The Contribution of Working Memory Components to Reading Comprehension in Children

By

Jacqueline Brooke Best
B.Sc., University of Lethbridge, 2005

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Supervisory Committee

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Dr. Gina Harrison, Department of Educational Psychology and Leadership Studies
Supervisor

Dr. John Walsh, Department of Educational Psychology and Leadership Studies
Department Member
Abstract

The study examines language, memory and reading skills in children from two private schools in Victoria, British Columbia. Phonological processing and word-level decoding were significantly correlated, suggesting that familiarity with letters and their associated sounds are important for word-level reading. Phonological processing and decoding skill performance were significantly correlated with STM span and not WM span, suggesting that word-level decoding is not attentionally demanding for this sample of children. Decoding speed was inversely related to STM span; faster reading times and larger STM spans were highly predictive of one another. The children’s WM and STM task performance were relatively similar and may be reflective of efficient strategy use, such as word recognition, which reduces attention for processing in WM.
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Chapter One

Working Memory and Reading Comprehension

The present research will address the unique contribution of memory in reading. Memory fractionates behaviorally and neurologically, supporting the compartmentalization of memory into specific areas (Shallice & Warrington, 1970). Baddeley’s model of working memory suggests that different memory components contribute differently and simultaneously during cognitive processing. A capacity limitation or processing inefficiency in one or more of these memory domains may contribute to variability in reading performance (Baddeley, 1996, 1999, 2000 & 2003). The present research addresses the contribution of different memory components by segregating their contribution during the cognitive process of reading in children. Reading research is important because there are different sources of reading failure and success. The present study will help to clarify how reading-specific skills, such as phonological articulation and non-specific skills, such as word vocabulary and long-term memory, contribute to reading comprehension in children. Importantly, how reading specific and non-specific skills integrate together in working memory is the premise of the present study.

There are distinct brain regions involved during reading comprehension, for example, the phonological loop (PL) is responsible for processing verbally based information, and the visual spatial sketchpad (VSSP) is responsible for processing visual and visual-spatial information. The episodic buffer (EB) is a component of the working memory system that is responsible for concurrent, integrative processing. The EB is thought to integrate information among memory domains, as they are separable. The EB functions to integrate verbal, visual-spatial and long-term information in a brain-system that is fundamentally heterogeneous. The purpose of the present
research it to address the specific contribution of memory domains; working memory, short and long-term memory, during reading in children.

*The Phonological Loop and Working Memory Resources*

Pronunciation of the alphabet is a skill necessary for reading that requires phonological articulation and verbal working memory (WM) (Daneman & Carpenter, 1980; Siegel, Linder, & Bruce, 1984). Both phonological articulation and verbal WM are considered necessary for reading comprehension and there is evidence that both are separate cognitive processes. Phonological articulation is a cognitive process for learning grapheme and phoneme relationships, a vital skill for decoding, word recognition and reading comprehension. Studies have indicated that phonological processing measures obtained at the very early stages of reading development are strong predictors of individual differences in word recognition performance (Bishop & Adams, 1990). Verbal WM is a general cognitive resource that is necessary for reasoning and comprehension tasks, and its allocation is based on attention and cognitive demand (Hoover, & Gough 1990; Baddeley, 1986, 1996 & 1999). A degree of awareness of the phonological structure of words helps to make learning to read words understandable for children. Without awareness of the phonological segments in words, understanding the alphabet is difficult (Torgesen, Wagner & Rachotte, 1994). Reading becomes accurate and fluent when phonological articulation reaches a level of automaticity; familiarity of the grapheme and phoneme relationships, known as grapheme to phoneme correspondence (GPC) rules (Deavers & Brown, 1997; Vousden, 2008).

Automaticity for the GPC rules is necessary to alleviate attentional control of verbal WM resources during reading comprehension. When phonological processing is difficult or inefficient, the demand of decoding requires more WM resources to process the phonological
components of a word; this is true for novel readers and individuals with specific reading disabilities (SRD) (Stanovich & Siegel, 1994). Impoverished phonemic awareness and deficient decoding skills result in inefficient processing of written words at the pre-lexical level. Inefficient processing impedes higher-order processes such as reading comprehension because WM resources are reduced to the level of the phoneme. Deriving meaning from text requires WM resources, a higher-order process that is inhibited if phonological processing is inefficient (Rapala & Brady, 1990). Variability in phonological awareness; therefore, results in poor reading comprehension when WM resources are unavailable to process the semantic content of text.

**Long Term Memory and the Episodic Buffer**

In addition to verbal WM resources and phonological articulation, long-term memory (LTM) influences reading comprehension. High frequency words or concrete words form a more robust semantic representation and are less susceptible to decay than unfamiliar words. The recall for word lists exceeds that of pseudo-word recall, suggesting that word recall may be facilitated by the word-meanings (Acheson, Postle & MacDonald, 2010). Semantic representations, therefore, influence processing in the phonological loop when phonological awareness is efficient. Plaut and Shallice (1993) report that individuals with deep dyslexia make semantic errors during reading, such as substituting *flower* for *tree*, and phonological errors, such as substituting *spoon* for *soon*. This suggests there is a relationship between verbal WM and previous knowledge. When WM resources regress to the level of the phoneme, the conceptualization of text using previous knowledge is compromised.

The EB is a temporary storage compartment that is responsible for integrating verbal short-term memory (STM) with LTM, suggesting that the demand to integrate previous knowledge with text may account for unique variance during reading comprehension (Baddeley,
2000). This study will address the contribution of different memory components, and language abilities during reading. The EB is suggested to integrate the contents of verbal STM with long-term knowledge during reading, and will be explored in the present study.

Reading comprehension, therefore, is a complex cognitive process that requires central executive control for the allocation of limited WM resources. WM provides a medium for processing the contents of verbal STM during reading. This study uses Baddeley’s Multi-component Model of WM (2000), and Hoover and Gough’s Simple View of Reading (1990) to address how different processes integrate, segregating the contribution of phonological articulation, word-recognition, verbal WM, and LTM during reading.

Summary

Verbal WM resources are necessary because reading comprehension is a dynamic cognitive process that incorporates LTM during phonological articulation (Was & Woltz, 2006). The incorporation of print with previous knowledge may require the EB of WM; a subsystem that integrates word- knowledge and text. Decoding, word recognition and the incorporation of previous knowledge must occur concurrently for successful reading comprehension, placing additional processing demands on the central executive of WM to incorporate these separate components (Was & Woltz, 2006).

Research Rational for Exploring the Episodic Buffer in Reading Comprehension

The premise of the present study is to address how general cognitive processes contribute to word-level decoding and reading. If reading-specific and reading non-specific information are integrated simultaneously, then processing of the EB may account for additional variance. The EB of WM is unexplained by other WM models, and it is not well understood. According to Baddeley’s Model of WM, the memory buffer serves as a temporary template to enhance
information in the STM subsystems with LTM. Previous knowledge for words and their meanings may integrate to facilitate decoding print, supporting the exploration of the EB. Importantly, the estimated capacity of the PL depends on the active maintenance and rehearsal of verbal information and is too small to explain the complexities of reading comprehension (Baddeley, 1975; Miller & Selfridge, 1950).

*Neuropsychological Evidence for an Episodic Buffer*

Baddeley (2000) suggests the EB integrates information between the phonological loop (PL) and visual spatial sketchpad (VSSP), in addition to integrating information from LTM stores. This indicates the EB has two functions: integrating information between verbal and visual-spatial WM and associating their contents with LTM. Neuropsychological evidence supports the requirement of an EB: Functional magnetic resonance imaging (fMRI) shows that there are separate STM capacities in amnesic patients; they have impaired STM recall and intact LTM retrieval. The incorporation of information in STM with previous knowledge requires an intermediary template for cognitive processing, leading to implications for a memory buffer when print integrates with LTM. The present study inquires as to how verbal WM integrates with previous knowledge during sentence comprehension. The executive demand of combining information from different processing domains is supported by the clear cognitive and neurological dissociation between STM and LTM stores (Shallice & Warrington, 1970; Vallar & Baddeley, 1984).

Jefferies, Ralph and Baddeley (2004) state that the requirement to integrate phonological with long-term linguistic information is not attentionally demanding per se; rather the integration of unrelated concepts is. This suggests that sentence recall is constrained when lexical-level information combines in WM. LTM for vocabulary and word-knowledge increase
the recall of sentences by contributing meaning to text, differing from the low retention of unrelated word lists. Jefferies et al., (2004) conclude that LTM is necessary to facilitate sentence comprehension when the STM capacity of the PL is reached. According to Was and Woltz (2006) the consolidation of word-knowledge occurs in parallel to phonological processing in verbal WM. The present study will explore the demand the contribution of memory, specifically how STM and LTM combine in the EB of WM. Reading comprehension; therefore, is a cognitive process that incorporates new information and uses previous knowledge for comprehensive purposes, held active in verbal WM (Alverez & Squire, 1994).

Definitions of Terms

The following are a list of terms and their definitions to provide clarification as they are frequently used throughout the thesis:

Reading comprehension: A complex cognitive process that requires the reader to process text and predict forthcoming information. The reader must simultaneously monitor the context and connect information to prior knowledge and experience. A skilled reader interacts with the text, using word recognition, decoding, fluency, long-term knowledge and vocabulary.

Processing efficiency: The ability to fluently and accurately decode word-level information. Individuals without a learning or reading disability decode letter-strings faster than low ability individuals, a processing difference that results from automatic, phonological articulation.

Short-term memory (STM): A memory trace with verbal and/or visual items, decaying in seconds if the information is not processed in WM. The recall of information in STM is not sufficient for complex cognitive processing because the items are not conceptualized using prior knowledge; however, STM is a necessary template for initiating complex reasoning.
Medial temporal lobe (MTL): The temporal lobes are involved in speech, memory and hearing. They are located on the either, lower side of the left and right hemispheres. The MTL includes the hippocampus and parahippocampal regions that are required for memory processing; therefore, learning new and retrieving information. The MTL operates with the neocortex to establish and maintain long-term memory through a consolidation process.

Long-term memory (LTM): Memory stored as meaning; it is functionally distinct from STM and WM. The establishment of LTM occurs after several recall and retrieval trials and the information’s perceived importance contributes to remembering. LTM may fade with time and interference, known as natural forgetting. There are declarative and procedural memories, distinguishable by their conscious recollection. The MTL operates with the neo-cortex to establish and maintain LTM through a consolidation process.

Semantic knowledge: Words that consistently activate their respective semantics are more resistant to decay, as they are readily used. Semantic memory is procedural and has to do with world knowledge that we gradually attain over time. LTM for general information and its acquisition is not contingent upon facts such as names or dates, as this is explicit or factual.

Word recognition (WR): WR develops through phonological processing, when words and letters become familiar or recognizable to the reader. WR is necessary for fluent reading because it allows WM resources to process text for meaning, focusing on words that are novel and require more attention.

Working memory (WM): A general cognitive process necessary for complex and elementary cognitive processes, as it provides the capacity for temporarily storing and manipulating information. It is necessary for representing information that is no longer available in the environment, correlating with activity in the frontal cortex, parietal cortex, anterior cingulate and
basil ganglia. These regions are crucial for WM functioning, indicated by imaging and lesion studies and individuals with Attention Deficit Hyperactivity Disorder (ADHD).

Vocabulary: A collection of words and their associated meaning(s) that come to exist from oral and/or read information, indicating that vocabulary is built through expressive and receptive practice. The role of vocabulary in reading comprehension is important to make unfamiliar words familiar and develop alternative meanings for one word, usually depending on the context. The reader will understand and store the word in its associated context(s).

Phonological loop (PL): Processes sound and phonological information, it can be divided into a short-term phonological store for holding verbal information and an articulatory loop for rehearsal. The rehearsal process is necessary for transferring written words to speech and requires cognitive resources and instruction to learn. A level of automaticity is necessary for phonological processing.

Phonemic awareness: Ability to distinguish, pronounce and manipulate the individual sounds of language. This ability is associated with articulatory ability of the PL and represents the sound system of language or speech, associating with processing of Boca’s or Broadmann’s area 44, located in the inferior frontal gyrus.

Decoding: Knowledge for alphabetic pronunciations for the graphophonemic connections, associating with processing of the PL. Decoding uses grapheme to phoneme correspondence (GPC) rules that is sub-lexical processing applied to pronounce words.

Planum temporale: A cortical area posterior to the auditory cortex in the temporal lobe. The planum temporale is more developed in the left hemisphere, making it the most asymmetrical structure in the brain (Kolb & Wishaw, 2003). This region is one of the most important areas for language, known as Wernicke’s area and it is required for associating sounds with visual stimuli.
Central executive (CE): A flexible, supervisory attention system that is responsible for the control and regulation of all cognitive processes. The CE is necessary for the control functions of WM resources, based on cognitive processing demand. The CE is responsible for shifting LTM, retrieval strategies and has the following functions during complex cognitive reasoning:

- Binding information into coherent episodes
- Coordinating the two slave systems
- Shifting between tasks or retrieval strategies
- Selective attention and inhibition

Visual spatial sketchpad (VSSP): A subsystem that processes information visually, it is used for the temporary storage and manipulation of spatial and visual information, such as remembering shapes and colors, or the location of objects in space. There are separate visual and spatial components, neurologically associated with activity in the posterior parietal lobe of the right hemisphere.

Episodic buffer (EB): The third subsystem and the most recent addition to Baddeley’s Model of WM that is concerned with processing information from the PL and VSSP. The EB is necessary to hold information that exceeds the capacities of the STM subsystems during complex cognitive reasoning. The EB also is responsible for integrating information from LTM. There are implications for a memory “buffer” during sentence comprehension because of the significant contribution that semantic knowledge makes.
Chapter Two

Working Memory and Reading Comprehension

Baddeley’s Model of Working Memory. Memory is not a unitary system; WM, STM and LTM operate as distinct cognitive entities (Baddeley, 1996). Baddeley’s Model of WM entails three components: A CE to delegate WM resources among cognitive domains, based on processing difficulty. The CE is necessary to control limited, WM and ensure global coherency among an increasingly modularized system (Baddeley, 1996). There are two subservient subsystems to the CE, process information and operate relatively independent of each other. The PL processes verbal and acoustic information and the VSSP processes visual-spatial information. The subsystems differentiate based on the type of information processed because during verbal and visual-spatial tasks there is both a neurological and behavioral dissociation (Was & Wolz, 2006).

Localization of the Subsystems: The Phonological Loop and the Visual/Spatial Sketchpad

Atkinson and Shiffrin (1968) state the locus for efficient reading is verbal articulation and the depletion of verbal WM resources is a product of inefficient processing in the PL (Cowan, 1988 & 1995; Engle, Tuholski, Lauglin, Conway, 1999; Baddeley, 1999). Phonological articulation is a skill that requires instruction for identifying the explicit GPC rules. When these skills become automatic, cognitive resources become available to process information that extend beyond the surface level characteristics of the phoneme (Schweizer & Koch, 2002). Perfetti and Curtis (1986) state that the activation of relevant knowledge while reading may be problematic for some children when there is difficulty from effortful decoding, indicating the importance of automatic articulation.
Efficient phonological articulation presupposes word recognition, a process that builds on
the automaticity of grapheme-to-phoneme correspondences. Ziegler and Goswami (2005)
suggest that specific instruction is necessary to determine the relationship between graphemes
and phonemes, and for the development of phonological awareness. The PL is responsible for
decoding text, and associates each phoneme with a specific letter in a given context. Efficient
phonological processing is learning that sounds and symbols have a specific relationship and is a
skill that is highly dependant on context (Stanovich, 2000). According to Siegel (1992) irregular
words and familiar words have orthographic representation because neighboring real words
significantly influences pseudo-word pronunciation. This contradicts dual-route theories, stating
that pseudo-words and familiar words process differently in the dorsal and ventral streams of the
brain. This research suggests that memory for letter-sound correspondences and words do not
dissociate neurologically; however, both require efficient phonological processing.

There is support for the localization of the PL, which is associated with activity in the
frontal lobe. This brain region has increased blood flow with the phonetic articulation of words
during sentence comprehension. To incorporate phonological information with word knowledge,
the EB may provide a template for the convergence of specific, localized information. The PL
sustains verbal-acoustic information in a phonological format via covert articulation, which is a
rehearsal process to replenish a memory trace and avoid decay of information. The PL is
responsible for sub-vocal speech, which is essential for successful reading comprehension
(Hoover & Gough, 1990). FMRI indicates this processes is localized, associating with
neurological activity in the planum temporale of the temporal lobe in the left hemisphere. The
planum temporale is more active in novel readers because phonological processing is unfamiliar
and the investment of cognitive resources is greater (Schweizer & Koch, 2002). The planum
temporale is less active in individuals who decode efficiently because articulation is automatic, placing less demand on cognitive resources (Carlin et al., 2003; Hoover & Gough, 1990).

Ericsson and Kintsch (1995) argue that traditional STM limitations of the PL do not support reading comprehension and other complex skills because of the requirement to integrate LTM (Just & Carpenter, 1992). Baddeley’s Model of WM considers how LTM integrates with the contents of WM during familiar tasks, and addresses the contribution of previous knowledge to reading. Baddeley’s Model of WM includes the EB for integrating LTM with verbal and visual-spatial information, contributing unique variance when there is a demand to integrate grapheme-phoneme associations with previous knowledge during reading comprehension. The PL and VSSP process specific information; Functional Magnetic Resonance Imaging (fMRI) and neuropsychological analysis support their heterogeneity during cognitive tasks (Carlin, Sanchez & Hynd, 2003; Siegel, 2003). Visual and spatial information associate with localized activity in the posterior region of the parietal lobe, differing from frontal lobe activity during phonological articulation.

Central Executive Processing

The CE is necessary to attend, select and inhibit irrelevant information during complex cognitive tasks (Baddeley & Hitch, 1974; Shallice & Warrington, 1970). The CE operates to delegate limited, WM resources, based on attention requirements and perceived difficulty. The CE is relatively separate from WM; however, there is overlapping activity. Differences in WM span influence comprehension; individuals with a learning disability have fewer WM resources to delegate, leading to poor performances in verbal and visual-spatial tasks (Swanson, 1999). Reading comprehension involves the simultaneous processing and storage of mental items, relying on WM resources to maintain word meanings during sentence comprehension. Executive
functioning is that of an attentionally based control system that inhibits and selects relevant information during sentence comprehension (Swanson, 1999). The CE influences reading comprehension because it allocates WM, the medium in which sound and symbol associations, syntax, orthography and semantic knowledge combine.

WM is a robust predictor for a wide range of complex cognitive tasks, ranging from reading comprehension to sorting non-verbal shapes into their semantic categories. Although WM span is a significant predictor of cognitive ability, a recent study by Hambrick and Engle (2002) show that the level of expertise or previous knowledge is the principle influence of recall. Their study assessed the following three variables during passage comprehension: Age, individual knowledge of the topic (famous baseball players), and WM capacity. All three variables influenced performance, but the level of expertise was a significant predictor of recall. This indicates LTM is important for passage comprehension and supports research for a memory buffer to incorporate LTM with verbal WM during sentence comprehension.

*Neuropsychological Support for Separate Working, and Short-term Memory*

Martin and Romani (1994), and Swanson and Saez (2003), report that the attentional control over WM relies heavily, but not exclusively on frontal lobe function. STM capacity is approximately six items for digits, words and letters. A limitation of STM involves its persistence; items decay quickly if attention is not maintained. Rehearsal is the technical term often employed. Theoretically, material can be kept in STM indefinitely; however, this would require constant rehearsal and would prevent processing for comprehension. The lateral pre-frontal cortex activates during WM tasks for cognitive operations that require the maintenance and manipulation of items. During verbal WM tasks, this area becomes activated, because of the concurrent processing demand to integrate word information during phonological processing.
For phonological processing during verbal WM tasks, the articulatory loop, or Broca’s area, is located in the left pre-frontal cortex, functions to store novel phonological input temporarily. The articulatory loop operates while comprehension is taking place to integrate phonological information with long-term, lexical knowledge. FWM correlates positively with listening span-tasks for sentence comprehension because of the concurrent processing and storage demand. FWM capacity is defined as the maximum number of sentences comprehended while maintaining perfect recall. The ability to retain unfamiliar phonological items may be important for the acquisition of novel vocabulary and a function of the phonological loop of WM. This will be further discussed in the Working Memory and Reading Comprehension section on page 27.

There is strong neuropsychological and behavioral support for separate WM and STM. Neurological impairments of STM show that there is dissociation between recall of lists of words and sentence repetition tasks. Individuals with verbal, STM impairment are able to engage in a listening span task for sentence comprehension; however, their recall for a list of words is impaired. STM is unable to extend its capacity by incorporating vocabulary and available semantic knowledge for word lists; however, sentence comprehension taps this component of LTM. This suggests other processes are engaged for sentence comprehension, in addition to STM capacity. What may account for preserved comprehension skill in individuals with impaired verbal STM? They lack the capacity to retain unrelated items; however, sentences engage LTM processes in such a way that comprehension is sustained despite anatomical damage. These individuals may engage distinct and separate processes for a listening span task, accounting for unique variance in reading comprehension, above the function of verbal WM.

Amnesic patients with intact WM and a verbal STM impairment, further support research for a separate STM capacity. They show recall for specific events in LTM, but are unable to
retain more than two words in STM (Baddeley, 2000). There is a dissociation between word recall and sentence comprehension for a listening span task because the processes necessary for a listening span task are qualitatively different. The listening span task engages LTM for previous knowledge. LTM influences information recall, for example, the conceptual span task uses words that belong to different semantic categories, requiring participants to recall the explicit exemplars that are associated with unspecified categories (beagle, husky, rose, collie, tulip, and sheltie). A correct response requires knowledge of a dog and flower category, followed by the explicit recall of an exemplar item. This suggests that LTM for inferential and explicit information can reconcile text ambiguity, for example, drawing on semantic knowledge to understand words with multiple meanings.

Baddeley’s model supports an increasingly modularized system that requires executive ownership to delegate attention to what is cognitively demanding. WM contributes to reading by allowing for associations between text with previous knowledge to occur, a necessary process for sentence comprehension (Martin & Romani 1994). Complex cognitive tasks, such as reading comprehension, require attentional control over WM resources. Resources will shift to what is cognitively demanding, such that when phonological processing is difficult, attention will be for pronunciation (Baddeley 1986 & 1996; Stanovich & Siegel 1994). Because WM resources are limited, a shift will compromise the processing of text for semantic content such as theme and word meanings. As phonological awareness increases, WM resources are available to consolidate and retrieve LTM during reading comprehension (Swanson & Ashbaker 2000 and Swanson & Saez 2003). Taken together, the delegation of WM is based on the cognitive complexity of a task or the executive attention necessary for information processing. WM availability is a product of
efficient subsystem processing, as it influences the amount of resources available for higher-order cognitive processing.

Summary

WM is a significant predictor of reading comprehension because it provides the medium for cognitive reasoning that is necessary for conceptualizing text in verbal STM. WM is composed of isolated memory subsystems that have limited storage and retrieval characteristics, indicated by material-type and subjects’ background (Just & Carpenter 1992). The CE delegates WM based on cognitive complexity, shifting resources to what is most demanding, meaning that individual strengths and weaknesses in articulation ability will determine the amount of WM resources available. The CE is as a supervisory attentional system that presides over cognitive tasks; essential for the inhibition, selection and attention to mental representations. The frontal lobes associate with executive WM processing for temporarily maintaining and manipulating items, fMRI shows that activity in the lateral pre frontal cortex correlates with this ability and occurs regardless of visual-spatial and visual non-spatial information processing.

The Episodic Buffer: A Third Subsystem

Vocabulary is explicit, long-term memory for words and their meanings, and is necessary for sentence comprehension in reading. LTM increases the capacity of the PL by integrating words and their meanings, (Jefferies et. al, 2004; Was & Woltz, 2006; Willis & Gathercole, 2001). LTM will mediate comprehension when skilled readers are able to use previous knowledge during decoding. The long-term retention for words and short passages in individuals without a SLD is better for related than non-related worlds, suggesting that successful reading comprehension requires previous knowledge for words and their meanings. LTM mediates subsequent recall by integrating with read material (Stanovich & Siegel, 1994). Finally, Jefferies
et al., (2004) and Was and Woltz (2006) show that for subsequent sentence recall, phonological processing and the integration of long-term, previous knowledge is required to take place in conjunction with one another. Memory buffer processing will allow for the components of the PL to combine with that of LTM, for the requirement of parallel processing.

Baddeley’s Model of WM includes a storage compartment for the integration of previous knowledge in LTM; words and their meanings account for robust variance in cognition by extending the capacity of verbal, STM (Baddeley 1986 & 1999). Verbal, STM for acoustic information is processed in the PL, and associates with LTM for linguistic content during reading comprehension (Hoover & Gough 1990). Reading is a complex cognitive process because the capacity of verbal STM, alone, is insufficient for reading comprehension. LTM associates with the contents of the PL, in WM, a cognitive process that requires these processes to integrate. The CE influences the content of the Verbal WM by attending to a given source of information.

A new addition to Baddeley’s model of WM is the EB, necessary for integrating information from the verbal and visual-spatial subsystems, and connecting their items to LTM. The EB is the intermediate component between WM and LTM, incorporating previous knowledge to enhance comprehension (Takashima, Jensen, Oostenveld, Maris, Van de Coevering & Fernandez, 2005). Baddeley (2000) states that the EB is a limited capacity system that depends heavily on executive processing, but is different from the CE because it is concerned with the storage of information rather than with attentional control. It is necessary for combining information from different modalities into a single, coherent mosaic. According to Takashima et al., (2005) the EB is also involved in consolidating or transferring information into LTM. The EB, therefore, is a mediating factor for developing vocabulary and semantic knowledge. The EB is also necessary for subsequent recall of relevant information, re-activating LTM that associates
with the contents of WM to aid cognitive reasoning. There are implications for an EB during reading comprehension to integrate semantic knowledge and word-specific information.

*The Episodic Buffer of Working Memory, a Subsystem for Integrating Information*

FMRI evidence supports that the formation of memories and their subsequent retrieval occur at the same time as phonological processing, suggesting the contents of WM associates with LTM during decoding (Was & Woltz, 2006). This suggests that concurrent or parallel processing is necessary for reading comprehension because phonological information is processed when word and sentence meanings are deciphered. Parallel processing in WM occurs when there is a demand to maintain phonemic properties of words while reconciling text ambiguity, a process associated with the EB. Automaticity of the PL and the availability of previous knowledge are necessary; however, processing efficiency of the EB may cause additional variance to sustain information during reading comprehension.

According to Daneman and Carpenter (1980) WM capacity positively correlates to reading comprehension, possibly relating to the binding of text with semantic representations in LTM, suggesting that WM mediates reading comprehension. WM resources influence the potential for parallel processing during decoding and linguistic comprehension because WM is the medium for maintaining and manipulating information. A processing difference in the EB will also influence reading comprehension because this is the compartment to incorporate information in long-term and WM. Processing in the EB may contribute unique variance to reading comprehension, in addition to, phonological articulation, WM resources, and previous knowledge pertaining to the text material.
Parallel Processing During Reading Comprehension

FMRI supports there is concurrent activity in the medial temporal lobe (MTL), inferior pre-frontal cortex, and posterior parietal lobe, suggesting there are heterogeneous regions contributing to reading comprehension simultaneously (Takashima et al., 2005 and Was & Woltz, 2006). The regions that primarily associate with phonological processing are the pre-frontal cortex and the MTL (Bunge & Wright, 2007). There is neurological support for a highly modularized memory system, consistent with Baddeley’s Model of WM. Another study by Rudner, Fransson, Ingvar, Nyberg and Ronnberg (2007), and Yoon, Okada, and Jung, (2008) state the MTL, specifically the hippocampus, is necessary for learning and memory formation, but not the maintenance of representations in the EB of WM. Rudner and colleagues, (2007) report that a memory buffer functions to bind the contents of verbal WM with semantic representations in LTM. Activity in different regions of the brain during complex, cognitive tasks suggests a memory buffer to combine information in a highly modularized system.

Functional Anatomy of Memory Formation

LTM is the consolidation of learned information that results in synaptic change. Learned grapheme and phoneme correspondence rules are a declarative memory that contributes to word recognition skills (Davachi, Mitchell, & Wagner, 2003). Neuropsychological studies of human memory show the transfer process of information to LTM is interrupted in individuals with damage to the left hippocampus of the MTL. This is also supported by Rudner and colleagues, (2007), reporting the left hippocampus is involved in the binding of phonological information and of semantic LTM. This indicates there are general processing requirements for the establishment of long-term, phonological knowledge. During sentence comprehension the MTL may incorporate text with previous knowledge, and contribute to reading.
Individuals with anterograde amnesia are able to retain and recall remote memories; however, they are impaired at maintaining information in STM. They have damage to the MTL, specifically the hippocampal region. The consolidation of information in LTM is crucial for memory and learning, suggesting the MTL functions to encode information in WM. STM and LTM dissociate neurologically, supported by individuals with anterograde amnesia, who are unable to form new memories. This process requires activity in the hippocampus region of the MTL for integrating information as long-term knowledge in the cortical regions of the brain.

Summary

Neurological and behavioral studies suggest the MTL is necessary for the formation of new memories; the hippocampal region is necessary for the formation but not the maintenance of representations in WM. There is a functional division of verbal and visual-spatial, STM and LTM because individuals with anterograde amnesia are unable to sustain the contents of STM but can integrate semantic information retrieved from LTM. This supports a multi-component model of WM and the modularization of the language system in the brain.

The short-term capacities of the PL are extended in verbal WM by incorporating previous knowledge. The process requires the EB, the third component of the WM system for integrating LTM in WM. If the MTL is necessary for the consolidation of STM as long-term knowledge, the PL will require the EB to incorporate word level information with semantic knowledge during reading. The demand to concurrently decode text and process its meaning may require the EB in WM.
Working Memory and Reading Comprehension

One of the most consistent findings in cognitive research on reading is that the construction of long-term lexical knowledge improves with verbal working memory capacity (Goswami & Ziegler, 2005; Montgomery, 1995). Evidence also comes from individuals with a specific language impairment (SLI), who have a deficient verbal working memory and subsequent, poor word-learning abilities. Thorn and Gathercole (1999) have shown that memory for non-words varies with age and reading ability, and relates to vocabulary acquisition. The ability to retain unfamiliar phonological items may be important for vocabulary development and require processing of the PL in WM. The developments of verbal WM involves qualitative changes, for example, word meanings change and are elaborated with practice, in addition to knowledge of multiple word meanings based on context. With time and practice, children associate word-level information with long-term, lexical knowledge. This indicates that WM facilitates learning in a bidirectional manner; novel information is incorporated with previous knowledge, and previous knowledge aids in deciphering information at the level of the phoneme.

Baddeley’s model of WM, (2000) emphasizes that WM systems do not undergo major developmental changes over the life-span, arguing instead that the systems change. Increases in articulation rate and word-meaning associations with STM allow for more appropriate memory traces and better performance for older children on verbal WM tasks. When reading processing is slow, either because of developmentally immature apparatuses, weak strategies, or experimentally imposed delays, memory representations are left to decay and the transfer of information to LTM is hindered. The estimates of WM capacity in younger children and poor readers are lower due to inefficient processing that requires more attention. Towse, Hitch and Hutton, (1998) show there are strong correlations between children’s WM span and the duration
of time required to complete the processing phase of a verbal or digit-span task. Partialling out processing time; however, did not account for all the variance between WM and cognitive ability. Articulation rate and number skills contribute unique variance to WM span, in addition to the duration of processing time. Leather and Henry (1994) suggest that verbal WM span tasks are better predictors than STM tasks of children’s scholastic abilities, specifically reading comprehension. In tasks like reading span and listening span, the participants develop representations of target words, previous sentences and related words in LTM. This is a more protracted WM process, elaborating on the items in STM. In digit span, there is no accompanying contextual information for digits in WM and indicates the importance of LTM for reading comprehension. Complex connections develop during reading comprehension that requires the contents of WM to integrate with previous knowledge.

There are quantitative changes in verbal WM that arise from automaticity of the PL leading to changes in the rehearsal process. Leather and Henry (1994) state that verbal STM span reflects the residual ability of accessible lexical level information in LTM once processing has been accomplished. WM span-tasks require both language processing ability for reading aloud, understanding a sentence, and generating a theme, in addition to the capacity to combine these mental functions and retain them for future use. WM capacity reflects the retention of information and the ability to engage in a secondary task, differing from STM that reflects only the retention of items.

Imbo and Vandierendonck, (2007) assessed children in Grade 2, 4 and 6 on their working memory capacity development and executive strategy use. The children were to verify simple addition problems (3 + 5 = 7), “true” or “false”, while their STM was phonologically loaded. In the initial phase of learning, transformations and counting strategies are used by younger
children; these procedural efforts require more WM resources and are less frequently used once addition, subtraction and multiplication facts are learned in LTM. There are age-related differences in strategy use that change the ratio of WM involvement for the arithmetic task. Older children directly retrieve arithmetic facts from LTM without taxing WM resources. They have faster retrieval, and younger children are slower because they use counting strategies. This suggests WM resources are needed during the initial phase of skill acquisition and that fewer WM resources are needed with learning. Siegel and Ryan (1989) and Daneman and Carpenter (1980) find similar results; both younger, normally achieving readers and learning disabled children at all ages have significantly smaller memory spans than older, normally achieving children. With development, children are increasingly able to remember the results from processing a sentence using semantics and syntax to fill in the space of a missing word. This supports an age-related growth in WM abilities in both language and numerical tasks (Siegel & Ryan, 1989).

Rivera, Reiss, Eckert and Menon, (2005) are in agreement with Imbo and Vandierendonck, (2007). They tested WM capacity in 8 to 19 year old children using fMRI, finding younger participants needed more WM and attention resources to achieve similar levels of mental arithmetic performance. Activation in the pre-frontal cortex decreases with age, coinciding with decreased dependence on WM resources with development. They also found developmental changes in the hippocampus of the medial temporal lobe. This region decreases in activity with age, and is necessary for processing declarative, procedural and visual information. This region is necessary for learning and memory formation, and suggests there is less emphasis on the assimilation of novel concepts and information. These studies suggest there is a developmental change in the relationship between WM resources and task performance. There is
a decrease in dependence for WM because strategies are more frequently used, retrieving information from LTM. Children who are younger require more WM resources because they are learning how to efficiently process verbal and numerical information efficiently. There are more efficient strategies for language and arithmetic in older, normally achieving individuals, leading to rapid retrieval of information from LTM stores. There is a changing, dynamic relationship between WM capacity and strategy use with age; WM does not decrease; there is less demand for cognitive resources with the elaboration of concepts and ideas in LTM. Children with SRI and general learning disabilities have limited WM capacity that result in constraints in encoding, storage and retrieval of information (Siegel & Ryan 1989). These findings support the requirement for general cognitive resources during language processing. Although language processing is localized to regions of the cortex, it is subject to the general processing principles and constraints that govern other cognitive domains.

Reading comprehension is a complex cognitive ability; phonological processing occurs while integrating conceptual information from previous knowledge. WM resources are necessary for maintaining and processing information during cognitive tasks and their capacity is determined by phonological processing efficiency. Verbal WM is necessary during reading comprehension to maintain the contents of the PL and integrate novel information with long-term knowledge. Daneman and Carpenter, (1980) state WM span is limited for digits, letters and words. The capacity available, depends on the time it takes to speak the contents aloud, and on the lexical status of the contents; for example, whether the contents are words known to the person or not. This also supports the bidirectional relationship between WM and relevant, previous knowledge.
Siegel (1994), states that individuals with a SRI have limited WM resources due to inefficient processing of the PL, leading to a transgression in resources at the level of decoding. Leong (1999) reported on adult students with and without learning disabilities and SRD, stating that individuals without a SRD are faster and more accurate at phonological articulation. When there is automatic processing of phonological information, decoding is quick and WM resources are available for higher mental processing. Individuals with a SRD are delayed in decoding letter-strings and are approximately 50-100 milliseconds slower than individuals without a SRD. Efficient processing of letter-strings results in automatic phonological articulation and increased activity on the left frontal and temporal cortices for verbal WM and auditory processing of speech sounds. Automaticity of the PL associates with faster reading speed and localized neuronal activity in Broca’s area of the left-frontal cortex in novel readers (Salmelin & Helenius, 2004). Milliseconds may seem insignificant, however, small processing differences influence the amount of cognitive resources available for comprehension. Individuals with poor phonological processing use their verbal WM resources to process print at the level of the phoneme.

In addition to inefficient phonological processing, Swanson (1999) has shown that individuals with a SRI have a unique WM capacity limitation. This suggests individuals with compromised WM have difficulty with verbal and visual-spatial processing because these tasks require the temporary storage and manipulation of information. Individuals with a phonological processing difficulty do so because their WM resources are insufficient to support decoding, in addition to poor phonological articulation. A WM limitation that presupposes perceived articulation difficulty indicates that the demand to concurrently monitor and process text accounts for unique variance during reading comprehension. Montgomery (1995) reports the PL functions to store novel phonological input temporarily while other cognitive tasks such as
listening comprehension take place. The ability to temporarily store novel material allows the
listener the opportunity to create long-term phonological representation of that material. Children
with a greater WM capacity, compared to those with less capacity, show better accuracy for
recalling sentences during a listening span task. A capacity limitation results in difficulty with
tasks that require the storage and processing of items. When the processing demands are
exceeded during cognitive processing, fewer items can be held in WM.

Variance in reading comprehension may be accounted for when there is a limitation in
cognitive resources due to inefficient phonological processing. Determining either a
transgression or limitation of WM resources will aid in determining the relationship between
WM and phonological processing. The question of a WM limitation that exists initially, or as a
product of inefficient phonological processing, is important to separate because instruction for
sound-symbol associations may free WM resources for higher cognitive processes.

Summary

Barron (1987) has stated that the initial computation of a word is for its phonological
properties and the meaningful realization of a word is through this initial, phonological
computation. Extending the capacity of the PL will incorporate text with semantically based
information for the development of word-based meaning. WM is necessary for the continual
accommodation or updating of pre-existing schemas, information, suggesting cognitive resources
contribute to learning, and memory processes during reading. Siegel & Linder (1984) and
Montgomery (1995) state the PL influences the amount of WM available for the retrieval and
consolidation process; when articulation is not automatic, cognitive resources shift to
accommodate for this processing difficulty. It is important to address how processing efficiency
and WM recourses contribute to reading comprehension, and to segregate how phonological
processing integrates with semantic knowledge during reading comprehension. Taken together, it is necessary to clarify how phonologically based information integrates with long-term knowledge via the EB of WM.

**Short-term and Working Memory**

The limited STM capacities of the visual non-spatial and visual-spatial subsystems suggest a temporary compartment for extending their capacities (Baddeley, 1975). Digit span is a measure for STM capacity, which is the recall for the largest number of items by an individual after a single trial (Swanson, 1999 and Swanson & Saez, 2003). The examiner begins with two digits, increasing the memory load until the participant is unable to recall the entire string in order. Age significantly influences digit recall, typically developing children recall two digits at the age of 2, four digits at the age of 5, five digits at the age of 7, six digits at the age of 9, and seven digits by adolescence (Gazzaniga et al., 2004). An increase in STM capacity is accompanied by strategies for recall, for example, *rehearsal* in WM (Baddeley, 1996 and Swanson & Ashbaker, 2000). *Rehearsal* is the repeated naming of to be remembered information that children begin to use at about age six or seven.

Executive attention for WM strategies is evident by 10 to 12 years of age; children will recall digits in their presented sequence and simultaneously organize verbal and numerical information into clusters or semantic categories by incorporating LTM (Gazzaniga et al., 2004). With increasing capacity and strategy, adolescents begin to make sense of information based on the semantic content of information. This information is important because the target population is required to efficiently organize the contents of verbal STM with previous knowledge; consequently, the individuals will be between 10 and 12 years of age.
Changes in processing may also explain increases in STM capacity (Kail & Hall, 1994). WM resources support both storage and processing and may extend STM capacity when phonological processing is efficient. An increase in STM, in addition to changes in processing speed, may free WM resources for storage of verbal information. The relationship between processing efficiency and WM capacity is dynamic and highly dependant on the difficulty of text. Phonological awareness tasks are highly associated with reading ability, and are linked with vocabulary learning. WM resources are allocated to support processing or storage, however, they are also necessary for the temporary activation of information from LTM. According to Engle, Tuholski, Laughlin and Conway (1999) there is a relationship between reasoning skills and WM capacity, such as reading, listening comprehension, learning to spell, following directions, vocabulary learning, note-taking writing, language comprehension and bridge playing. WM is an excellent predictor of a broad range of intellectual abilities, suggesting that domain-specific tasks require WM resources. The retention and retrieval of LTM requires WM resources, however, Baddeley’s view does not provide a precise description of the mechanisms by which the semantic information contributes to WM performance. The present study may assist in clarifying the contribution of LTM to reading comprehension if the EB is involved in integrating word-level information with previous knowledge.

**Long-term Memory**

The time required for storage of new retrievable information in LTM begins within 10 seconds from the time an item enters attention in WM. Therefore, there is an overlap between WM and LTM processing (Simon & Gilmartin 1973; Tulving, 1972; Takashima et al., 2005). LTM contributes to an active WM system that is constantly integrating current information with stored knowledge. LTM providing previous knowledge and specific skills, and alleviates the
processing demand on WM (Just & Carpenter, 1992). LTM is information retained over time and will not decay when attention shifts or when information is no longer available in the environment (Peterson & Peterson, 1959; Gazzaniga et al., 2004). There is overwhelming neuropsychological evidence for the dissociation between declarative and non-declarative LTM, associating with processing in the temporal lobe; declarative memory correlates with increased blood flow into the hippocampus and parahippocampal regions of the MTL and non-declarative memory is associated with activity in the perirhinal cortex and amygdala. Declarative memory is knowledge for facts and events and non-declarative memory is memory for world knowledge or conceptual information (Gazzaniga et al., 2004). The atrophy of memories for facts following damage to the MTL supports an anatomical division of LTM stores.

FMRI lends support for LTM, showing brain activity in different regions for tasks that access general world knowledge and recollection for facts and events; this suggests there is a division between implicit and explicit knowledge. It is important to acknowledge the neurological differences between declarative and non-declarative LTM when addressing variance in reading comprehension. Knowledge for theme, pre-lexical GPC rules and word meanings are stored in distinct regions of the brain based on explicit and implicit processing segregation. For example, GPC rules are factual and explicit in content and are classified as declarative, explicit memory (Alverez & Squire, 1994; Gazzaniga et al., 2004). In contrast, the general theme of a passage may be non-declarative if there is emphasis for processing emotional undertones or a moral lesson of a passage. The division of LTM initiates discussion for a temporary storage compartment for binding LTM with pre-lexical word information during reading comprehension.
Summary

Declarative and non-declarative LTM contribute to reading comprehension when previously read information aids in predicting forthcoming text. Common words and theme, for example, aid in reconciling text ambiguity, suggesting that semantic knowledge and vocabulary influence passage comprehension during reading. The context of a passage will influence how an individual comprehends words in a sentence, for example, bank will associate with money or sediment on a riverside depending on the general theme of the passage.

Measuring Reading Comprehension

Francis, Snow, August, Carlson Miller and Iglesias, (2006) address specific sources of failure in reading comprehension, such as word reading efficiency, oral language skills and vocabulary. These are processes for comprehension and are important to distinguish for individualizing instruction and intervention programs in children who experience reading difficulty. The premise of the present study was to segregate and determine the skills that contribute to reading comprehension. A weakness in any one cognitive process may lead to reading failure; however, identification of these components requires diagnostic testing. The Reading Comprehension Test of the Wechsler Individual Achievement Test-Second Edition is not for assessing the cognitive processes involved in reading comprehension. This measure assesses reading comprehension achievement; it does not identify specific contributing cognitive capacities and precursor skills. For example, efficient word-level decoding may contribute to overall reading comprehension. According to Pots and Petersons (1985), there are four precursor skills; the ability to retain information from text, accessing relevant information in memory, making inferences that incorporate both these components, and developing adjusted knowledge schemas for using new sources of information. These cognitive processes are all necessary for
successful reading comprehension. It is important to determine which components of reading comprehension falter if remedial and compensatory support is to be individualized and beneficial. These four components are processes that are not unique to language and reading, rather, a general memory system involved in learning and knowledge acquisition. It is important to pinpoint different areas of difficulty for the purpose of exploring the relationship between specific precursor skills and comprehension because failure may result from different areas of mental processing. Taken together, a comprehensive test that isolates the four contributing factors will be useful for diagnostic purposes and for tailoring individualized programs for improving reading comprehension. Pots and Petersons (1985) draw attention to the importance of an assessment tool that in conjunction with other measures of precursor skills will create profiles of students’ cognitive processes and their reading comprehension. The premise of the present thesis is to assist in developing a comprehensive test for reading comprehension, taking into account the complexity of the memory and language system.

The diagnostic assessment of reading comprehension may grow from further research that explores the processes of reading; this proposal will address WM processes during reading comprehension, specifically the EB during reading comprehension. Previous research by Baddeley supports the requirement of a memory buffer for retrieving information, integrating information with LTM, and developing adjusted knowledge schemas for future comprehensive purposes. These components are similar to the precursor skills for assessing reading comprehension identified by Pots and Petersons (1985). The following three models further elucidate the modularity of memory and language, suggesting that knowledge and text-based information are processed differently. Given the separateness of these processes, reading comprehension may involve the EB of WM for integrating different types of information. The
purpose of this study is to explore how different memory and language components come
together in WM; specifically, how the EB contributes unique variance to reading comprehension.

*Introduction of Models*

The following models guide the present research since they indicate that reading
comprehension requires the PL for articulation and previous knowledge for linguistic
comprehension. Decoding and previous knowledge equally contribute; without one, reading
comprehension will not occur (Hoover & Gough, 1990). The following models state that WM
resources support reading comprehension when linguistic knowledge is adequate and decoding is
efficient. Individuals with reading disabilities are insensitive to phonological similarity and
require attention from WM resources to accommodate for this processing difference, resulting in
poor reading comprehension (Swanson & Berninger, 1995; Siegel & Linder, 1984). According to
Hoover and Gough (1990), successful reading comprehension is a product of decoding and
linguistic comprehension.

There are three models supporting research for a memory buffer as evidenced in reading
comprehension. Hoover and Gough (1990) state there are reading specific and non-specific skills
that are necessary for reading comprehension. The skills that are reading-specific require
processing of the PL and the non-specific skills do not. Non-specific skills are for text
comprehension, for example, understanding word meanings and the moral undertones of text.
Research suggests that decoding and linguistic comprehension are separate components of
reading. Individuals with dyslexia have average to superior linguistic comprehension without
adequate decoding skills, as a result, they are unable to make sense of print. A dissociation
between decoding and linguistic comprehension is also demonstrated in typically achieving
children. A dissociation is evident in the early school years because decoding and linguistic
comprehension are relatively unrelated. This relationship increases in the later school grades as a result of fluent decoding and word recognition that eventually contribute to sentence comprehension. Swanson and Berninger (1995) present a WM deficit model, showing that phonological processing and WM capacity are dissociable and are central components to reading comprehension (Hoover & Gough, 1990). Finally, Baddeley and Hitch (1974) provide support for a multicomponent model of WM and suggest the EB is a cognitive template for specifically integrating text with previous knowledge, in addition to verbally and visually based STM.

These three models suggest the following: Reading requires specific, phonological processing skills that are unique to the PL; this is consistent with research on the localization of phonological processing by Baddeley and Hitch (1974). Hoover and Gough (1990) also support that phonological processing is a specific and separate component to reading comprehension. Phonological processing alone, however, is insufficient to support reading. Baddeley and Hitch (1974) suggest a role for the EB in reading comprehension to combine previous knowledge and text-based information in WM. A coherent, mental representation of text requires WM memory for the consolidation and retrieval of information, indicating the involvement of a memory buffer for the conceptualization of text based information. The EB is important to explore as a mediator between the PL and LTM during reading comprehension.


Baddeley and Hitch (1974), *Multi-component Model of Working Memory*

The Multi-component Model of WM by Baddeley and Hitch (1974), states that the EB is responsible for integrating verbal and visual-spatial information with previous knowledge. The
PL and VSSP are limited in the number of items they can hold, known as a STM capacity limitation. These stores are temporary compartments or templates for verbal and visual-spatial items, when the items are not used; they decay due to time and interference. The PL is responsible for verbal-acoustic information, specifically articulation ability and verbal STM. Baddeley (2000), states that complex cognitive processes, such as reading, exceed the STM capacity of the PL. There are implications for a memory buffer to incorporate verbal-acoustic information with previous knowledge and extent the verbal STM capacity.

*Swanson and Berninger (1995), Working Memory Deficit Model*

Swanson and Berninger’s WM deficit model (1995), indicates that individuals with a phonological impairment have a common deficit in WM resources. This limitation in cognitive resources compromises the simultaneous storage and manipulation of verbal information during reading comprehension. Swanson and Berninger (1995) and Swanson and Sachse-Lee (2001), show that WM predicts reading comprehension and verbal STM predicts word recognition, indicating that verbal WM processing is independent of verbal STM. If verbal articulation and STM dissociate, then there is modularity within the PL. During reading comprehension, WM resources and processing in the PL contribute unique variance to reading comprehension. This is relevant to the proposed research because the EB requires WM resources to integrate the contents of LTM with verbal STM. A limitation in verbal WM resources will compromise reading comprehension, in addition to inefficient processing of the PL.

*Hoover and Gough (1990), The Simple View of Reading*

According to Hoover and Gough (1990), in *The Simple View of Reading*, decoding and linguistic knowledge are necessary for reading comprehension. They are separate components of reading skill and neither alone is sufficient for reading (Gough & Tunmar, 1986). *The Simple*
View states that reading requires decoding, word recognition, vocabulary, sentence comprehension, paragraph comprehension and text comprehension; the last four components are constituents of linguistic comprehension and are not skills specific to reading. Skills that are specific to reading relate to processing in the PL that is processing for the grapheme-phoneme relationships.

A central claim to the simple view of reading is that reading consists of only two components; decoding and linguistic comprehension (Hoover & Gough, 1990). Decoding, as defined in The Simple View, is efficient word recognition because it is the automatic application of GPC rules (Deavers & Brown, 1997 and Vousden, 2008). This is recognition of grapheme-phoneme combinations that result in the computation of their phonological representation and word recognition. A compelling body of research suggests that skilled readers compute the phonological information as part of the recognition process and that word recognition is a necessary, automatic component that develops through efficient phonological awareness.

Linguistic comprehension, according to The Simple View, is the second component of reading comprehension. This is the ability to answer questions pertaining to the content of a listened narrative. Relevant information and word knowledge, for example, are not specific to reading but are necessary for comprehension. Linguistic comprehension is a form of top-down processing; understanding or computation based on previous knowledge. Phonemic decoding is bottom-up processing, a skill that applies GPC rules for pre-lexical processing. The activation of relevant knowledge is problematic for some children who have difficulty decoding because their cognitive resources are unavailable for comprehensive purposes (Cutting et al., 2006 and Barron, 1987). Efficient decoding; therefore, will allow cognitive resources to process information for semantic meaning and relate print with relevant knowledge.
The Simple View of Reading does not reduce reading to decoding, but asserts that reading involves phonological articulation, without this skill, linguistic comprehension is of no use. Stanovich, (1981) states that only decoding and linguistic comprehension make significant independent contributions to reading comprehension, and that knowledge in a specific area of expertise relates to reading comprehension if decoding is efficient.

Summary

Phonological processing is necessary to establish reading skill but is insufficient, alone, if knowledge of the material is nil (Hoover & Gough 1990). There is strong support that attentional demand dictates the delegation of WM, a fluid cognitive resource that fluctuates for processing between the contents of STM stores. Individuals with SRD inefficiently process word level information and require more WM resources for pronunciation (Stanovich & Siegel, 1994). A WM transgression results when decoding is not automatic (Swanson & Ashbaker, 2000). This study addresses processing in the EB, taking into account WM capacity, phonological processing efficiency, and previous knowledge during reading comprehension. This concerns integrative processing during reading comprehension, beyond the level of phonological processing and WM resources.

There is behavioral evidence for modularity of the PL, associating with activity in the planum temporale, a posterior region of the temporal lobe (Geshwind & Levitsky, 1968). Reading begins with learning the grapheme-phoneme associations, eventually leading to word recognition once a level automaticity permits fluent decoding. It is necessary to address functioning in the EB because reading comprehension requires the incorporation of phonology with semantic knowledge for word meaning. Processing efficiency in the EB will influence the potential to incorporate material between anatomically distinct regions, the planum temporale
and Broca’s area for phonological articulation and verbal STM, and cortical areas for LTM retrieval during reading comprehension. The functional anatomy of phonological processing is consistent with Baddeley’s Multi-component Model of WM, a model that is unique from others because it includes the activated contents of LTM. These elements coordinate in a temporary memory buffer and account for complex, cognitive reasoning by extending the capacity of STM.

Purpose of Research

The present study was conducted to examine the contribution of phonological articulation and decoding skill, verbal STM, WM and LTM during reading in children. This study used the Auditory Digit Sequencing task to measure WM processing of the EB, consistent with research by Swanson & Saez (2003); Montgomery, (1995); Baddeley (2000); and Willis & Gathercole, (2001) and Was & Woltz, (2006). The EB incorporates information from LTM, and binds numerical and verbal material together in WM. The Auditory Digit Sequencing task was used to assess processing of the EB because of the demand to concurrently process text and numerically based information. The EB is thought to bind verbal and numerical information from the subsidiary systems and form a unitary representation in LTM. During reading there are different cognitive processes that may draw from verbal STM and WM to develop lexical knowledge. This study examined the contribution of the EB, as phonological processing and long-term knowledge incorporate with STM for comprehensive purposes during reading.
Chapter Three

Methodology

Participants. Typically achieving children between the ages of 10 to 12 years were recruited from two private schools in the greater Victoria region. The final sample consisted of sixteen children (10 girls) with a mean age of 11 years, 6 months (range: 11 years 0 months to 12 years 11 months). The study was approved by the Behavioral Ethics Review Board at the University of Victoria (Appendix A, certificate of approval) and all children had parental permission and gave their own consent to participate (Appendix B, consent forms). The sessions began in November 2009, and ended in February 2010. All participants were native English speakers, and in good health with no intellectual, social, emotional, sensory, neuropsychological or physical impairments.

Children who were between the ages of 10 to 12 were recruited because research suggests WM capacity and strategy use is efficient by this age; they are able to make sense of information based on semantic content which places less demand on WM resources (Cowan, 1995, Hutton & Towse, 2001; Rivera et al., 2005; Imbo & Vandierendonck, 2007). Typically achieving children organize verbal information in STM, and make sense of it using previous knowledge during reading. They are able to allocate WM resources beyond the level of the phoneme when phonological articulation has developed to a level of automaticity, or is familiarized. Children with SRI have a smaller WM capacity because they have inefficient phonological processing; therefore, their WM resources are unavailable for comprehension. Individual differences between children's WM capacity and efficiency of phonological processing may account for differences in reading in typically achieving children (Swanson & Saez 1994; Gathercole &
Pickering, 2000; Imbo & Vandierendonck, 2007; Jackson & Coney, 2005). The children in the present study may be skilled at reading because they have developed phonological processing to a level of automaticity, alleviating the cognitive effort for simple computations and letter-sound decoding.

Measures

The children completed a battery of standardized measures assessing language, reading and memory. The measures for WM, expressive vocabulary, word knowledge, phonological processing, word-level reading and reading comprehension were given to each child in one session. Appendix C gives a description of the measures used in the present study.

Word Knowledge and Vocabulary

The Vocabulary subtest of the Wechsler Intelligence Scale-Fourth Edition (WISC-IV; Wechsler, 2003) was used to assess knowledge for words and semantic memory for word meanings given a specific context. This task was administered according to the instructions described in the test manual. Vocabulary development and verbal working memory capacity have a positive relationship, contributing to long-term, phonological representations and word learning (Montgomery, 1995). The examiner orally presented words and the child was asked to provide an oral definition or describe the nature of their meaning(s). By expressing their knowledge of the word, the Vocabulary subtest demonstrates general word knowledge, learning ability, LTM retrieval, and oral articulation ability. Raw scores were converted to standard scores based on the WISC-IV normative sample. Internal consistency estimates as reported in the manual are .88 for children 11 years of age, and .89 for children 12 years of age.
**Working Memory Measures**

*Digit Span.* The Forward and Backward Digit Span subtest from the WISC-IV were administered according to the instructions described in the test manual to assess WM capacity. The Digit Span Forward begins with 2 digits to recall and progress’ to a maximum of 7 digits using numbers 0 through 9. This task required the participant to retain the sequential order of numbers that were presented aloud by the examiner. Digit Span Backwards required the child to manipulate numbers and letters, following specific instructions to order the digits in a different sequence than the examiner. The potential to concurrently hold multiple items while reconciling the numerical order is a measure of WM capacity. The internal consistency estimate as described in the test manual for digit span forward for children 11 years of age are .82 and .85 for children 12 years of age. The internal consistency estimate for the digit span backward is .76 for children 11 years of age and .81 for children 12 years of age.

*Auditory Digit Sequencing.* The Auditory Digit Sequencing Subtest from Swanson’s Cognitive Processing Test (S-CPT; Swanson, 1996) is a measure that required children to remember numerical information embedded in short sentences, referring to a location, street and address. This subtest assessed processing in the EB of WM because it required the children to integrate verbal with non-verbal information; the numerical information associates with LTM using memory strategies. The examiner read a sentence to the child and asked a process question on how he or she is currently remembering the material. The processing strategies are from the *Subtest 3 Strategy Card* of the S-CPT, they are a pictorial representation: a) repeating the numbers to your self (b) saying the numbers in pairs (c) associating the numbers with a street name. There are nine items, each with a process and strategy question. The strategy scores were calculated from the initial testing condition and not from the gain scores.
Language Measures

Phonological Processing. The Elision subtest of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgersen & Rachotte, 1999) was administered to assess phonological processing. This subtest consists of 20 items arranged in increasing difficulty. The examiner orally presented a real word back and then again without a syllable or phoneme. For example, “repeat the word kite without the /k/.” Testing was discontinued if the participant missed three consecutive items. Raw scores were recorded for each task and the test-retest reliability for ages 5 to 17 is .77 to .93. The manual reports adequate content, construct and criterion-related validity.

Reading Measures

Decoding. The Word Attack subtest from the Woodcock Johnson Test Achievement Test-Third Edition (WJ-III; Woodcock, McGrew & Mather, 2001) was administered to assess decoding, or the application of GPC rules. GPC rules are necessary for the production of written words’ pronunciation and are necessary to develop recognition for familiar words (Barron, 1987). This task required children to repeat nonsense or pseudo-words that carry no semantic representation. There were 31 phonetically consistent letter patterns in English orthography that increase in difficulty. This task assessed knowledge of the GPC rules that is necessary for skilled word-level decoding. Testing discontinued after 6 consecutive errors, and all raw and standard scores were recorded to determine, and compare performance. The internal consistency estimate for children ages 8 to 10 is .81, and ages 11 to 13 is .73.

Word Recognition. The Letter-Word Identification subtest from the WJ- III was administered to assess word recognition or explicit memory for written words. One of the main characteristics of efficient reading is fluent and accurate recognition of the words. This skill
arises from the ability to perceive different sequencing of letters as familiar phonologic-orthographic patterns, and associate this information with vocabulary (Fawcett & Nicholson, 1994). Raw scores were recorded for each task and the internal consistency estimates a described in the manual for children ages 8 to 10 is .85, and ages 11 to 13 is .84.

Reading Comprehension. The Reading Comprehension Test from the Wechsler Individual Achievement Test-Second Edition (WIAT-II; Wechsler, 2003), a norm referenced measure, required children to read words, sentences, and passages. The reading comprehension score was determined by the child’s answers to the subsequent comprehension questions orally given by the examiner after the child completed reading the passage. Each read passage was timed and all verbal responses are recorded. The passage is available for the examinee during the questioning period, if the examinee did not respond within 20 seconds, the examiner continued to the next item. Raw scores were converted to standard scores based on the WIAT-II normative sample, and the test-retest reliability for ages 10 to 12 ranges from .94 to .98, with overall reliability of .94.

Procedure

Students completed all tasks individually during a one-hour session on the campuses of their schools. Testing commenced a room in their class that was quiet and well lit, with only the examiner and the child to minimize visual and auditory interference. The measures were counterbalanced into a series of five blocks across phonological processing, decoding, WM, processing of the EB, and LTM for lexical, semantic and general knowledge. The order of tasks within each block was fixed and the vocabulary measures were given first for each block.

Limitations in the Present Design

The purpose of the present study was to examine the relationship between memory and language during reading, specifically, how word-level information is integrated as lexical, LTM.
The EB of WM was proposed to contribute unique variance to reading comprehension as a template to integrate the contents of verbal STM with LTM. Unfortunately recruitment proved to be a major limitation to this study’s design. The small sample size meant that the power was limited in the analyses conducted and resulted in less significant correlations between variables that may have reached significance if there were more participants (Cohen, 1988). While five private schools with a potential pool of 60 participants was approached, only two of the schools agreed to be included. Due to this limitation, this study was unable address processing in the EB of WM as intended; however, the relationship between other memory, language and reading variables were examined.
Chapter Four

Results

Introduction. The descriptive analyses for the reading, memory and language measures will be presented first, describing the children’s performances across the measures. The mean score, standard deviation, and range of performances for each measure are presented and subsequently discussed. The correlation analyses speak to the relationships between the reading, memory and language measures and are presented following the descriptive analyses.

A correlation analysis was used to quantify the relationships between the language, reading and memory measures (Appendix D, correlation matrix). The correlation coefficient represents the linear dependence between two variables, and is denoted as $r$ (Pearson Product Moment Correlation Coefficient). The strength of the correlation coefficients and Baddeley’s Model of WM guided the order of entry of the predictor variables for the regression analyses. Reading comprehension did not significantly correlate with any of the language and memory measures; therefore, it was not entered as the criterion variable. The WA subtest, a measure of decoding skill, was used as the criterion variable for one regression equation. The Elision subtest, a measure of phonological processing and DSF, a measure of STM, were the predictor variables. Phonological processing and STM span was unable to account for a significant amount of the decoding skill variance in this sample of children. The small sample size likely contributed to the number of insignificant correlations and the weak predictive power of the model; it is well documented that phonological processing and verbal STM are strong predictors of word-level decoding and future reading skills. Although the premise of the present study was to speak to the contribution of the EB to reading comprehension, this was unable to be addressed. Reading
comprehension did not significantly correlate with processing of the EB; therefore, the EB will be discussed as a component of WM. No conclusions were drawn about its contribution to language and reading. The correlation analyses will guide the discussion section, and address the relationships between the language, reading and memory measures.

To determine if sex, grade or school significantly affected student performance, each was analyzed separately using a one-sample t-test. Neither sex, grade, nor school significantly influenced performance on any of the language, reading or memory measures. Table 1 describes students’ performance across the dependent measures and lists the mean, standard deviation, minimum and maximum scores, and range for each measure. Raw scores were converted to standardized scores and are presented according to the reading, memory and language measures.

Table 1

Means, Standard Deviations, and Range for Reading, Memory and Language Tasks

<table>
<thead>
<tr>
<th>Reading Measures</th>
<th>M</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS (recorded in seconds)</td>
<td>229.56</td>
<td>87.76</td>
<td>132</td>
<td>408</td>
<td>276</td>
</tr>
<tr>
<td>RC</td>
<td>125.25</td>
<td>4.91</td>
<td>113</td>
<td>133</td>
<td>20</td>
</tr>
<tr>
<td>LWID</td>
<td>124.13</td>
<td>13.23</td>
<td>106</td>
<td>152</td>
<td>46</td>
</tr>
<tr>
<td>WA</td>
<td>114.81</td>
<td>10.25</td>
<td>96</td>
<td>131</td>
<td>35</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Memory Measures</th>
<th>M</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSF</td>
<td>11.13</td>
<td>2.68</td>
<td>6</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>DSB</td>
<td>9.06</td>
<td>2.23</td>
<td>5</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>DST</td>
<td>13.31</td>
<td>3.97</td>
<td>12</td>
<td>26</td>
<td>12</td>
</tr>
<tr>
<td>ADS</td>
<td>10.94</td>
<td>2.17</td>
<td>7</td>
<td>15</td>
<td>8</td>
</tr>
</tbody>
</table>
Table 1

Means, Standard Deviations, and Range for Reading, Memory and Language Tasks

<table>
<thead>
<tr>
<th>Language Measures</th>
<th>M</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elision</td>
<td>11.06</td>
<td>2.48</td>
<td>5</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Vocab</td>
<td>11.13</td>
<td>2.21</td>
<td>7</td>
<td>15</td>
<td>8</td>
</tr>
</tbody>
</table>

Note. RS = Reading Speed is reported in seconds. RC = Reading Comprehension; LWID = Letter-word identification; WA = Word Attack; DSF; Digit Span Forward; DSB = Digit Span Backward; DST = Digit Span Total; ADS = Auditory Digit Sequencing; Vocab = Vocabulary Subtest of the WISC IV; Elision = Elision Subtest of the CTOPP.

Reading Scores

The RC subtest of the WIAT-II included a reading speed score (RS), reflecting the number of seconds required to read each passage silently. The children's RS and RC scores were an indicator of decoding efficiency and passage comprehension. The children’s comprehension scores ranged from high average to very superior and are presented in a histogram in Appendix E. The decoding speeds were converted to quartiles based on grade and are also presented in Appendix E. Eleven out of the 16 children obtained decoding speeds that were in the fourth quartile range; between 0 and 243 seconds. One participant obtained a score that was in the first quartile; 397 seconds and above (403 seconds). The mean reading speed was 229.6 seconds, indicating these children were able to fluently decode text while understanding the content of the passages they read.

Performance on the LWID subtest, a measure of word recognition or explicit memory for written words, was superior (mean score 124.1). See Appendix F for a histogram displaying the children’s word recognition skills. The children’s word recognition scores ranged from average
to very superior; 13 of the children scored superior and very superior word-recognition skills. A second measure of word knowledge was the Vocabulary subtest of the WISC-IV. The children obtained standard scores (mean score 11.1) that ranged from low average to superior in performance. See Appendix F for a histogram displaying the standard scores on the Vocabulary subtest. Taken together, these children have well-established word recognition skills and word-knowledge, as they were able to recognize words and comprehend their meanings based on context.

Language Scores

Performances on the Elision subtest of phonological processing indicated that this group of children was able to discriminate between phonemes or speech sounds accurately. See Appendix G for a histogram of the children’s phonological processing performance. Performances ranged from borderline to superior phonological processing abilities, with a mean standard score of 11.06. 81% of the children obtained scores within 1 standard deviation above or below the mean, reflecting minimal variability in performance. This sample of children is also skilled in decoding, as their mean level of performance on the WA subtest was high-average. The children’s decoding scores ranged from average to very superior. See Appendix H for a histogram of the children’s decoding performance.

Memory Span Scores

Based on standard scores the DSF and DSB performances were average. The DSF task ranged from low average to above average with a mean of 11.12. Performance on the DSB task ranged from borderline to average with a mean of 9.06. See Appendix I for the STM and WM span standard scores. The DSB task was slightly more difficult for this sample of children, and not an uncommon result. The cognitive requirements for the DSB are assumed to be greater
because the storage and processing element is more taxing on WM resources. Based on standard scores, the range of performance on DSF is 8 (6 to 14), and for DSB the range is 7 (5 to 12). This suggests there is a relatively homogeneous performance between tasks that index STM and WM span. Older children, compared to younger children have less variability in their STM and WM spans due to stored proficiencies. For example, efficient strategies, previous knowledge and processing efficiency contribute to homogeneity of variance. Engle and colleagues (1999) performed an analysis on the unique and shared variance in WM and STM tasks and found that WM and STM are highly related but separable constructs. The consistently high correlations between STM and WM task performances make it difficult to determine whether reading skill variability and WM performance are primarily due to a system related to storage and/or executive processing of WM (Daneman & Carpenter, 1980; Engle et al., 1999). Engle and colleagues (1999) suggest that complex span tasks of WM capacity reflect the construct STM and an additional element, controlled attention. The correlations between WM and STM performance will be presented in the following section and the potential differences in perceived processing and storage demands will be addressed in the discussion.

**Correlation Analyses**

*Introduction.* The language, reading and memory performances are divided into three sections. The first section quantifies the relationship between the reading and memory measures, and the second quantifies the relationships between reading, language and memory measures. The third section describes the relationships between the memory measures. The correlations among the reading and memory variables are displayed in *Table 2*, the correlations between variables for reading, memory and language are in *Table 3*, and the correlations among the measures of memory span are in *Table 4*. 
A bivariate correlation analysis was used to quantify the relationships between performance on the reading, language and memory measures. The correlation coefficient indicates the predictive relationship between paired variables, and a large coefficient allows for more predictive power. To test statistical significance, an alpha level of .05 was selected. The following measures were correlated at the .01 level and are highly predictive of one another. The Vocabulary subtest and LWID ($r = .79$) were highly correlated, suggesting that knowledge of word meanings strongly predicts fluent decoding and word recognition. DSF and DSB ($r = .77$) were highly correlated, indicating that STM and WM task performances are highly predictive of one another. Those children that performed well on the STM span task were also those children who performed well on the complex span task of WM. DSF and decoding speed ($r = .70$) were highly correlated and support processing speed and available STM span share a bidirectional relationship. Those children with more available memory resources are those children who are able to process text quickly. Finally, ADS and DSB ($r = .67$) were strongly correlated, suggesting that the cognitive demands required to successfully perform these tasks were similar.

**Reading and Memory Correlations**

The RS scores were recorded in seconds and are negatively correlated with performance on the DSF task, a measure of STM span ($r = -.70$). RS was used to assess phonological processing speed while the participants read the passages from the RC Subtest of the WIAT-II. A significant inverse relationship between STM span and processing speed indicate that fast processing times significantly correlate with more available STM. As the children processed text more quickly, STM span increased. The RC subtest of the WIAT-II was correlated with the Vocabulary subtest of the WISC-IV ($r = .58$), suggesting that vocabulary and reading comprehension are strongly predictive of one another. This indicates that those children with
higher reading comprehension scores are also those children with more elaborate vocabularies. Word-knowledge is a strong predictor of reading comprehension, and reading comprehension is a strong predictor of word-knowledge. Research by Nation and Snowling (1998) suggests that vocabulary and word-knowledge were highly correlated in children and adults. Individuals with an interconnected knowledge base may comprehend text better than those whose representations are sparse. If word meanings are poorly represented in semantic memory then less information will be accessed and fewer relationships between concepts will be made. This suggests that previous knowledge for words and their meanings influence reading comprehension by allowing accurate word reading and access to relevant vocabulary.

Table 2

Reading and Memory Correlations

<table>
<thead>
<tr>
<th>Measure</th>
<th>Measure</th>
<th>r</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS</td>
<td>DSF</td>
<td>-.703*</td>
<td>.002</td>
</tr>
<tr>
<td>RS</td>
<td>DST</td>
<td>-.596</td>
<td>.015</td>
</tr>
<tr>
<td>RS</td>
<td>DSB</td>
<td>-.393</td>
<td>.131</td>
</tr>
<tr>
<td>RC</td>
<td>Vocab</td>
<td>.584</td>
<td>.081</td>
</tr>
</tbody>
</table>

Note. RS = Reading Speed; DSF = Digit Span Forward; DST = Digit Span Total; RC = Reading Comprehension; Vocab = Vocabulary Subtest of the WISC (LTM), r = Pearson product-moment correlation coefficient * correlation is significant at the 0.01 level.

Reading, Memory and Language Correlations

There was a significant positive correlation between DSF, a measure of STM and the Elision subtest, a measure of phonological processing (r = .56). A significant positive correlation was found between DSF and WA (r = .55), indicating that as word-level decoding performance increases, so does memory span. The Elision subtest and the WA subtest were positively
correlated \( r = .51 \), an anticipated relationship considering that knowledge of the sounds of letters that compose the alphabet helps children learn to decode print. Phonological processing skill is related to decoding, but occurs in the absence of print. This sample of children has average phonological processing skills (mean 11.1 SD) and high-average word-level decoding skills (mean 114.81). When children develop efficient word-level decoding skills, they are able to recognize words quickly. There was a strong positive correlation LWID and WA \( r = .53 \), supporting the finding that efficient decoding skills predict word-recognition. It has been suggested that decoding skill accuracy supports reading comprehension; however, in the present study only vocabulary was significantly correlated with reading comprehension \( r = .58 \).

Table 3

**Reading, Memory and Language Correlations**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Measure</th>
<th>( r )</th>
<th>( p )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>WA</td>
<td>Elision</td>
<td>.510</td>
<td>.044</td>
</tr>
<tr>
<td>DSF</td>
<td>Elision</td>
<td>.568</td>
<td>.022</td>
</tr>
<tr>
<td>DSF</td>
<td>WA</td>
<td>.559</td>
<td>.024</td>
</tr>
<tr>
<td>WA</td>
<td>LWID</td>
<td>.531</td>
<td>.034</td>
</tr>
</tbody>
</table>

Note. WA = Word Attack; Elision = Elision Subtest of the CTOPP; DSF = Digit Span Forward; LWID = Letter-Word Identification, \( r \) = Pearson product correlation coefficient.

**Memory Span Correlations**

The DSB subtest assessed WM capacity and the DSF subtest assessed STM capacity. The DST score combines the DSB and DSF scores; however, for the purpose of the present study the raw scores of the DSB and DSF were assessed separately. STM and WM differ in their storage and processing demands, and this distinction will be addressed by separating STM and WM
tasks. It has been argued on empirical and conceptual grounds that there are separate contributions of working and STM to word-level decoding. Supporting previous research by Engle and colleagues (1999), there was a positive correlation between DSB and DSF. This was an anticipated finding considering WM and STM tasks share some processing and attentional demands. Supporting Engle and colleagues (1999), there is a very strong relationship between STM and WM performances ($r = .77$). The discussion addresses the similarities and differences between STM and WM, and how the perceived processing demands may determine the degree to which storage and processing elements are involved. When decoding is efficient, the corresponding duration of time necessary to process and store phonologically based information is shorter. Processing difficulties require more WM resources because the cognitive load is greater. Phonological and word-level decoding ability did not significantly correlate with WM; however, STM did. Simple span tasks of STM primarily engage storage, and not additional processing components that activate attentional resources. The attentional demand to decode text was minimal for these children, as they were processing text efficiently and accurately. DSF, a measure of STM, was the only memory measure that significantly correlated with phonological processing and word-level decoding. The dissociation between WM and STM will be addressed in the discussion section with respect to perceived processing and storage demands during phonological processing and word-level decoding.

The ADS Task measures processing of the EB of WM, and was positively correlated with DSB and DSF performance. This was anticipated because DSB and DSF have share storage and processing requirements. The EB requires executive attention of WM to maintain task relevant information in an active state and to regulate controlled processing; however, it did not correlate with any language or reading measures. This suggests these children did not engage WM to
process text because they did not find the reading and language tasks cognitively demanding. Finally, these children did not engage processing of the EB, a component of WM that is necessary to bind information between the memory subsystems and long-term knowledge. The EB of WM was unable to be explored as a contributor to reading comprehension due to the insignificant relationship that ADS had with reading comprehension.

Table 4

<table>
<thead>
<tr>
<th>Measure</th>
<th>Measure</th>
<th>r</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSF</td>
<td>ADS</td>
<td>.516</td>
<td>.041</td>
</tr>
<tr>
<td>DSB</td>
<td>ADS</td>
<td>.673*</td>
<td>.004</td>
</tr>
<tr>
<td>DSB</td>
<td>DSF</td>
<td>.778*</td>
<td>.000</td>
</tr>
<tr>
<td>DSF</td>
<td>DST</td>
<td>.953*</td>
<td>.000</td>
</tr>
<tr>
<td>DSB</td>
<td>DST</td>
<td>.932*</td>
<td>.000</td>
</tr>
</tbody>
</table>

Note. DSF = Digit Span Forward; DSB = Digit Span Backward; ADS = Auditory Digit Sequencing; DST = Digit Span Total. r = Pearson product-moment correlation coefficient * Correlation is significant at the 0.01 level.

The Limitations in Addressing the Contribution of the Episodic Buffer

The premise of the present study was to address the contribution of the EB during RC, as the EB of WM is unexplained by other WM models. Baddeley’s Model states that the EB serves as a temporary template to integrate information between the STM subsystems and LTM. Previous knowledge is necessary for RC, and the EB serves to integrate words and their meanings during decoding. No significant correlations between processing of the EB and the language and reading measures were found. Based on these results, the EB was unable to be explored. ADS and Vocabulary nearly reached significance ($r = .47$); however, the predictive
relationship between long-term memory for word-knowledge and processing of the EB was unable to be explored. There were significant correlations between the ADS, DSF and DSB tasks. This was to be expected considering the EB requires executive attention of WM to maintain task relevant information in an active state and to regulate controlled processing.

**Predictive Ability of Phonological Processing and STM**

The premise of regression analysis was to determine the predictive importance of phonological processing and STM to word-level decoding. Scores for phonological articulation and STM span tasks were regressed on to the decoding scores using a stepwise regression procedure. The predictor variables; phonological processing, as measured by the Elision subtest, and STM, as measured by the DSF subtest were entered in order of their expected theoretical importance according to Baddeley’s model of WM. Phonological processing was entered first, followed by verbal STM; language and reading research including adult and children participants reveals that efficient phonological processing results in subsequent larger memory spans. Secondly, phonological processing is served by a limited WM system because children with articulation difficulties draw on these limited resources when their processing is inefficient. In keeping with Baddeley's theory, there is a trade-off between storage and encoding efficiency because more efficient phonological processing abilities allow more items in verbal memory to be held (Baddeley, 1975; Hulme, Thomson, Muir & Lawrence, 1984).

The Adjusted R-squared value determined how well the predicted scores correlated with the actual decoding performances in this sample of children. For step 1, the Adjusted R-squared value of phonological processing was .207, indicating that 20.7% of decoding variance was accounted for by phonological processing (Model 1: $F_{1,14} = 4.920 \ p < 0.05$). The Adjusted R-squared value increased to .270 when STM was added to the equation in step 2. STM span,
accounted for an additional 7% of the remaining variance in decoding skill (*Model 2: F*₂,₁₃ = 3.769 *p < 0.05*). Although *Models 1* and 2 were significant predictors of decoding, the confidence coefficients for the lower and upper boundary indicated that the beta weights of the predictor variables were not significant predictors of decoding performance.

**Table 5**

*Predictive Ability of Phonological Processing and STM*

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SEB</th>
<th>p</th>
<th>LL</th>
<th>UL</th>
<th>Adjusted R Sq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elision</td>
<td>.510</td>
<td>.94</td>
<td>.04</td>
<td>.069</td>
<td>4.131</td>
<td>.207</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elision</td>
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<td>1.10</td>
<td>.30</td>
<td>-1.217</td>
<td>3.556</td>
<td></td>
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<tr>
<td>DSF</td>
<td>.398</td>
<td>1.02</td>
<td>.16</td>
<td>-.695</td>
<td>3.737</td>
<td>.270</td>
</tr>
</tbody>
</table>


**Summary**

The predictive relationship between phonological processing and decoding decreases when STM is added to the second model. This suggests that memory span accounts for variance in decoding that phonological processing did previously. Research suggests that phonemic knowledge predicts knowledge of the grapheme and phoneme relationships, to some degree. STM, when added to the equation, may account for additional storage and processing demands that are in common with word-level decoding and phonological processing tasks. The following discussion pertains to the correlation coefficients between the measures of language, reading and memory.
Discussion

Based on the language, reading and memory performances, these children have learned to efficiently use the phonological code to decode text. STM, word-level decoding and phonological processing were significantly correlated, an anticipated finding because children require knowledge of speech sounds and word knowledge to come together for successful reading. Although phonological processing and decoding ability were not significantly correlated with RC, phonological processing is regarded as a strong predictor of future reading skills (Wagner, Torgensen & Rachotte, 1994). Letter and word recognition share a large part of their variance with decoding skill because learning to read requires knowledge of the relationships between graphemes and phonemes, or GPC rules. Once these rules are familiar, children are able to decode and recognize words fluently. Automaticity of the GPC rules is important to develop word recognition and fluent reading, and are skills that require fewer resources for controlled processing. The significant positive relationship between WA and LWID performances \((r = .53)\) suggest that there is shared variance in decoding and word recognition, and that recognizing words requires knowledge of decoding rules.

With age and reading experience, children develop word-reading skills that reduce the usefulness of phonological awareness (Parilla, Kirby & McQuarrie, 2004). Existing research suggests there is a developmental progression from phonological processing to word reading and word recognition that facilitates comprehension. Efficient readers decode print quickly and accurately, indicating that letter and word-recognition frees cognitive resources for comprehension purposes. Efficient word-level decoding corresponds with an increase in verbal STM capacity, this relationship is supported in the inverse relationship between STM span and
decoding speed. Poor readers have subsequent STM deficits when processing in the phonological loop is effortful. Perceived processing difficulty influences verbal STM capacity, a characteristic observed in novel and poor readers (Swanson & Saez, 2003).

Parilla and colleagues (2004) argue that verbal STM is related to word-level reading via articulation rate. Readers with poor sub vocal articulation rates have poor memory spans as a consequence of slow processing of information in the articulatory loop of WM. Although the present study did not address the predictive importance of reading speed, it was inversely correlated to STM span in this sample of children. This suggests that faster reading times, correlate with more available STM capacity. Alternatively, this sample of children may have larger STM spans that accommodate faster decoding speeds. When word recognition is automatic, the PL of WM is not engaged in effortful, controlled processing. This sample of children has efficient phonological processing, decoding and word recognition skills; however, no conclusions were drawn regarding their contribution to RC.

The relationship between STM, phonological processing and word-level decoding may be reflected in their perceived processing and storage demands. It is argued that STM and WM tasks share similarities, and that WM tasks require an additional processing element for controlled attention when the task requires the maintenance and manipulation of STM contents (Cowan, 1995). Taken together, the significant relationship between STM and decoding may be explained in the level of controlled processing required for decoding. This sample of children are familiar with the phonological code, and have developed useful word-reading and recognition skills that require less attention from limited memory resources. In support of this, performance on the phonological processing and decoding tasks did not correlate significantly with DSB, a measure of WM (Elision and DSB, $r = .23$; WA and DSB, $r = .42$).
The children’s STM and WM task performances were relatively homogeneous. Younger children typically show larger differences in STM and WM task performances because they have not acquired domain-specific skills and proficiencies that are useful to draw on to complete complex cognitive tasks. When children learn efficient strategies, such as multiplication and word recognition, fewer WM resources for controlled attention are necessary. Younger children would be expected to engage their WM resources more than older children who are able to draw on domain-specific knowledge. STM and WM tasks, therefore, may differ in the extent to which controlled attention is required. Some researchers suggest that once the domain-specific processing of memory subsystems are accounted for, the limited capacity control system of WM accounts for a large portion of the remaining variance. Memory span research suggests that the variability seen in STM and WM may be due to experience, processing demand, strategy use and developmental age. This study did not address the explicit differences in processing and storage demands during the STM and WM task; therefore, no conclusions regarding the trade-off between storage and processing demands can be drawn. Younger children typically show larger variability in WM and STM spans that may be a reflection of the amount of effort required to process the information, as they are learning the strategies necessary to read that requires the PL of WM. Once word recognition strategies are established, there is a reduced demand on verbal WM resources that is typical of older children.

Younger children differ from older children in the extent they rudimentarily process verbal information. Domain-specific knowledge requires less executive attention from WM because there are stored strategies to decode text and word knowledge. The results in the present study indicate that the level of attention required, influences the engagement of WM resources. Case, Kurland and Goldberg (1982) found that the amount of operating resources needed to
complete STM tasks decrease with age, and there was functional increase in storage capacity. These children may have a reduced demand for WM resources because they efficiently apply the phonological code in verbal STM. The children in the present study have reached a level of automaticity in the PL that does not tax WM resources.

There was a positive correlation between vocabulary and word-identification, as measured by the LWID subtest \((r = .79)\). This indicated the sample of children were able to recognize words and were familiar with their meanings. There was a positive correlation between vocabulary and RC \((r = .58)\), suggesting that word-knowledge and comprehension are moderately predictive of one another. This supports research on vocabulary and RC performance in children and adults. Individuals who possess an extensive network of memory representations for words and their multiple meanings also have good comprehension abilities (Nation & Snowling, 1998). If word meanings are poorly represented in semantic and explicit memory then the information is not easily accessed and readily available during comprehensive tasks. Nation and Snowling (1998) also found that children with good comprehension showed priming for both low and highly associable word-pairs. Children with poor comprehension showed a selective association for highly associable words. The children who comprehended text well were able to relate the material with concepts and words that were not immediately apparent. In the present study, performances across tasks measuring word-recognition, decoding and vocabulary were strongly predictive of one another, and the performances ranged from average to superior.

The Elision subtest of phonological processing and the LWID subtest of word-recognition were not significantly correlated \((r = .47)\); however, word-level decoding and word-recognition were \((r = .53)\). Although this difference is minimal, it may reflect a developmental progression from phonologically based reading to decoding and word-recognition in older
children. When there is rapid letter and word-identification, less WM resources are necessary to decode print. Efficient phonological processing leads to orthographic word-recognition that is founded in the establishment of phonological skills (Stuart & Coltheart, 1988). Swinney (1978), suggests that word recognition is accomplished before conscious attention of phonological WM activates. This supports the present findings, as decoding skill, word-recognition, and phonological processing do not significantly correlate with WM task performance. The speed of reading and word recognition reflects efficient decoding and phonological processing skills, indicating automaticity in the PL. Automaticity is necessary to develop domain-specific knowledge, and is necessary for fluent and accurate reading. When children begin to recognize words automatically, cognitive resources are freed at the lexical and sub-lexical levels. If the reader is using the phonological code effectively to process words, then less cognitive resources are required to engage this process. When articulation is slow, as indicated by articulatory rate, word-recognition is not contributing which enables verbal WM. The WM demands from inefficient articulation are reflective of difficulties processing graphemes and phonemes. This sample of children is efficient in their use of the phonological code and require fewer WM recourses to process text. Their application of grapheme and phoneme relationships is not engaging verbal WM to the extent that readers with difficulties would be anticipated to do so. As with any task being learned, it requires a substantial amount of attention and resources.

*Reading Speed and STM Span*

The inverse relationship between STM and reading speed supports that articulation rate influences verbal STM in this sample of children, and that STM capacity influences speed of reading. In support of the trade-off between STM and WM processing demands, a relationship between phonological processing and WM capacity is more likely to be observed in younger
children or individuals with reading difficulties because they perceive phonological processing as difficult. Once children have learned the sounds and symbols that constitute the alphabet, their memory resources are reallocated to processing information beyond the level of the phoneme. If perceived processing and storage demands are reflected in decoding and phonological processing task performances, then it is relevant to discuss how perceived processing demand influences the availability of WM resources.

Limitations

It is difficult to make conclusions about the extend the present findings may be generalized to other typically achieving children, as the sample size is small and the children attend private school. The purpose of the present study was to describe the dynamic interplay between the explicit and implicit cognitive functions during reading, specifically the demand to integrate different types of information: numerical, verbal and previous knowledge. The template for integrating the contents of STM may involve the EB of WM; however, this construct was unable to be addressed for the following reasons: It was proposed that the EB serves as a temporary store for integrating LTM, however, the measures for LTM, ADS, and reading comprehension did not correlate significantly and this dynamic relationship was unable to be explored. LTM for vocabulary and ADS, a measure of EB processing nearly reached significance \( r = .47 \), and may have with a larger sample size. The present study was unable to partial the variance of specific memory components during reading comprehension, however, there are applicable findings pertaining to articulation rate, STM and WM span and word-level decoding. The contribution of strategy selection was not addressed or included in the correlation matrix, and will only be used to describe how the children chose to remember information during the ADS task. Research suggests that strategy use influences articulation speed and STM capacity,
however, the present study did not address this relationship. Finally, the contribution of the EB of WM remains a component of Baddeley’s model of WM to be explored.

**STM and Phonological Processing**

The correlation analyses show there is a strong relationship between phonological processing efficiency variability in STM span ($r = .56$). Verbal STM is linked to the proficient use of the phonological code, and those developmental gains in verbal STM are correlated with efficient linguistic processing (Swanson & Saez, 2003). Children with reading problems have a shorter STM span that is specific to processing information in verbal memory (Stanovich, 2000). At the age of 8, children are able to recall significantly more non-rhyming words than at age 5 (Conrad, 1971). This incremental increase in memory span is reported consistently using digit span measures, letter strings, and sentence tasks, and the correlation analyses support that non-language abilities, such as memory, contribute to variance in linguistic processing. Differences in STM span account for variability in phonological processing, a relationship in performance that was revealed in this sample of typically achieving children. Although there is an incremental increase in memory span with age, differences in phonological processing efficiency are also related to exposure to print (Luce, Feustel & Pisoni, 1983). Print exposure is relevant and important to research; however, it was not quantified in the present study.

**Word Recognition and Reading**

When children begin to develop strategies for recall, they are developing efficient ways to maintain and process information that are not taxing their memory resources. Children learn implicit and explicit ways to retain information in LTM that require less executive attention. A multiplication strategy, rather than counting, lessens processing demands, and the use of word recognition strategies allow for fluent reading once words become familiar. The mean standard
score (124.1) on the LWID subtest, a measure of word recognition, indicated a superior level of performance in this sample of children. This measure requires the child to pronounce words correctly, thereby accurately using the GPC rules and memory for familiar words. The correct pronunciation of these words; however, did not imply knowledge of word meanings.

Efficient orthographic processing for written words involves the computation of letter identity and letter position, and there is strong evidence suggesting that each individual letter in a string of letters can be processed simultaneously in successful readers. There is some evidence for sequential component, with superior identification for letters at the beginning of the string. The LWID subtest of word recognition and the WA subtest of decoding are significantly correlated ($r = .53$), indicating that word recognition involves orthographic processing and knowledge of the grapheme and phoneme correspondences. It is becoming increasingly clear that orthographic, phonological processing and word-level decoding skills are activated in silent and oral reading in successful readers.

When accurate word-level decoding is applied efficiently, as it was in this sample of children, it will facilitate accurate and fluent reading. Although the present study did not find a significant positive correlation between word recognition and RC performance, it is likely due to the small sample size. When decoding and word recognition skills are efficient and accurate, more STM capacity is available, as evidenced by the significant correlation between WA and DSF subtest performances ($r = .55$).

*Strategies for Remembering*

The contribution of strategy use will be discussed; however, it was not correlated with any of the memory, language and reading variables. Strategy use will be described as a skill commonly used to maintain information in verbal WM. The participant's strategy selection may
provide insight into why the children’s STM and WM task performances were similar, as efficient strategies are able to reduce the amount of effort required to maintain and process information. No conclusions can be drawn from this study; however, the results provide reason to explore how strategy use influence STM and WM spans.

This sample of children has developed efficient strategies for grouping and chunking similar information together. During the ADS task, the children were able to choose a picture that best reflected their strategy for retaining numerical (address) information embedded in a sentence (street name). The sample of children primarily selected Picture A (61.2%), indicating they were repeating the information in WM. Picture B was the second most frequently used strategy (33.9%), indicating the children were also using chunking or grouping strategies by pairing digits together to reduce the storage load. All of the children attempted using different strategies for remembering information, however, 12 of the participants chose to only use either A or B strategies. Strategy C was used the least; it represented pairing the numerical information with the street name. None of the children chose Picture D, which represented using a rhyming strategy. Although this sample of children frequently used strategy A, which is the most taxing on memory resources, the children also displayed an affinity to frequently alternating between A and B. Strategy B reduces processing and storage demands, as it reflects grouping information into larger units, presumably decreasing the demand to repeat individual digits and avoid decay. Children become increasingly aware that certain strategies will enhance recall. This has been observed in more frequent and spontaneous use of rehearsal strategies, and better subjective organization of material. Torgensen (1978), reports that good readers are more likely than poor readers to use a chunking strategy, or to consciously impose a plan to recall the materials. Good
and poor readers, both benefited in recall of items when the experimenter imposed chunking and grouping strategies.

A moderate correlation between the ADS and DSF task ($r = .57$) may indicate that variance in the ability to store and process numeric and verbally based information predicts variance in STM capacity. Alternatively, STM capacity may predict the amount of resources necessary for executing these cognitive processes. The covariance between ADS and the digit-span scores may further indicate a trade-off between storage and processing demands. ADS and DSB were highly correlated ($r = .67$), and it is likely that this sample of children required more WM resources to complete the ADS task to maintain and manipulate the information to solve the problem. This differs from the relationship between WM, phonological processing, and word-level decoding, as none of the reading and language measures were significantly correlated with WM performance.

**Conclusion**

These children were efficient in decoding letters and words and required fewer WM resources for processing. Efficient decoding and word recognition strategies may have reduced the demand of WM resources. The relationship between explicit strategy use and language, reading, and memory was not addressed in the present study. The non-significant relationship between WM and the reading and language tasks suggests that these tasks were not attentionally demanding for these children and may be a reflection of automaticity in the PL. This is also supported by the inverse relationship between STM span and decoding speed, as efficient decoding strategies result in speeded word reading and a subsequent increase in available memory resources. These findings differ from those of novel readers, who are learning the phonological code and have less exposure to print (Stanovich, 2000; Engle et al., 1999).
The children were able to use decoding skills and lexical knowledge to recognize words, and retrieve associated word knowledge during word-recognition and vocabulary tasks.

Similar variances between STM and WM tasks performances suggest a relatively homogeneous range of scores. Homogeneity of variance is a characteristic of older children because they have efficient strategies and stored proficiencies to complete cognitive tasks. Younger children show larger variability in WM and STM spans that may be due to the amount of effort required to process cognitive tasks. Younger children are learning efficient decoding and word recognition strategies that require practice and the PL of WM. Once word recognition and chunking strategies are familiar, there is a reduced demand of verbal WM that is typical of older children. Efficient decoding skills may lessen the extent to which controlled attention is necessary, and children who are learning the sound and symbol relationships for reading would require executive processing for controlled attention in WM. When domain-specific skills reach a level of automaticity, fewer WM resources are necessary.

The homogeneity of variance between STM and WM scores may be a reflection of perceived processing demand. Engle and colleagues (1999) reports that efficient strategy use is reflected in less variance between STM and WM capacities. There is a minimal difference between the participants WM and STM task performances, indicated by similar, small standard deviations from the mean. The standard deviation of STM is 2.68 and the standard deviation for WM is 2.23, a difference of .44. Engle and colleagues (1999) suggests that with development, efficient strategy use decreases the demand of WM. Efficient word recognition and familiarity with GPC rules reduces the attention for processing and may also account for the non-significance between WM and any of the language or reading measures.
Less efficient processing of the PL, less exposure to print, and developmental age will influence decoding skill and the amount of WM resources available for processing information. With experience and instruction, strategy use and phonological awareness improve. Efficient decoding strategies reduce the demand of WM in older children; however, some argue that children with larger WM capacities are able to assimilate more efficient coding strategies (Potts & Peterson, 1985). This is also a possibility, as the present sample of children used rehearsal strategies more frequently than the chunking strategy. Rehearsing information in WM is the most taxing strategy and would require a WM capacity to maintain and manipulate the information to complete the tasks successfully. The present sample of children frequently alternated between rehearsal and grouping strategies, however, the influence of strategy selection on memory, language and reading was unable to be addressed.
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151-161.


Appendix A: Consent Forms

**Parent Consent Form**

**Project Title:** The Relative Contribution of Working Memory to Reading Comprehension in Children

**Researcher:** Jacqueline Brooke Best (Master’s student, Department of Educational Psychology and Leadership Studies, University of Victoria)

**Supervisor:** Gina L. Harrison (Assistant professor, Faculty Member, Department of Educational Psychology and Leadership Studies, University of Victoria).

**Purpose and Objectives of the Research:** Your child’s classroom is being invited to participate in a study on the relationship between memory and reading. This study is important to help clarify the relationship, specifically how long-term memory influences reading in children. There is minimal research on how long-term memory influences word-level reading comprehension and this study may provide valuable information for identifying different sources of reading skills among children. Research has shown that different skills contribute to reading comprehension and this study may provide unique information for teachers on the contribution of long-term memory.

**Project Details and Procedures:** Your child may voluntarily participate in this research, working independently with a researcher on a collection of tasks and activities for language, memory, and reading. Students will be asked to repeat word-lists, letter-sounds, sequences of numbers, and read sentences aloud. Students will also answer questions on the content of what they have read to assess their comprehension.

**Participants Selection:** This study requires children who are between 10-12 years old without behavioral, developmental, or learning disabilities.

**What is Involved:** A collection of tasks similar to daily classroom activities for language, memory, and reading comprehension will be given to your child. Participation in this study will have no effect on schoolwork or grades, and only those children who receive parental permission and who themselves agree to participate will be involved.

**Inconvenience:** There are no known risks to your child if he/she chooses to participate in this project. Participation may cause some inconvenience to your child, including time away from the classroom and missed work. This project requires one individual session of about one hour.

**Potential Risks:** The potential risks of participating in this study are minimal. Although your child will be completing tasks that are similar to typical classroom activities, he/she may become fatigued during the one hour session. I will try to minimize this risk by offering a short break or rescheduling the session for

**Parent Copy**

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</tr>
<tr>
<td><strong>Researcher:</strong> Jacqueline Brooke Best (Master’s student, Department of Educational Psychology and Leadership Studies, University of Victoria)</td>
</tr>
<tr>
<td><strong>Supervisor:</strong> Gina L. Harrison (Assistant professor, Faculty Member, Department of Educational Psychology and Leadership Studies, University of Victoria).</td>
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another day. Your child may also withdraw from the study at anytime without explanation or consequence.

**Benefits:** This project will clarify how language, memory, and reading are related in children, specifically long-term memory. This study is an excellent opportunity for children to receive individual attention from researchers at the University of Victoria because research supports that instruction for remembering information, or strategy use, improves long-term memory. Children’s subsequent recall improves when they are given instruction on how to remember; for example, grouping information based on similar characteristics.

**Voluntary Participation:** Participation in this research must be completely voluntarily. You, the parent, must consent for your child to participate in this study, and I will also ask your child for his/her assent before he/she begins the tasks. If your child decides to participate, he/she can withdraw at anytime without any explanation or consequence. If he/she withdraws from the study, the data will not be used.

**Anonymity and Confidentiality:** During data collection a record of your child’s name and a copy of both yours and your child’s consent form. Your child will not be identified by name; he/she will be given an ID number for the collection of the project information. The principal investigator, Brooke Best and supervisor, Dr. Gina Harrison will only know your child’s ID number. This information will be kept confidential. The consent forms and student language, memory, and reading assessments will be kept in a locked file cabinet in the MacLaurin Building in Dr. Harrison’s research office in the Educational Psychology and Leadership Studies Department at UVic. The research findings will not reveal the identity of your child. The teacher and other classmates will likely know who the participating children are since they will be leaving the classroom and going to another room to complete the data collection tasks.

**Dissemination of Results:** The results of this study will be shared in Ms. Brooke Best’s master’s thesis, conference presentations, and published papers.

**Disposal of Data:** Data from this study will be disposed of after a period of 10 years. Paper copies will be shredded and electronic data will be erased.

**Contact:** Should you have any questions or concerns regarding your participation in this study, please do not hesitate to contact me at jbbest@uvic.ca or Dr. Harrison at harrison@uvic.ca

In addition to being able to contact the researcher at the above phone number and e-mail, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca).
Consent: Your signature below indicates that you understand the conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

I (circle one) **give/do not give** my permission for my son/daughter

(name)_________________________________________ to participate in the project entitled *The Relative Contribution of Working Memory to Reading Comprehension in Children*.

_________________________ ___________________________ __________
Name of Parent Signature Date

*Keep one copy of the consent form, and return the signed copy back to your child’s teacher.*

*Thank you for your help with this important project 😊*
Appendix A: Consent Forms

This form gives you the information you need to decide if you would like to help me with a project on what makes a good reader. This project is called “The Relative Contribution of Working Memory to Reading Comprehension in Children.” I would really like you to participate in the activities and tasks for this project. What we learn from your participation will help other researchers understand how reading and memory are connected. This research may help teachers when they teach reading.

If you decide to be in this project, you will work on a collection of language, reading, and memory activities. These activities will take about an hour of regular class time. Whether or not you decide to participate in these activities will not affect your schoolwork or grades.

All of the information on the tasks and activities you give us will be confidential which means it will be kept private or secret. All of the work you do on paper will have a secret number attached to it and only me and my professor at UVIC will know your number.

If you have any questions at any time, you can ask me during the study or you can e-mail me at jbbest@uvic.ca or phone me at (250) 920-8191. You can also e-mail my professor Dr. Gina Harrison at harison@uvic.ca or call her UVic office phone at (250) 721-7783.

If you agree to be in this project please print your name on the line below to let us know you understand what the project is about and that your questions have been answered. You may keep a copy of this form. Thank you for your help.

Name: _______________________________________

Signature: _____________________________________

Date: _________________________________________

A copy of this consent form will be left with you, and a second copy will be taken by the researcher.
Appendix B: Description of Measures

**Language Measures**

**C1. Vocabulary Subtest of the Wechsler Intelligence Scale-Fourth Edition (WISC)**


**Task Description:** For verbal items, words on a card will be read aloud by the examiner, and the participant will give a definition for them. Task instructions described in the manual will be used. Starting and stopping rules for the test will be based on the basals and ceilings described in the test manual.

*Example:* a) “What is an umbrella?” b) “What does brave mean?”

**Task Instructions:** Researcher says, “I am going to read some words aloud to you and I would like you to tell me the definitions or the meaning of these words. Some of the words are easy and some are hard. You are to just try your best, are you ready to begin?”

**Administrative Time:** 5-10 minutes

**Task Measures:** This task measures verbal comprehension by assessing word knowledge and verbal concept formation. It also measures a child’s learning ability, long-term memory and language development. Test-retest reliability for ages 10-13 is .93. The test manual reports adequate content, construct, and criterion-related validity.

**C2. Elision Subtest of the Comprehensive Test of Phonological Processing (CTOPP)**


**Task Descriptions:** The Elision subtest requires children to say a word after dropping out specific parts of the word or designated sounds (a word from a compound word or phoneme) of an
orally presented word. The task instructions described in the manual will be followed.


Task Instructions: Researcher says, “Let’s play a word game. Say paintbrush. Now say paintbrush without saying paint.” [Administer Items 1-3 of Elision Subtest]. Researcher says, “Okay, now let’s try some where we can take away smaller parts of the words. Say hat. Now say hat without saying /h/.” The researcher will correct if necessary and continue with two more practice items. If the child responds incorrectly to all of the practice items the researcher will discontinue administering the subtest. If the child responds incorrectly on one of the practice items the researcher will continue to administer the remaining practice items.

Administration Time: 5 minutes

Task Measures: The Elision Subtest measures the extent to which an individual can say the word that is left after dropping out designated sounds, an aspect of phonological processing. Test-retest reliability for ages 5-17 is .77-.93. The manual reports adequate content, construct, and criterion-related validity.

Memory Measures

C3. Forward and Backward Digit Span Subtest of the WISC-Fourth Edition


Task Description: Digit Span Backward is a core working memory subtest that requires the child to repeat numbers in reverse order of that presented by the examiner. Task instructions described in the manual will be used and starting and stopping rules for the test will be followed.

Example: Researcher says, “Let’s try these numbers. Remember you are to say them backward: 5-6.”
Task Instructions: 

*Researcher says, “I am going to say some numbers, when I stop, I want you to say them backward. If I say 8-2, what would you say?”* The correct answer is 2-8.

Administrative Time: 5 minutes

Task Measures: Digit Span Backward requires cognitive flexibility and mental alertness. This subtest is a measure of auditory working memory capacity, sequencing skills, attention, and concentration. Test-retest reliability for ages 10-13 ranges from .83-.85. The manual reports adequate content, construct, and criterion-related validity.

**C4. Auditory Digit Sequencing of S-CPT**


Task Description: This task assesses the child’s ability to remember numerical information embedded in a short sentence. The information is a location or address. The examiner reads a sentence and asks a process question. The examinee is then required to answer the process question and tell how he/she will remember the information, or a strategy for remembering. These strategies are given as pictures representing different ways to rehearse: A), chunking (B), associating, and (C) elaborating information.

*Example: Researcher says, “Imagine you are a taxi driver and you have to drive people around in a car. Suppose somebody wanted you to drive them to the hospital located at 2-9 Maple Street.”*

*Process question: Researcher says, “Now what was the name of the street (If the examinee misses this question, the examiner discontinues this subtest)?”*

*Strategy question: After the examinee has correctly answered the process question the researcher says, “Now point to the picture that you think will help you remember the address.”*

*Recall question: Researcher says, “Now tell me the numbers of the address of the hospital in order (The examiner uses the Profile/Examiner Record Booklet to record numbers recalled).”*
Task Instructions: 

Researcher says, “I’m going to read you some sentences that have information I want you to remember. All the sentences have to do with remembering an address, but I would like you to pay attention to all information in the sentence because I will ask you a question about the sentence. After I present this information, and before you recall it, I will ask you to choose a strategy, or a way of remembering the information (for children under 10).”

The examiner will show the Subtest 3 Strategy Card containing the pictures, each deciphering a person using one of the four strategies while explaining each strategy.

Administration Time: 15 minutes

Task Measures: This subtest assesses the ability to remember numerical information embedded in a short sentence using strategies for recall.

Reading Measures

C5. Reading Comprehension Test from the WIAT-Second Edition


Task Description: There are 3 types of items in the Reading Comprehension subtest: words, sentences, and passages. Children read the sentences aloud, and the words and passages may be read aloud or silently. The general instructions and starting and stopping rules for the test will be followed.

For the word items (1-5), a score of 0 will be given for each incorrect response and a score of 2 for each correct response.

The sentences are scored for oral reading accuracy. A score of 1 will be given for each target word read correctly. The target words are on the record form in BOLD type.

The passages are included within each item. Beginning with item 20, the passages are timed. The child will be allowed to look at the passages while answering questions,
if the child does not begin responding 10 seconds after the question is asked, the examiner will go on to the next item.

Example: The child reads aloud, “You might think that cheese would be the choice of mice, but they fancy nuts, grain, and seeds more.” The researcher says, “What does the word fancy mean in the sentence?” The researcher points to the word fancy in the sentence.

2 Points for the response: They like or prefer the food better.

1 point for the response: They adore or enjoy.

Task Instructions: None of the words will be read to the child, if he/she asks for reading assistance the researcher says, “I cannot help you with any of the words, so just do the best you can.” If the child pauses for 5 seconds on any word read orally the researcher says, “If you cannot figure out the word, go on to the next.” Word reading errors will be recorded on the record form, and 1 point will be given for each target word read correctly. Instructions in the manual and grade-appropriate start points will be followed.

Administration Time: 15-20 minutes

Task Measures: This task assessed reading performance, word identification skills, and reading vocabulary. The test-retest reliability for ages 10-12 ranges from .94-.98, with an overall reliability of .94.


Task Description: The subtest requires the repetition of non-sense or pseudo-words that carry no semantic or meaningful representation.
There are 31 phonetically consistent letter patterns in English orthography that increase in difficulty. A correct response will be given a score of 1 and an incorrect response is a score of 0. Words that are not fluently pronounced will be given a score of 0. Participants will not be penalized for mispronunciations from articulation errors, dialect variations or regional speech patterns. Starting and stopping rules for the test will be followed, based on the basals and ceilings described in the test manual.

Examples: a) Researcher says, “Read each of these words to me. Don’t go too fast.” The pseudo-words are: Floxy (Flok-se), hap, mel, fim, ven, jop.

b) Researcher says, “leck (Lek), diestrum (Dis-trum), chur (Cher), vorse (Vors), gradly (Grad-le).

Task Instructions: It is necessary for the researcher to know the exact pronunciation of the word for each item before administering the test. The letters printed with slashes (i.e. /p/) indicate the phoneme, rather than the letter name should be given. If the subject pronounces a word by letter or syllable instead of reading it fluently the researcher says: “First read the word silently and then say the word smoothly.” This instruction will be given once during the test only.

Administration Time: 10 minutes

Task Measures: This task measures pseudo-word decoding and assesses phonological processing because the letter-sound meanings are not represented as words in the mental lexicon. The test-retest reliability for ages 8-13 ranges from .73-.81.


Task Description: The initial items require the child to identify letters that appear in large type on the participant’s side of the Test
Book. The remaining items require the child to pronounce words correctly. He/she does not need to know the meaning of the word to answer correctly. The items become increasingly difficult as the selection of words become less familiar to the child. Starting and stopping rules for the test will be followed, based on the basals and ceilings described in the test manual. Letter-Word Identification has a median reliability of .91 in the age range 5 to 19.

Task Instructions: 

Researcher says, “I am going to ask you some questions and to solve some problems. Some questions and problems will seem very easy, while others will seem hard. Please do your best.” It is essential that the examinee knows the exact pronunciation of the word for each test item before administering the test. If the child pronounces a letter of a syllable instead of reading it fluently the researcher says, “First read the word silently and then say the word smoothly.” This instruction will be given only once. A correct response is a score of 1 and an incorrect response a score of 0. Words that are not read fluently will be scored as incorrect. If the child’s response is not clear he/she will be allowed time to complete the page and then asked to repeat all the items on that page. The item in the question will only be re-scored.

Administration Time: 10 minutes

Task Measures: This task assesses word recognition, explicit memory for written words and decoding skill. The test-retest reliability for ages 8-13 ranges from .84-.85.
## Appendix C: Correlation Matrix

<table>
<thead>
<tr>
<th></th>
<th>LWID</th>
<th>WA</th>
<th>Elision</th>
<th>Vocab</th>
<th>DSF</th>
<th>DSB</th>
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### Appendix C: Correlation Matrix

<table>
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Note. LWID=Letter Word Identification, WA=Word Attack, Elision=Elision, Vocab=Vocabulary, DSF=Digit Span Forward, DSB=Digit Span Backward, DST=Digit Span Total, ADS=Auditory Digit Sequencing, RS=Reading Speed, RC=Reading Comprehension.
Appendix D: Reading Comprehension Test, Including Decoding Speed, from the WIAT-Second Edition
Appendix D: Reading Comprehension Test, Including Decoding Speed, from the WIAT-Second Edition

Grade 6 and 7 raw score to quartile score conversion for reading speed in seconds:

<table>
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<th>Decoding Speed</th>
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<tr>
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<td>3. 202</td>
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<td>4. 178</td>
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<tr>
<td>5. 201</td>
<td>Q4</td>
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<td>6. 171</td>
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<td>7. 134</td>
<td>Q4</td>
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<tr>
<td>8. 196</td>
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<td>9. 138</td>
<td>Q4</td>
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<td>11. 232</td>
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<td>12. 281</td>
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<tr>
<td>13. 282</td>
<td>Q3</td>
</tr>
<tr>
<td>14. 386</td>
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<td>15. 320</td>
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<td>16. 408</td>
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Note: Q = Quartile range. Q1 = 0-25th percentile, Q2 = 25th – 50th percentile, Q3 = 50th to 75th percentile, Q4 = 75th to 100th percentile.
Appendix E: Letter-Word Identification and Vocabulary from the WJ-Third Edition

![Histogram of Standard Score Letter Word Identification]

- Std. Dev = 13.23
- Mean = 124.1
- N = 16.00
Appendix E: Vocabulary Subtest from the WISC-Fourth Edition
Appendix F: Elision Subtest from the CTOPP

![Bar graph showing standard scores with mean, standard deviation, and sample size information]

- Std. Dev = 2.49
- Mean = 11.1
- N = 16.00

Standard Score CTOPP
Appendix G: Word Attack from the WJ-Third Edition

Standard Score Word Attack

Std. Dev = 10.25
Mean = 114.8
N = 16.00
Appendix H: Digit Span Forward from the WISC-Fourth Edition

![Bar Graph]

- **Mean**: 11.1
- **N**: 16.00
- **Std. Dev**: 2.68

Forward Digit Span
Appendix H: Digit Span Backward from the WISC-Fourth Edition

Backward Digit Span

Std. Dev = 2.24
Mean = 9.1
N = 16.00