rest of the group on the two measures of decoding ability, the word identification and word attack tests. It is unknown what influence, if any, the outlier score had on the overall analysis.

Conclusion

This study proposed to tease out the differential contributions of auditory-verbal and visuospatial WM to decoding ability in second- and fifth-grade students who were poor decoders. The hypothesis that auditory-verbal WM would highly predict word attack and word identification at second grade and moderately predict it by fifth grade was partially met. This finding did support the phonological loop is involved in word attack skills, and that the rehearsal component was already in place for these second-grade children. Complex auditory-verbal WM did predict second grade word attack ability, but it did not predict anything else. The hypothesis that visuospatial WM would minimally correlate to second grade word identification and moderately correlate to fifth grade word identification was not met. In fact, not only was the hypothesis not met, the findings suggested an alternative theory. While there was no influence of complex visuospatial WM on word identification at either grade level, and there was no influence of complex visuospatial WM on second grade word attack, there was a negative correlation at the fifth grade level on word attack skills.

This sample of students differed from the samples included in the literature review in that they did not have deficits in WM. This was contrary to the theory proposed by Reiter et al. (2005) that children who are poor decoders have impairments in executive functions that cause weak auditory-verbal and visuospatial WM skills. There is apparently another explanation for the inability to read pseudowords and real words fluently.

REFERENCES

Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2009). The cognitive and behavioral characteristics of children with low working memory. *Child Development, 80*(2), 606-621. doi: 10.1111/j.1467-8624.2009.01282.x

Baddeley, A. (1986). *Working memory*. Oxford, UK: Oxford University Press.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423. doi: 10.1016/S1364-6613(00)01538-2

Baddeley, A. (2003). Working memory and language: An overview. *Journal of Communication Disorders, 36*(3), 189-209. doi: 10.1016/S0021-9924(03)00019-4.

Baddeley, A. D., Allen, R. J., & Hitch, G. J. (2010). Investigating the episodic buffer. *Psychologica Belgica, 50*(3-4), 223-243.

Beneventi, H., Tonnessen, F. E., Ersland, L., & Hugdahl, K. (2010). Working memory deficit in dyslexia: Behavioral and fMRI evidence. *International Journal of Neuroscience, 120,* 51-59. doi: 10.3109/00207450903275129.

Berends, I. E., & Reitsma, P. (2006). Addressing semantics promotes the development of reading fluency. *Applied Psycholinguistics, 27,* 247-265. doi: 10.1017.S0142716406060279

Boada, R., & Pennington, B. F. (2006). Deficient implicit phonological representations in children with dyslexia. *Journal of Experimental Child Psychology, 95,* 153-193. doi:10.1016/j.jecp.2006.04.003

Bunge, S. A., Hazeltine, E., Scanlon, M. D., Rosen, A. C., & Gabrieli, J. D. E. (2002). Dissociable contributions of prefrontal and parietal cortices to response selection. *NeuroImage, 17,* 1562-1571. doi: 10.1006/nimg.2002.1252

Cibelli, E. (2012). *Shared early pathways of word and pseudo-word processing: Evidence from high-density electrocorticography*. UC Berkeley Phonology Lab Report. 111-127.

Coltheart, M. (2005). Analysing developmental disorders of reading. *Australian Journal of Learning Disabilities, 10*(3/4), 53-62. doi: 10.1080/194041500509546799

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*(1), 204-256. doi: 10.1037/0033-295x.108.1.204

Cowan, N., AuBuchon, A. M., Gilchrist, A. L., Ricker, T. J., & Saults, J. S. (2011). Age differences in visual working memory capacity: Not based on encoding limitations. *Developmental Science, 14*(5), 1066-1074. doi: 10.1111/j.1467-7687.2011.01060.x

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

Ehri, L. C. (1999). Phases of development in learning to read words. In J. Oakhill & R. Beard (Eds.), *Reading development and the teaching of reading* (pp. 79-108). Oxford, England: Blackwell.

Elman, J. (1993). Learning and development in neural networks: the importance of starting small. *Cognition, 48,* 71-99.

Engle, R. (2010). Role of working-memory capacity in cognitive control. *Current Anthropology, 51*(S1), S17-S26. doi: 10.1086/650572

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *The Psychology of Learning and Motivation, 44,* 145-199. doi: 10.1016/S0079-7421(03)44005-X

Facoetti, A., Zorzi, M., Cestnick, L., Lorusso, M. L., Molteni, M., Paganoni, P., … Mascetti, G.G. (2006). The relationship between visuo-spatial attention and nonword reading in developmental dyslexia. *Cognitive Neuropsychology, 23,* 841-855. doi: 10.1080/02643290500483090

Farrington-Flint, L., Coyne, E., Stiller, J., & Heath, E. (2008). Variability in children's early reading strategies. *Educational Psychology, 28,* 643-661. doi: 10.1080/01443410802140958

Frijters, J. C., Lovett, M. W., Steinbach, K. A., Wolf, M., Sevcik, R. A., & Morris, R. D. (2011). Neurocognitive predictors of reading outcomes for children with reading disabilities. *Journal of Learning Disabilities, 44*(2), 150-166. doi: 10.1177/0022219410391185

Gathercole, S. E. (1999). Cognitive approaches to the development of short-term memory. *Trends in Cognitive Science, 3,* 410-418. doi: 10.1016/51364-6613(99)01388-1

Gaulin, C. A. & Campbell, T. F. (1994). Procedure for assessing verbal working memory in normal school-age children: Some preliminary data. *Perceptual and Motor Skills, 79,* 55-64. doi: 10.2466/pms.1994.79.1.55

Griffiths, Y. M., & Snowling, M. J. (2002). Predictors of exception word and nonword reading in dyslexic children: The severity hypothesis. *Journal of Educational Psychology, 94*(1), 34-43. doi: 10.1037/0022-0663.94.1.34

Hannon, B. (2013). Understanding the relative contributions of lower-level word processes, higher-level processes, and working memory to reading comprehension performance in proficient adult readers. In D. E. Alvermann, N. J. Unrau, & R. B. Ruddell (Eds.), *Theoretical models and processes of reading* (6th ed.) (pp. 840-885). Newark, DE: International Reading Association.

Hitch, G. J., & Towse, J. N. (1995). Working memory: What develops? In F. Weinert & W. Schneider (Eds.), *Memory performances and competencies: Issues in growth and development* (pp. 3 – 22). Mahwah, NJ: Erlbaum.

Hoeft, F., Meyler, A., Hernandez, A., Juel, C., Taylor-Hill, H., Martindale, J.L., … Gabrieli, J.D.E. (2007). Functional and morphometric brain dissociation between dyslexia and reading ability. *PNAS Proceedings of the National Academy of Sciences of the United States of America, 104* (10), 4234-4239.

Hoffman, L. M., & Gillam, R. B. (2004). Verbal and spatial information processing constraints in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 47,* 114-125. doi: 10.1044/1092-4388(2004/011).

Hoien-Tengesdal, I., & Tonnessen, F. E. (2011). The relationship between phonological skills and word decoding. *Scandinavian Journal of Psychology, 52,* 93-103. doi: 10.1111/j.1467-9450.2010.00856.x

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: A latent-variable approach to verbal and visuospatial memory span and reading. *Journal of Experimental Psychology: General, 133*(2), 189-217. doi: 10.1037/0096-3445.133.2.189

Katzir, T., Kim, Y., Wolf, M., Kennedy, B., Lovett, M., & Morris, R. (2006). The relationship of spelling recognition, RAN, and phonological awareness to reading skills in older poor readers and younger reading-matched controls. *Reading and Writing, 19,* 845-872. doi: 10.1007/s11145-006-9013-2

Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test* (2nd ed.). San Antonio, TX: Pearson.

Kirby, J. R., Parrila, R. K., & Pfeiffer, S. L. (2003). Naming speed and phonological awareness as predictors of reading development. *Journal of Educational Psychology, 95,* 453-464. doi: 10.1037/0022-0663.95.3.453

La Pointe, L. B., & Engle, R. W. (1990). Simple and complex word spans as measures of working memory capacity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 1118-1133.

Leiner, H. C., Leiner, A. L., & Dow, R. S. (1993). Cognitive and language functions of the human cerebellum. *Trends in Neurosciences, 16*(11), 444-447. doi: 10.1016/0166-2236(93)90072-T

Magimairaj, B. M., & Montgomery, J. W. (2012). Children's verbal working memory: Role of processing complexity in predicting spoken sentence comprehension.

Journal of Speech, Language, and Hearing Research, 55, 669-682. doi: 10.1044/1092-4388(2011/11-0111).

Mather, N., Hammill, D.D., Allen, E.A., & Roberts, R. (2004). *Test of Silent Word Reading Fluency.* Austin, TX: Pro-Ed.

Melby-Lervag, M., & Hulme, C. (2012). Is working memory training effective? A meta-analytic review. *Developmental Psychology, 49(2),* 270-291. doi: 10.1037/a0028228

Menghini, D., Finzi, A., Carlesimo, G. A., & Vicari, S. (2011). Working memory impairment in children with developmental dyslexia: Is it just a phonological deficity? *Developmental Neuropsychology, 36,* 199-213. doi: 10.1080/87565641.2010.549868

Nevo, E., & Breznitz, Z. (2013). The development of working memory from kindergarten to first grade in children with different decoding skills. *Journal of Experimental Child Psychology, 114*(2), 217-228. doi: 10.1016/j.jecp.2012.09.004

O'Brien, B. A., Wolf, M., Miller, L. T., Lovett, M. W., & Morris, R. (2011). Orthographic processing efficiency in developmental dyslexia: An investigation of age and treatment factors at the sublexical level. *Annals of Dyslexia, 61,* 111-135. doi: 10.1007/s11881-010-0050-9.

Olson, R. K., Forsberg, H., Wise, B., & Rack, J. (1994). Measurement of word recognition, orthographic, and phonological skills. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learning disabilities* (pp. 243-277). Baltimore, MD: Brookes.

Prabhakaran, V., Narayanan, K., Zhao, Z., & Gabriel, J. D. E. (2000). Integration of diverse information in working memory within the frontal lobe. *Nature Neuroscience, 3*(1), 85-90. doi: 10.1038/71156

Price, C. J., Wise, R. J. S., Watson, J. D. G., Patterson, K., Howard, D., & Frackowiak, R. S. J. (1994). *Brain, 117*(6), 1255-1269. doi: 10.1093/brain/117.6.1255

Pugh, K. R., Mencl, W. E., Jenner, A. R., Katz, L., Frost, S. J., Lee, J. R., . . . Shaywitz, B. A. (2000a). Functional neuroimaging studies of reading and reading disability (developmental dyslexia). *Mental Retardation and Developmental Disabilities Research Reviews, 6,* 207-213. doi: 10.1002/1098-2779(2000)6:3

Pugh, K. R., Mencl, W. E., Shaywitz, B. A., Shaywitz, S. E., Fulbright, R. K., Constable, R. T., . . . Gore, J. C. (2000b). The angular gyrus in developmental dyslexia: Task-specific differences in functional connectivity within posterior cortex. *Psychological Science, 11*(1), 51-56. doi: 10.1111/1467-9280.00214

Reiter, A., Tucha, O., & Lange, K. W. (2005). Executive functions in children with dyslexia. *Dyslexia, 11*(2), 116-131. doi: 10.1002/dys.289.

Roid, G. H., & Miller, L. J. (1997). *Leiter International Performance Scale – Revised.* Wood Dale, IL: Stoelting Co.

Salmon, E., Van Der Linden, M., Collette, F., Delfiore, G., Maquet, P., Degueldre, C.,... Franck, G. (1996). Regional brain activity during working memory tasks. *Brain, 119,* 1617-1625. doi: 10.1093/brain/119.5.1617

Samuels, S. J. (1987). Information processing abilities and reading. *Journal of Learning Disabilities, 20*(1), 18-22. doi: 10.1177/002221948702000104

Sandak, R., Mencl, W. E., Frost, S. J., Rueckl, J. G., Katz, L., Moore, D. L., . . . Pugh, K. R.

(2004). The neurobiology of adaptive learning in reading: a contrast of different training conditions. *Cognitive, Affective, & Behavioral Neuroscience, 4*(1), 67-88. doi: 10.3758/CABN.4.1.67

Savage, R., Lavers, N., & Pillay, V. (2007). Working memory and reading difficulties: What we know and what we don't know about the relationship. *Educational Psychology Review, 19,* 185-221. doi: 10.1007/s10648-006-9024-1

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed developmental model of word recognition and naming. *Psychological Review, 96,* 523-568.

Semel, E., Wiig, E., & Secord, W. (2003). *Clinical evaluation of language fundamentals* (4th ed.). San Antonio, TX: Pearson.

Shaywitz, B. A., Shaywitz, S. E., Blachman, B. A., Pugh, K. R., Fulbright, R. K., Skudlarski, P., . . . Gore, J. C. (2004). Development of left occipitotemporal systems for skilled reading in children after a phonologically based intervention. *Biological Psychiatry, 55,* 926-933.

Stanovich, K. E. (2000). *Progress in understanding reading.* New York, NY: Guilford.

Swanson, H. L., & Jerman, O. (2007). The influence of working memory on reading growth in subgroups of children with reading disabilities. *Journal of Experimental Child Psychology, 96,* 249-283. doi: 10.1016/j.jecp.2006.12.004

Towse, J. N., Hitch, G. J., & Hutton, U. (1998). A reevaluation of working memory capacity in children. *Journal of Memory & Language, 39,* 195-217. doi: 10.1006/jmla.1998.2574

Unsworth, N., & Engle, R. W. (2006). Simple and complex memory spans and their relation to fluid abilities: Evidence from list-length effects. *Journal of Memory and Language, 54,* 68-80. doi: 10.1016/j.jml.2005.06.003

Unsworth, N., & Engle, R. W. (2007). On the division of short-term and working memory: An examination of simple and complex span and their relation to higher order abilities. *Psychological Bulletin, 133*(6), 1038-1066. doi: 10.1037/0033-2909.133.6.1038

Unsworth, N., Redick, T. S., Heitz, R. P., Broadway, J. M., & Engle, R. W. (2009). Complex working memory span tasks and higher-order cognition: A latent-variable analysis of the relationship between processing and storage. *Memory, 17*(6), 635-654. doi: 10.1080/09658210902998047

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1999). *Comprehensive test of phonological processing.* Austin, TX: Pro-Ed.

Wallach, L., Wallach, M., Dozier, M., & Kaplan, N. (1977). Poor children learning to read do not have trouble with auditory blending but do have trouble with phonemic recognition. *Journal of Educational Psychology, 69,* 36-39.

Weismer, S. E., Evans, J., & Hesketh, L. J. (1999). An examination of verbal working memory capacity in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 42,* 1249-1260.

Woodcock, R. W. (2011). *Woodcock reading mastery tests* (3rd ed.). Bloomington, MN: Pearson.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson Test of Cognitive Abilities.* Rolling Meadows, IL: Riverside.

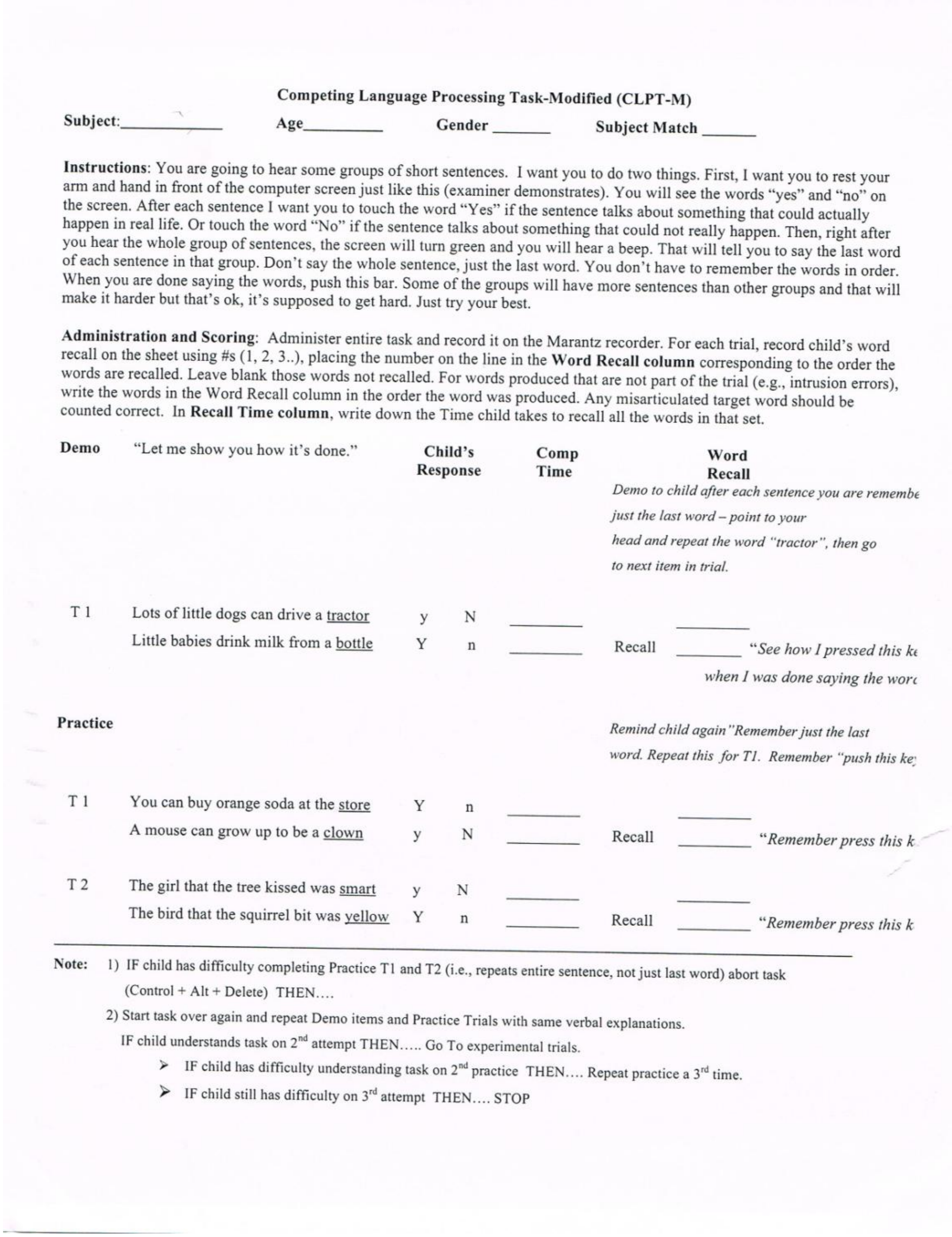
Yanai, T., & Maekawa, H. (2011). Working memory in junior high school students with reading difficulties: results from an n-back task. *Japanese Journal of Special Education, 48*(6), 555-567.

APPENDICES

Appendix A

Competing Language Processing Measure

Appendix A: Competing Language Processing Measure



Competing Language Processing Task-Modified (CLPT-M)

Subject:____________ **Age**_________ **Gender** _______ **Subject Match** ______

Instructions: You are going to hear some groups of short sentences. I want you to do two things. First, I want you to rest your arm and hand in front of the computer screen just like this (examiner demonstrates). You will see the words "yes" and "no" on the screen. After each sentence I want you to touch the word "Yes" if the sentence talks about something that could actually happen in real life. Or touch the word "No" if the sentence talks about something that could not really happen. Then, right after you hear the whole group of sentences, the screen will turn green and you will hear a beep. That will tell you to say the last word of each sentence in that group. Don't say the whole sentence, just the last word. You don't have to remember the words in order. When you are done saying the words, push this bar. Some of the groups will have more sentences than other groups and that will make it harder but that's ok, it's supposed to get hard. Just try your best.

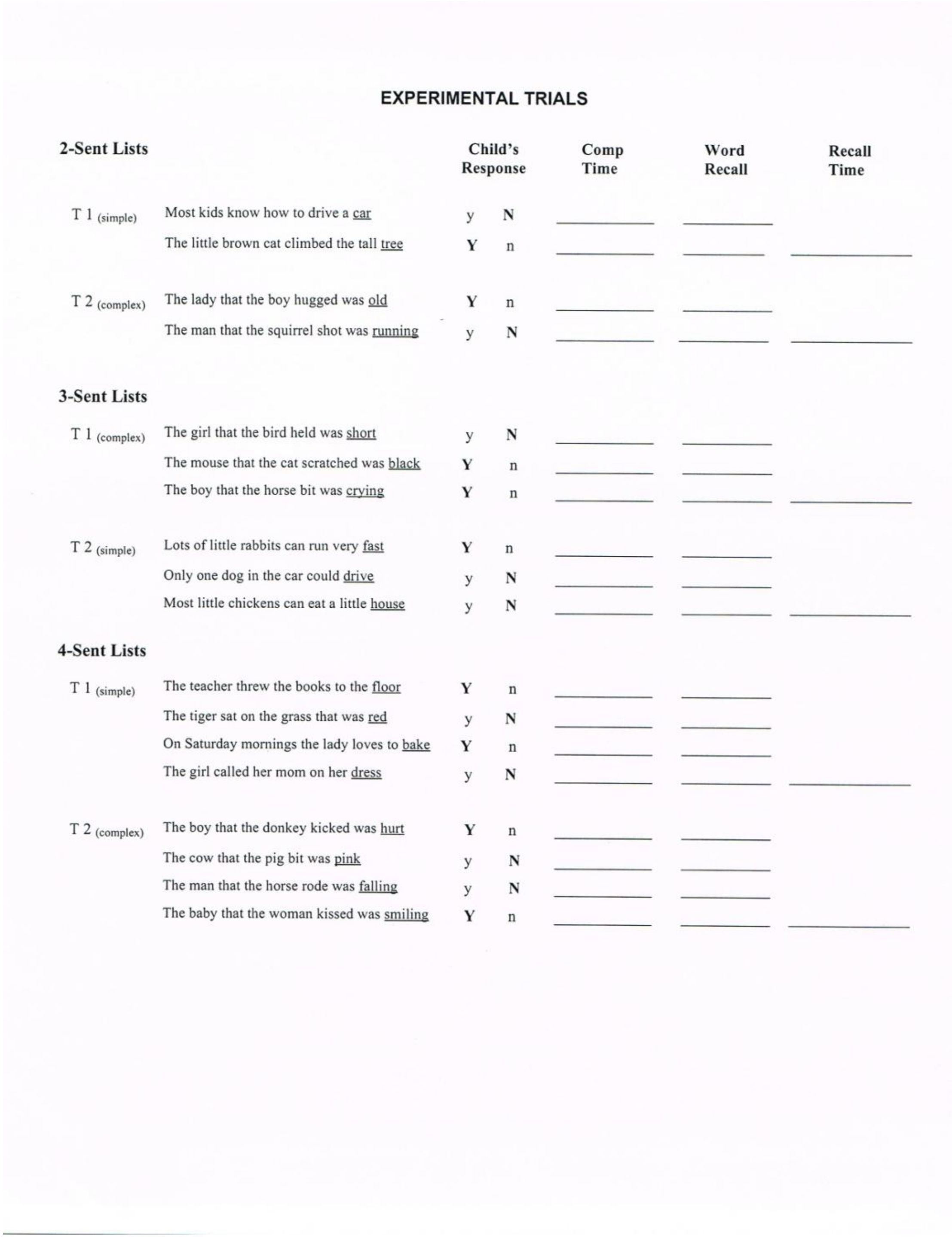
Administration and Scoring: Administer entire task and record it on the Marantz recorder. For each trial, record child's word recall on the sheet using #s (1, 2, 3..), placing the number on the line in the **Word Recall column** corresponding to the order the words are recalled. Leave blank those words not recalled. For words produced that are not part of the trial (e.g., intrusion errors), write the words in the Word Recall column in the order the word was produced. Any misarticulated target word should be counted correct. In **Recall Time column**, write down the Time child takes to recall all the words in that set.

Demo	"Let me show you how it's done."	**Child's Response**		**Comp Time**		**Word Recall**	
					Demo to child after each sentence you are remembe just the last word – point to your head and repeat the word "tractor", then go to next item in trial.		
T 1	Lots of little dogs can drive a tractor	y	N	________		________	
	Little babies drink milk from a bottle	Y	n	________	Recall	________	*"See how I pressed this ke when I was done saying the wor*
Practice					*Remind child again"Remember just the last word. Repeat this for T1. Remember "push this ke*		
T 1	You can buy orange soda at the store	Y	n	________		________	
	A mouse can grow up to be a clown	y	N	________	Recall	________	*"Remember press this k*
T 2	The girl that the tree kissed was smart	y	N	________		________	
	The bird that the squirrel bit was yellow	Y	n	________	Recall	________	*"Remember press this k*

Note: 1) IF child has difficulty completing Practice T1 and T2 (i.e., repeats entire sentence, not just last word) abort task (Control + Alt + Delete) THEN….

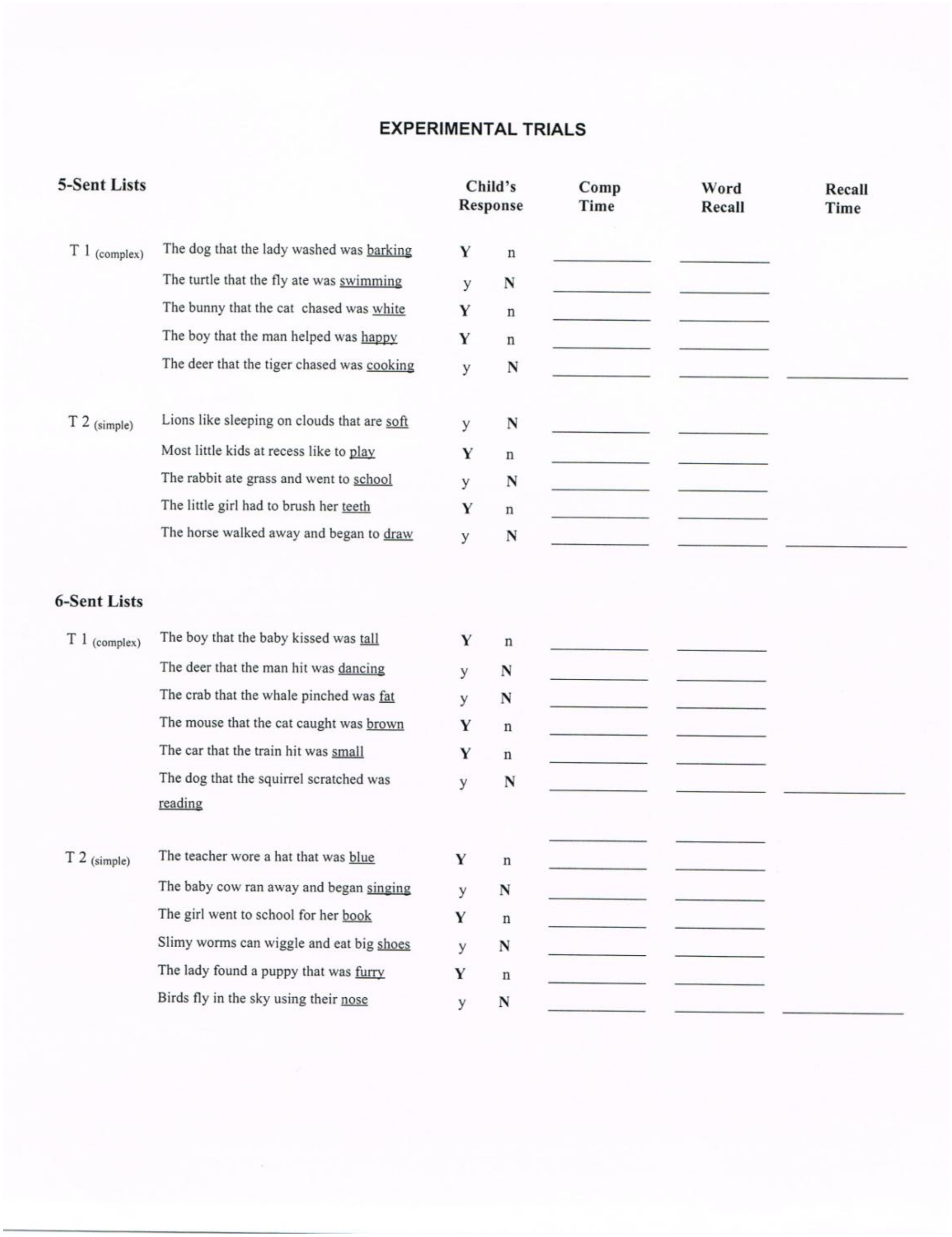
2) Start task over again and repeat Demo items and Practice Trials with same verbal explanations. IF child understands task on 2nd attempt THEN….. Go To experimental trials.

- IF child has difficulty understanding task on 2nd practice THEN…. Repeat practice a 3rd time.
- IF child still has difficulty on 3rd attempt THEN…. STOP



EXPERIMENTAL TRIALS

2-Sent Lists		**Child's Response**	**Comp Time**	**Word Recall**	**Recall Time**
T 1 (simple)	Most kids know how to drive a car	y **N**			
	The little brown cat climbed the tall tree	**Y** n			
T 2 (complex)	The lady that the boy hugged was old	**Y** n			
	The man that the squirrel shot was running	y **N**			
3-Sent Lists					
T 1 (complex)	The girl that the bird held was short	y **N**			
	The mouse that the cat scratched was black	**Y** n			
	The boy that the horse bit was crying	**Y** n			
T 2 (simple)	Lots of little rabbits can run very fast	**Y** n			
	Only one dog in the car could drive	y **N**			
	Most little chickens can eat a little house	y **N**			
4-Sent Lists					
T 1 (simple)	The teacher threw the books to the floor	**Y** n			
	The tiger sat on the grass that was red	y **N**			
	On Saturday mornings the lady loves to bake	**Y** n			
	The girl called her mom on her dress	y **N**			
T 2 (complex)	The boy that the donkey kicked was hurt	**Y** n			
	The cow that the pig bit was pink	y **N**			
	The man that the horse rode was falling	y **N**			
	The baby that the woman kissed was smiling	**Y** n			



EXPERIMENTAL TRIALS

5-Sent Lists

		Child's Response	Comp Time	Word Recall	Recall Time
T 1 (complex)	The dog that the lady washed was barking	**Y** n			
	The turtle that the fly ate was swimming	y **N**			
	The bunny that the cat chased was white	**Y** n			
	The boy that the man helped was happy	**Y** n			
	The deer that the tiger chased was cooking	y **N**			
T 2 (simple)	Lions like sleeping on clouds that are soft	y **N**			
	Most little kids at recess like to play	**Y** n			
	The rabbit ate grass and went to school	y **N**			
	The little girl had to brush her teeth	**Y** n			
	The horse walked away and began to draw	y **N**			

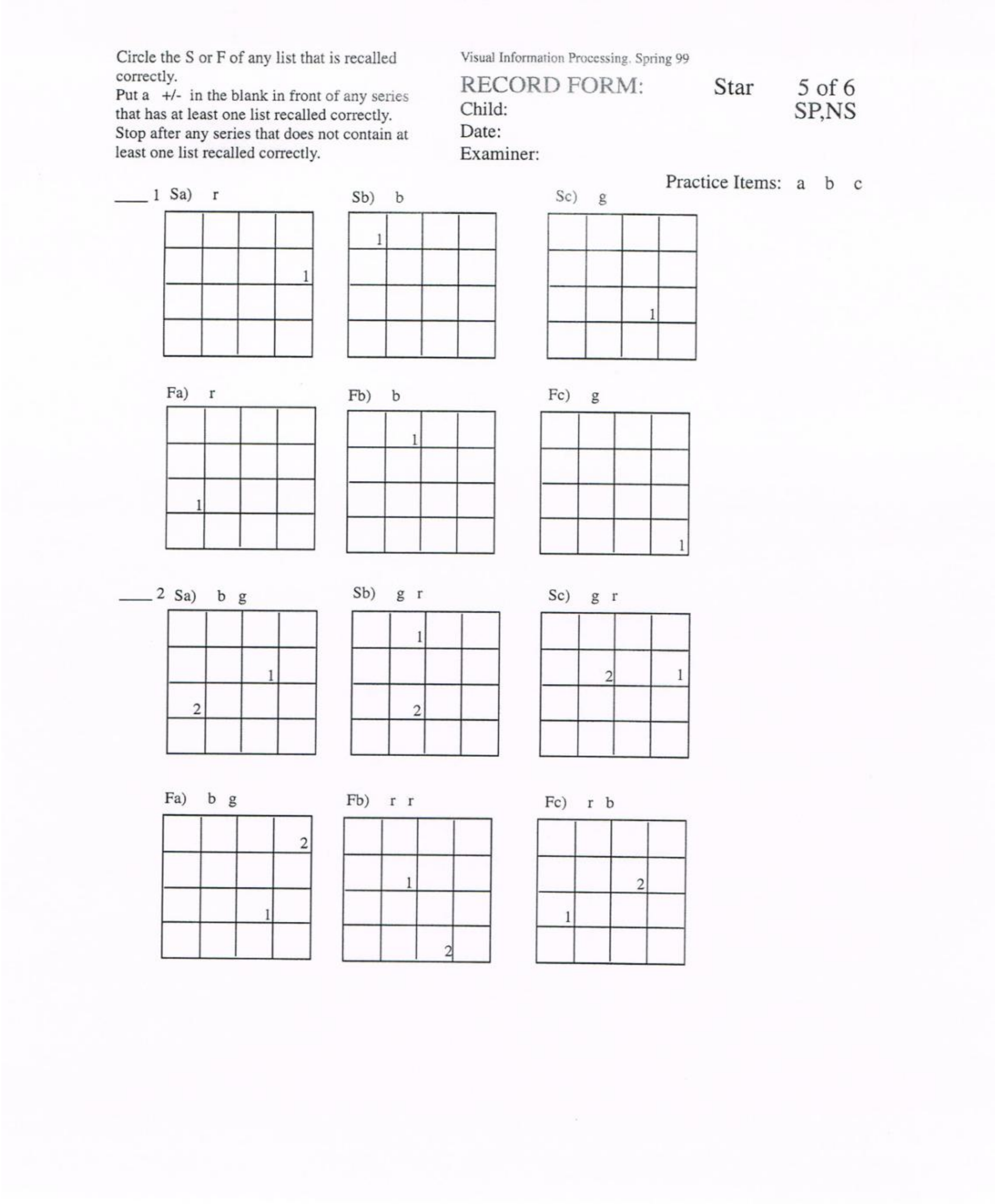
6-Sent Lists

		Child's Response	Comp Time	Word Recall	Recall Time
T 1 (complex)	The boy that the baby kissed was tall	**Y** n			
	The deer that the man hit was dancing	y **N**			
	The crab that the whale pinched was fat	y **N**			
	The mouse that the cat caught was brown	**Y** n			
	The car that the train hit was small	**Y** n			
	The dog that the squirrel scratched was reading	y **N**			
T 2 (simple)	The teacher wore a hat that was blue	**Y** n			
	The baby cow ran away and began singing	y **N**			
	The girl went to school for her book	**Y** n			
	Slimy worms can wiggle and eat big shoes	y **N**			
	The lady found a puppy that was furry	**Y** n			
	Birds fly in the sky using their nose	y **N**			

Appendix B

Visual Information Processing Measure

Appendix B: Visual Information Processing Measure



Circle the S or F of any list that is recalled correctly.
Put a +/- in the blank in front of any series that has at least one list recalled correctly.
Stop after any series that does not contain at least one list recalled correctly.

Visual Information Processing. Spring 99

RECORD FORM: Star 5 of 6
SP,NS
Child:
Date:
Examiner:

Practice Items: a b c

____ 1 Sa) r

			1

Sb) b

1			

Sc) g

		1	

Fa) r

1			

Fb) b

	1		

Fc) g

			1

____ 2 Sa) b g

		1	
2			

Sb) g r

	1		
	2		

Sc) g r

	2		1

Fa) b g

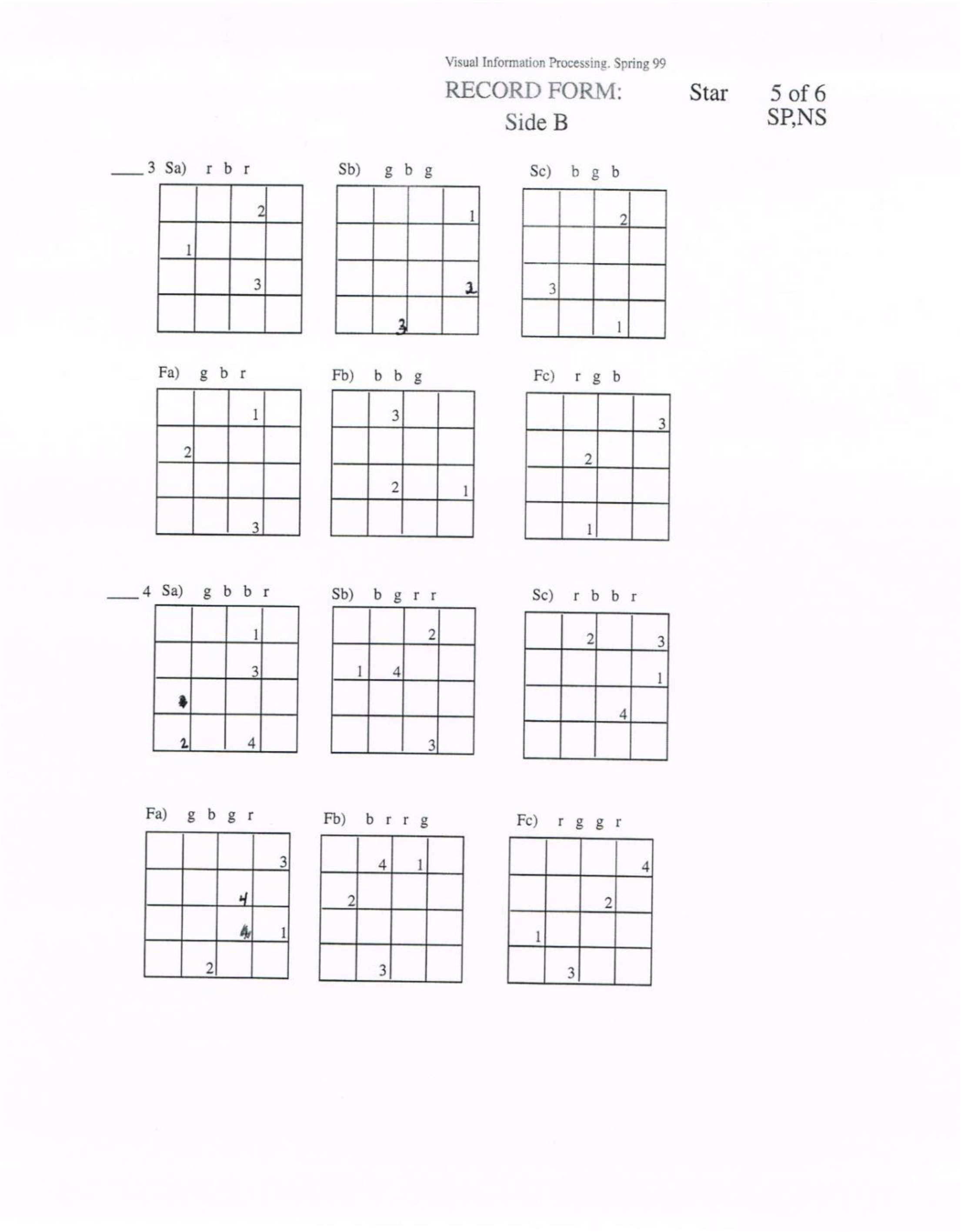
			2
		1	

Fb) r r

	1		
		2	

Fc) r b

		2	
1			



Visual Information Processing. Spring 99

RECORD FORM: Star 5 of 6

Side B SP,NS

____ 3 Sa) r b r

		2	
1			
		3	

Sb) g b g

			1
			2
	3		

Sc) b g b

		2	
3			
		1	

Fa) g b r

		1	
2			
		3	

Fb) b b g

	3		
	2		1

Fc) r g b

			3
	2		
	1		

____ 4 Sa) g b b r

		1	
		3	
[illegible]			
2		4	

Sb) b g r r

		2	
1	4		
		3	

Sc) r b b r

	2		3
			1
		4	

Fa) g b g r

			3
		4	
		4	1
	2		

Fb) b r r g

	4	1	
2			
	3		

Fc) r g g r

			4
		2	
1			
	3		

Visual Information Processing. Spring 99

RECORD FORM: Star 5 of 6

Side C SP,NS

Child:

____ 5 Sa) g b r ~~b~~ g r

	4		1
3		2	
			5

Sb) r g b r r

3			
	1		
	4		5
	2		

Sc) g b g g b

1		2	
	5		
3			4

Fa) g b b r b

3			
		2	4
1			
			5

Fb) r g b r g

5			1
			3
	2		
			4

Fc) r b r r b

5			
2			3
4		1	

____ 6 Sa) b r g r g g

3	5		6
1			
4		2	

Sb) b b g r b r

4	2	6	
	1		3
	5		

Sc) g b b g r g

	3		
1		5	
		2	
6			4

Fa) r r b g r g

	2	5	
			1
4		3	6

Fb) b b g r b r

6	1	4	
3			
		2	
	5		

Fc) r r g b g r

3			
	1		4
	5		6
			2

CURRICULUM VITAE

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EDUCATION

Doctor of Philosophy, Specialization in Language and Literacy, Utah State University. Anticipated graduation is 2013.

Chair: Ronald B. Gillam, Ph.D., CCC-SLP

Master of Science in Speech and Language Pathology, Nova Southeastern University, Fort Lauderdale, FL. Graduated with a 3.95 GPA, August 2009

Bachelor of Science, Rockford College, Rockford, IL
Graduated Magna Cum Laude, May 1996
Major: Elementary Education; Minor: Psychology

UNIVERSITY EXPERIENCE

Research Lab Supervisor **2010-Present**

Child Language Research Lab, Utah State University
Responsibilities included collecting data, scoring data, developing record keeping systems, conducting reliability checks, implementing interventions, developing rubrics, analyzing data, and overseeing research assistants.

Instructor **2011-2012**

Emma Eccles Jones College of Education & Human Services, Utah State University

- Reading Assessment and Intervention, graduate level, co-taught with Cindy Jones, Ph.D.
- Language Assessment and Intervention – School Age, graduate level, co-taught with Julie Wolter, Ph.D., CCC-SLP

CLINICAL & TEACHING EXPERIENCE

Founder and Director **2010-Present**

Cache Valley Speech, Language and Learning Center, Logan, Utah.

I served a diverse population of pediatric clients with articulation, language, fluency, and literacy delays and disorders, handled fiscal management, developed a business plan, implemented a marketing program, launched a website and social media campaign, and participated in community outreaches to educate the public on the services speech-language pathologists offer.

Research Coordinator **2012**

Oversaw a project to collect child narrative language samples to establish national norms for ProEd.

Speech-Language Pathologist **2012-Present**

Sunshine Terrace, Logan, Utah.

As a PRN therapist, my responsibilities included assessing and providing dysphagia, cognitive, language, and speech production treatments for residents in a skilled nursing facility.

Speech-Language Pathologist **2010-2012**

Infinity Rehab, Tremonton, Utah.

As a PRN employee, my responsibilities included assessing and providing dysphagia, cognitive, language, and speech production treatments for residents in a skilled nursing facility.

Speech-Language Pathologist **2010-2012**

Alpine/Encompass Home Health, Providence, Utah.

My responsibilities as a PRN employee included assessing and providing dysphagia, cognitive, language, and speech production treatments for home health care clients.

Speech-Language Pathologist **2009-2010**

A & J Rehabilitation Services Inc., Michigan City, IN.

Responsibilities included serving clients of all ages in hospital, outpatient rehabilitation, private practice, and skilled nursing facilities.

Speech-Language Pathologist **2008-2010**

South LaPorte County Special Education Cooperative, LaPorte, IN

Responsibilities included assessment and intervention for students from diverse backgrounds; initiated a Response to Intervention (RTI) program in the school; collaborated with teachers, parents, and special educators.

Elementary and Junior High Teacher **1997-2008**

Kindergarten, LaPorte Community School Corporation, LaPorte, IN. 2001-

2008
Pre-kindergarten and third grade, South Bend Hebrew Day School, South Bend, IN. 2000-2001
Sixth, seventh and eighth-grade language arts, St. Paul Lutheran School, Michigan City, IN. 1999-2000
Third grade, Rockford Christian Elementary School, Rockford, IL. 1997-1999
Pre-kindergarten, Keith Country Day School, Rockford, IL. 1996-1997

NATIONAL PRESENTATIONS

Lugo-Neris, M., **Squires, K.,** Bedore, L., Peña, E., and Gillam, R., (June, 2013). *A Comparison of Two Narrative Scoring Procedures with Bilingual Children.* Poster presentation at the Symposium in Research on Child Language Disorders, Madison, WI.

Wolter, J., and **Squires, K.** (November, 2012). *Word Study Intervention: Multilinguistic Techniques for Promoting Language Literacy Success*. Presented during the American Speech-Language-Hearing Association Convention, Atlanta, GA.

Squires, K., Gillam, S. (November, 2012). *How SLPs Can Use RTI to Help Struggling Early Readers*. Poster presentation during the American Speech-Language-Hearing Association Convention, Atlanta, GA.

Squires, K. (November, 2012). *A Review of Hypotheses & Neuroimaging Evidence of Dyslexic Bilinguals.* Poster presentation during the American Speech-Language-Hearing Association Convention, Atlanta, GA.

Squires, K., Gillam, R., Lugo-Neris, M., Peña, E., and Bedore, L. (November, 2011). *Story retelling of bilingual children with SLI*. Presented during the American Speech-Language-Hearing Association Convention, San Diego, CA.

Squires, K., Gillam, R., Peña, E., Bedore, L., and Lugo-Neris, M. (June, 2011). *Story retelling by bilingual children with language impairments and typically-developing controls: A preliminary study*. Poster presentation at the Symposium in Research on Child Language Disorders, Madison, WI.

Gillam, S.L., Olszewski, A., and **Squires, K.** (November, 2010) *Classroom-based narrative intervention for diverse learners: SLP value added*. Seminar presented at the American Speech-Language-Hearing Association Annual Convention, Philadelphia, PA.

Gillam, S.L., Olszewski, A., and **Squires, K.** (November, 2010) *Tracking narrative and literate language progress (TNL-Pr): A progress-monitoring tool*. Seminar presented at the American Speech-Language-Hearing Association Annual Convention, Philadelphia, PA.

REGIONAL, STATE, AND LOCAL PRESENTATIONS

Squires, K. (May, 2012). *How SLPs Can Help Teachers Address Mediating Factors Underlying Phonological Awareness Skills*. Presented during a Professional In-Service for Canyons School District, Sandy, UT. *Invited Speaker*.

Squires, K. and Gillam, R. (April, 2012). *Story Retelling by Bilingual Children with Language Impairments and Typically-Developing Controls*. Poster presentation at the FLISPA Research and Leadership Conference, Logan, UT.

Squires, K., and Olszewski, A. (October, 2011). *How SLPs can help teachers address mediating factors underlying phonological awareness skills.* Presented during the Inter-Mountain Area Speech and Hearing Convention (IMASH), Salt Lake City, UT. *Invited speaker*.

Squires, K. (May, 2011). *Therapy interventions to improve cognition*. Presented during the Alzheimer's Association 2011 Conference Series, Logan, UT. *Invited speaker*.

Squires, K. (April, 2011). *Story retelling by bilingual children with SLI and their typically-developing controls: Preliminary study of a progress monitoring tool*. Presented during the Inter-Mountain Graduate Research Symposium at Utah State University, Logan, UT.

Squires, K. (April, 2009). *Speech-language pathologists working in the public schools.* Presented to members of the LaPorte Federation of Teachers, LaPorte, IN, and made available to members of the Indiana Federation of Teachers. *Invited speaker*.

PUBLICATIONS (PEER REVIEWED)

Squires, K. & Gillam, S., Reutzel, D.R. (2013). Characteristics of Children Who Struggle with Reading: Teachers and Speech-Language Pathologists Collaborate to Support Young Learners. *Early Childhood Education Journal*.

Squires, K. (2013). Addressing the shortage of speech-language pathologists in school settings. *Journal of the American Academy of Special Education Professionals.*

Wolter, J. & **Squires, K.** (in press). Spelling: Instructional and intervention frameworks. In B. Ehren, E. Silliman, A. Stone, & G. Wallach, (Eds.), *Handbook of Language and Literacy: Development and Disorders, 2nd ed.*

Squires, K., Gillam, R., Lugo-Neris, M., Peña, E., & Bedore, L. (under review). Narrative development in bilingual children with and without language impairments: Macrostructure and microstructure changes. Submitted to *International Journal of Language and Communication Disorders.*

Squires, K. & Wolter, J. (in preparation). A systematic review of orthographic interventions on spelling performance of students with reading disabilities.

Squires, K. (in preparation). A review of the hypotheses and neuroimaging evidence concerning bilinguals with dyslexia.

Gillam, S., **Squires, K.** & Olszewski, A. (in preparation). When should an English language learner (ELL) begin to read and write in English? To appear in Damico, J.S. & Nelson, R. (Eds). *English Learners at School: A Guide for Speech-Language Pathologists.*

GRANT AFFILIATIONS

Squires, K. (Student contributor) (2012). *Comparison of Two Working Memory Training Programs on Memory and Reading Outcomes for Students with Reading Disabilities: A Randomized Control Trial* — Slocum, T. & Gillam, R. (Co-PIs). Institute of Education Sciences: Special Education. $3,497,129.

GRANTS

Unity Foundation of LaPorte County, 2010. Received $2,500 for summer speech clinic.

Michigan City Education Foundation, 2000. Received $177 for middle school drama club.

HONORS, AWARDS & RECOGNITIONS

Outstanding Graduate Student SLP Researcher of the Year May 2012

Communicative Disorders and Deaf Education, Utah State University

American Speech-Language-Hearing Association Award for Continuing Education March 2012

Doctoral Fellowship August 2010-May 2013

Fully funded Ph.D. fellowship for the *Interdisciplinary Doctoral Program to Promote Evidence-Based Language and Literacy Practices*, U.S. Department of Education, Office of Special Education and Rehabilitation, Preparation of Leadership Personnel.

Future Leaders in Speech-Language Pathology & Audiology Fellowship August 2011-May 2012

A nearly $11,000 fellowship funded by the U.S. Department of Health and Human Services Maternal and Child Health Bureau.

Presidential Fellowship, Utah State University August 2010-May 2011

Provided $12,000 to attend the Ph.D. program at Utah State University.

Nominated for the Nova Southeastern University Alumni of the Year Award November 2010

Nova Southeastern University Special Recognition Award March 2010

Outstanding Student in the Speech-Language Pathology Program, Nova Southeastern University

Golden Apple Award 2007

Awarded to outstanding teachers who have been nominated by parents in the LaPorte Community School Corporation.

CERTIFICATIONS AND LICENSES

Certified by the American Speech-Language-Hearing Association

Utah Speech-Language Pathology License, Utah Division of Occupational and Professional Licensing

Indiana Elementary Teacher’s License, with endorsements in kindergarten, languagearts and social studies

Indiana Teacher’s License in Communication Disorders

Indiana Speech-Language Pathology License from the Indiana Professional Licensing Agency

Illinois Standard Elementary Teaching License, with endorsements in language arts and social science

Certified in the Compton P-ESL Method of Accent Modification

American Heart Association certification in CPR

ADVANCED TRAINING

Getting Started as a Successful Proposal Writer and Academician Workshop, Office of Research and Graduate Studies, Utah State University, Logan, UT, April 2012

Grant Writing Seminar, Intermountain Graduate Research Symposium, Utah State University, Logan, UT, April 2011

Near Infrared Spectroscopy (NIRS), Level 3 Fully Trained User. Proficient in NIRS operations including neural imaging and data collection.

NATIONAL SERVICE

Language Science Program Committee member for the 2012 American Speech-Language-Hearing Association Convention, Atlanta, Ga.

MEMBERSHIPS IN PROFESSIONAL ASSOCIATIONS

Past and Present

American Speech-Language-Hearing Association

ASHA Special Interest Group: Language, Learning and Education

ASHA Special Interest Group: Issues in Higher Education

Society for the Scientific Study of Reading

International Dyslexia Association

International Reading Association

American Telemedicine Association

Utah Speech-Language-Hearing Association

Indiana Speech-Language-Hearing Association

Michigan Speech-Language-Hearing Association

Golden Key International Honour Society

MEMBERSHIPS IN COMMUNITY ORGANIZATIONS

Psi Iota Xi, LaPorte County, IN, 2002-2010. Served as vice president from 2009-2010. Psi Iota Xi sponsors a summer clinic for children with communication disorders