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Working memory cross-modal binding and decoding ability in children in the first and second grades

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WORKING MEMORY CROSS-MODAL BINDING AND DECODING ABILITY IN
FIRST AND SECOND GRADE CHILDREN

A Dissertation Proposal Presented
to
The Faculty of the School of Education
Learning and Instruction Department

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Education

by
Eduardo Sanchez
San Francisco
May 2007

This dissertation, written under the direction of the candidate's dissertation committee and approved by the members of the committee, has been presented to and accepted by the Faculty of the School of Education in partial fulfillment of the requirements for the degree of Doctor of Education. The content and research methodologies presented in this work represent the work of the candidate alone.

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i

Dedication

The completion of this dissertation is dedicated to my family and friends whom I love very very much, and to Drs. Susan, Evans, Lanna Andrews, and Nikki Miller without whose encouragement, patience and wisdom I could not have done it.

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Table of Contents

Table of Figures

Table of Tables

CHAPTER I: Statement of the Problem

Introduction

This correlational study examined the relationship between graphophonic word-reading ability (decoding) and the ability to integrate speech sounds and static visual patterns in working memory. Graphophonic word-reading is a specific type of word reading in which individuals read words by using the letter-sound correspondences within words. Word-reading or word identification are terms that refer generally to the reading of individual words in isolation by any method (e.g. by analogy, by sight, or decoding). The integration of speech sounds and static visual patterns in working memory may also be called working memory cross-modal binding ability, which is an hypothesized function of the recently proposed episodic buffer component of working memory (Baddeley, 2002).

Research has suggested that working memory functioning is related to decoding throughout childhood (Alloway, Gathercole, Willis, & Adams, 2004; Baddeley; Conlin, Gathercole, & Adams, 2004; Gathercole, Pickering, Ambridge, & Wearing, 2004; Howes, Bigler, Burlingame, & Lawson, 2003; Jeffries & Everatt, 2004; Jorm, 1983; Kibby, Marks, Morgan, & Long, 2004; Seigel & Ryan, 1989; Strattman & Hodson, 2005; Swanson & Alexander, 1997; Swanson & Ashbaker, 2000; Swanson, Ashbaker & Lee, 1996; Swanson, Saez & Gerber, 2006; Swanson, Trainin, Necoechea, & Hammill, 2003). However, the relationship between graphophonic word-reading development and the integrative functions of the working memory system is unclear and relatively unexamined, compared to the other components of working memory.

According to Baddeley (1986, 2005), working memory is a multi-component cognitive processing system responsible for the temporary (2-4 seconds) storage and processing of visual and verbal information, from sensory input and material retrieved from long-term memory (LTM). The working memory construct can be thought of as an elaboration of what is commonly referred to as short-term memory. However, working memory differs from short-term memory in that in addition to providing short-term memory *storage*, the working memory construct includes a *processing* dimension. The original model of working memory (Baddeley & Hitch, 1974) has been recently modified (Baddeley, 2002). The four components of the *current* model of working memory are: 1) the central executive (CE), a general attentional control system; 2) the phonological loop (PL), specialized to store sound-based material; 3) the visualspatial sketchpad (VS) which is specialized to store static visual patterns and spatial sequences; and 4) the episodic buffer (EB), a modality-free storage system capable of integrating or binding material from the PL, VS and from long-term memory (LTM) into multifaceted episodes.

The episodic buffer is a recent addition to the working memory construct and may specifically support learning to decode words by enabling children to integrate or bind phonological material (words sounds) and orthographic material (letter patterns) into graphophonic (symbol/sound) pairs during early elementary reading instruction. The efficiency with which a child initially binds phonological and orthographic units in working memory during word reading instruction may be related to how accurately these sound/symbol (graphophonic) pairs are encoded in long-term memory (Craik, 1983; Windfuhr & Snowling; 2001). The establishment of a robust graphophonic store in long-

term memory may be important for children who are learning to read words graphophonically in the early elementary years.

According to Ehri (1998; 2005), the establishment of a store of graphophonic associations in long-term memory is important for the development of word-reading ability in the early elementary years, when children with typical word-reading development pass through a stage of graphophonic word-reading development. During the graphophonic word-reading stage, children appear to increase their ability to use letter-sound associations to read complex and unfamiliar words (Ehri & McCormik, 1998; Ehri & Soffer, 1999; Ehri & Wilce, 1985; Gough, Juel & Griffith, 1992; Leslie & Thimke, 1986). In order to do this, children may rely in part on the contents of a growing store of graphophonic associations in long-term memory. Working memory cross-modal binding ability may enhance a child's ability to decode complex and unfamiliar words, by determining a child's ability to bind phonological and orthographic material in working memory during reading instruction, thereby increasing a child's ability to establish a robust graphophonic store in long-term memory. In other words, children who are better able to bind a greater number and variety of graphophonic units in working memory during reading instruction may, in turn, be able store a greater number of quality (strongly bound) graphophonic units in long-term memory during reading instruction. As a result, these children will have a greater number of graphophonic pairs available to help them decode words that are complex or unfamiliar during the act of reading, than children with deficient working memory cross-modal binding ability. Therefore this study proposed that a relationship between cross-modal binding ability and the ability to

graphophonically decode individual words exists in children in the first and second grades.

Research has suggested that the development of working memory cross-modal binding ability corresponds closely to the graphophonic stage of word-reading development (Smith, 2006). This suggests that the development of working memory cross modal binding ability (a proposed mechanism of the hypothesized episodic buffer) may be related to graphophonic word reading development. Furthermore, research has also suggested that early elementary word-reading instruction that makes explicit connections between the sounds within words, and the letter patterns that represent these sounds, is effective for struggling readers in the early elementary years (Bhattacharya & Ehri, 2004; Castiglioni-Spalten & Ehri, 2003; Ehri, Nunes, Stahl, & Willows, 2001; Ehri & Stahl, 2001; Gaskins, Ehri, Cress, O'Hara, & Donnelly, 1997). These interventions may compensate for deficient development in cross modal binding ability. If this is so, it is reasonable to suggest that the episodic buffer (specifically the cross-modal binding mechanism of the episodic buffer) is an important support mechanism for graphophonic word-reading development in the early elementary years.

Purpose of the Study

This study examined the relationship between working memory and graphophonic word-reading ability in children in the early elementary years. Specifically this study examined the relationship between the ability to integrate spoken pseudo-words (phonetically correct yet false words) and abstract static visual patterns (Japanese Kanji characters) in working memory (an hypothesized function of the episodic buffer) and graphophonic word-reading ability, in a sample of children in the first and second grade

with a wide range of reading ability. In addition, this study explored the relationship between the cross-modal binding mechanism of the hypothesized episodic buffer component (a recent addition to the working memory construct) and the established components of working memory (the phonological loop, the visualspatial sketchpad and the central executive). The determination of these relationships further clarifies the relationship between working memory and word-reading ability, by specifying the mechanisms of the working memory system and their relationship to graphophonic word-reading ability. This knowledge may, in turn contribute to more effective word-reading instruction in the early elementary years by allowing early elementary word-reading interventions to be tailored to a child's particular working memory deficit.

<center>Theoretical Rational</center>

The primary theoretical framework of this study is Baddeley's working memory construct (Baddeley, 1986, 2000, 2002, 2005). This study proposed that the episodic buffer component of the working memory system supports graphophonic word-reading development by helping to increase the efficiency with which children are able to form associations between spoken sounds and printed letter patterns (graphophonic associations) in working memory during reading instruction. Development in working memory cross-modal binding ability may directly contribute to the establishment of a graphophonic store in long-term memory during the early elementary years, which may be important for early elementary word reading development.

If the cross-modal binding mechanism of the episodic buffer fails to develop typically during the early elementary years, children may have difficulty establishing a robust store of graphophonic associations in long-term memory during word-reading

<center>5</center>

instruction. As a result, these children may have fewer graphophonic pairs available to use when attempting to decode complex and unfamiliar words during reading activities, and thus be unable to decode these as words easily as children who have experienced typical episodic buffer development. This section presents an overview of the working memory system, and the individual components of working memory.

Before continuing to describe the working memory construct, a brief comment should be made about the relationship between the terms episodic buffer and cross-modal binding ability. The episodic buffer was proposed to account for the binding of material stored in the various memory systems (Baddeley, 2002, in press). It is possible that the episodic buffer may be comprised of several sub-mechanisms in addition to the cross-modal binding mechanism examined in this study (Baddeley, 2002), In other words, the binding of material in a single modality (visual or verbal) may occur by way of a different mechanism than the binding of material from different modalities (cross-modal). However, the episodic buffer has not yet been sufficiently specified to allow claims to be made regarding the structural complexity of the episodic buffer. This study examined only cross-modal binding in working memory, which, by the most conservative revision of the working memory model, is accomplished via the hypothesized episodic buffer (Baddeley , 2002, in press), and which is also directly inferred from the results of experiment (Logie, Della Sala, Wynn, & Baddeley, 2000). Although the episodic buffer may be comprised of several sub-mechanisms, this study only examined the cross-modal binding mechanism of the episodic buffer. As such, the term episodic buffer (EB) is used somewhat interchangeably with the term working memory cross-modal binding ability. With these semantics in mind, the working memory construct is described below.

Working memory (WM) is construed to be a complex processing system responsible for the storage and processing of visual and verbal information over brief periods of time (2-4 seconds). The term short-term memory is sometimes used to make a simple distinction between temporary memory systems (working memory) and permanent memory systems (long-term memory, LTM). Also, the term short-term memory (e.g., verbal short-term memory or visual short-term memory) can be used to refer to the simple storage systems within the working memory system (e.g., the phonological loop and the visualspatial sketchpad).

In every day experience the working memory system may help individuals perform common, yet complex, cognitive tasks such as remembering a phone number while looking for the phone, following a series of directions while looking for an address (Baddeley, 1986; 2002), or retaining a sentence long enough to understand its meaning (Daneman & Carpenter, 1980). The current model of working memory (Baddeley, 2002), which includes the episodic buffer hypothesis, is an attempt to further specify the working memory model proposed by Baddeley and Hitch (1974), and to resolve some problematic issues that have arisen since the initial proposal of the working memory model. The following paragraphs briefly describe the development of the working memory model and the issues that led to the proposal of the revised working memory model and the episodic buffer hypothesis.

The separation of the short-term and long-term memory system was discussed as early as 1890. William James made a distinction between *primary* (short-term) and *secondary* (long-term) memory. James observed that while one type memory functions in the immediate present (e.g., holding a name in memory while looking for a pencil and

paper to write the name down), another type of memory is linked to past events that have been stored for an indefinite period of time (such as remembering one's way around a city visited years ago). Primary memory was conceived to be limited in capacity, transient, retrieved easily and related to one's present conscious experience; whereas secondary memory appeared to be virtually limitless in capacity, required effort to retrieve, was linked to unconscious processes and referred to the relatively distant past. Studies by Brown (1958), and Petersen and Petersen (1959) supported the distinction between short-term and long-term memory system, by showing that when subjects are prevented from rehearsing material (i.e., a series of 3 digits), memory for this material decays after approximately 4-5 seconds. The results of these studies suggested that the material was being stored by a temporary system whose capacity was limited by both time and amount of material (six to eight items). In addition to the capacity constraints suggested by Brown, and Peterson & Peterson, individuals' performance on "immediate serial recall" tasks (which require subjects to immediately recall an ordered sequence of aurally presented digits) suggested that individuals were using two different types of memory systems to recall the sequence. For example, when an individual's memory for an ordered sequence of six digits is plotted on what is called a serial position curve (see Figure 1 below), memory for the first few items presented and the last few items presented are remembered with more accuracy than items presented in the middle of the sequence.

Glanzer (1972), suggested that the memory advantage for the first few items (called the primacy effect) reflected the encoding in long-term memory (since subjects had time to rehearse these items longer than others in the sequence), and that the memory

advantage for the last few items (called the recency effect) reflected storage in short-term memory (since these items were presented last, and as such were still fresh in short-term memory). These findings established the experimental paradigm in which tasks that
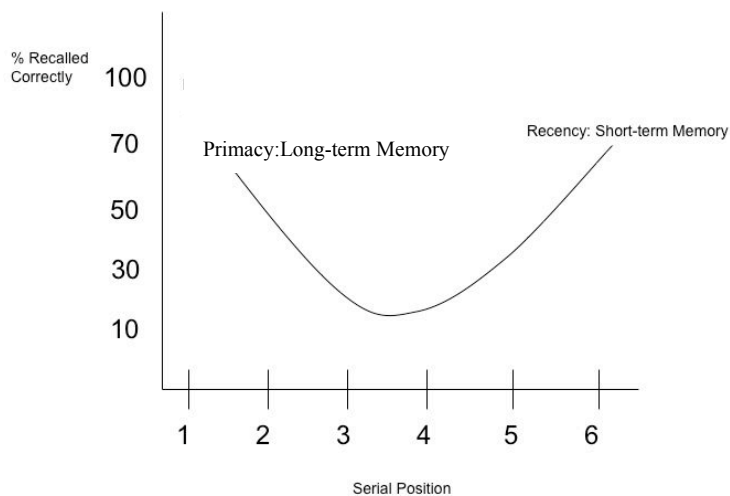
Figure 1. The Recency and Primacy Effects on Immediate Serial Recall

required immediate recall were taken to reflect the operation of the short-term memory system, while delayed recall tasks reflected the operation of the long-term memory system.

In an earlier study on immediate recall for serially presented material, Conrad (1964) found that the errors on the serial recall task were related to phonological similarity. In other words, when asked to recall a sequence of letters, subjects often substituted letters that were phonologically similar. For example, during recall the letter "C" may be substituted for the letter "B", or the letter "M" may be substituted for the letter "N". Additional studies showed that memory for phonologically similar items (e.g., B, C, D) was poorer than memory for phonologically dissimilar items (X, T, R) and that

this "phonological similarity effect" interacted with the recency portion of the serial

memory curve and performance on immediate recall tasks, while a semantic similarity

effect (memory advantage for items that were similar in meaning) interacted with the

primacy portion of the serial recall curve and performance on delayed recall tasks

(Baddeley, 1966; Kintsch & Buschke, 1969). These findings suggested that short-term

memory for verbal material was being held in a short-term memory store that was based

on phonological coding, whereas material in long-term memory was organized

semantically.

In 1968, Atkinson and Shiffrin proposed the modal model of memory (Figure 2).

In the modal model, short-term memory was conceived of as a unified store of limited

capacity. An implication of this model is that the amount of time material is held
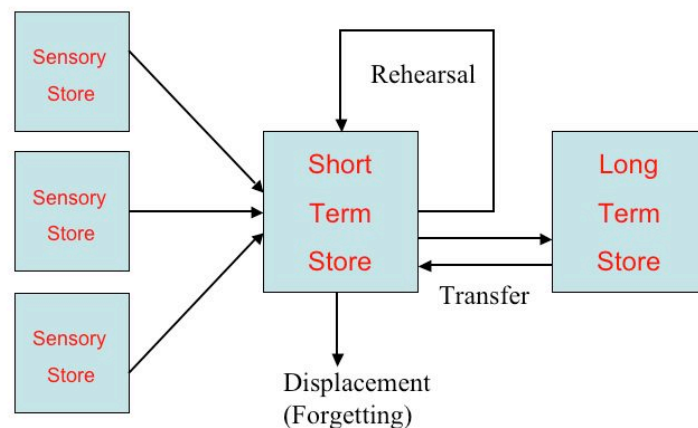
Figure 2. Atkinson & Shiffrin's Modal Model of Memory (1968).

in working memory directly determines how well material is eventually transferred into

long-term memory. In other words, the short-term memory was thought to operate as a

"bottleneck" for information being transferred into permanent storage, or long-term memory.

There was substantial evidence in the literature to support the modal model. For example, the memory performance of individuals with amnesia supported the modal model. Milner (1960) described individuals who performed normally on immediate recall tasks, and who showed evidence of a recency effect, but who had impaired long-term memory and displayed no primacy effects. Shallice and Warrington (1970) described patients with the opposite pattern – impaired performance on immediate recall tasks, no recency effects, but who presented normal long-term memory functioning. This differential pattern of impairment strongly suggested that two distinct memory systems were operating on to-be-remembered material. However, research also yielded results that could not be adequately explained by the short-term memory model as proposed by Atkinson and Shiffrin (1968) and certain implications of the modal model were found to be untenable.

Craik and Lockhart's "levels of processing theory" (1972) called into question the prediction implied by the modal model, that encoding in long-term memory is directly related to the amount of time material is held in short-term memory. The levels of processing theory suggested that encoding in long-term memory was not simply related to the amount of time material was held in short-term memory, but encoding is also related to *how* this material was processed, while it was held in short-term memory. For example, when individuals were instructed to organize a set of words according to semantic categories, recall for the set of words was better than when they were instructed to attend only to the phonological characteristics of the stimuli. Both semantic and

phonological processing strategies resulted in better recall than when participants were instructed to attend to the basic visual features of the stimuli. Thus, more *elaborated* processing of material in working memory appeared to produce better recall of the material (Craik & Lockart, 1972). This research suggested that short-term memory may have more complex functions than simple storage.

A second problem with the modal model arose when the cognitive processing of neurologically impaired patients was considered, in light of their memory problems. For example, the modal model implied that short-term memory was the gateway to long-term memory, acting as a bottleneck for the storage and retrieval of material held in long-term memory. Therefore, the implication was that an individual's short-term memory functioning would constrain his or her general cognitive processing. In other words, individuals who had impaired short-term memory functioning, should show significant problems in general cognitive processing, because their impaired short term memory would limit the flow of information from material in and out of long-term memory. This general cognitive impairment was not observed in some patients with deficient short-term memory functioning. These inconsistencies contributed to the proposal of the working memory model depicted in Figure 3 (Baddeley & Hitch, 1974).

As Figure 3 demonstrates, the initial model of working memory was comprised of a general attentional control system called the central executive (large oval), which is supported by two peripheral storage systems (rectangles) called the phonological loop and the visualspatial sketchpad. The working memory model is similar to the short-term memory system of the modal model, as a clear distinction is made between short-term memory and long-term memory. However, working memory is different from short-term

memory, in that the structure is componential and contains a processing mechanism (the central executive). While in the modal model, short-term memory was a simple unified storage system, the working memory system has specialized components and a limited capacity attentional controller. In this way the working memory model is an elaboration of the short-term memory model.
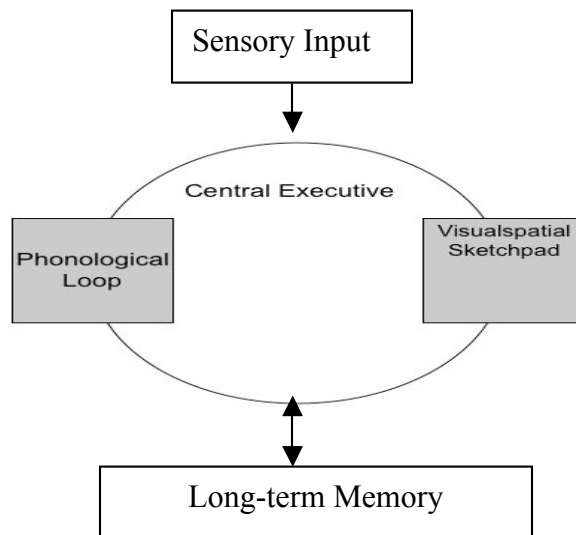
Figure 3. Baddeley and Hitch's 1974 Working Memory Model (adapted)

The most general mechanism of the working memory system is the central executive (large oval). The two specialized storage-only mechanisms called, the phonological loop, the visualspatial sketchpad (rectangles), can be thought of as specific working memory mechanisms. The central executive (CE) is hypothesized to be a general attentional control system responsible for coordinating the functioning of the total working memory system. The phonological loop (PL) is a storage system capable of maintaining phonological (sound-based) material through the use of phonological store and an articulatory rehearsal mechanism. The visualspatial sketchpad (VS) is specialized for the storage of visual and spatial material, and may be comprised of two mechanisms

13

tentatively called the visual cache and the inner scribe, which may be further specialized to store static visual patterns and spatial sequences, respectively.

It is helpful to conceive of working memory as functioning on two levels: general and specific. Complex working memory tasks require that an individual employ several working memory mechanisms, such as the listening span task and backward digit recall task (described below), and can be thought of as reflecting an individual's general working memory functioning. In other words, in order to complete the task, an individual must coordinate multiple processes in working memory (i.e. storage and processing). Thus, the task reflects how well an individual's working memory system functions as a whole or in general. In contrast, simple working memory tasks, such as the verbal or visual span tasks (also described below), require only the storage of material in working memory, through either the phonological loop or the visual spatial sketchpad, but not both. Simple working memory tasks do not require processing. As such, simple working memory tasks reflect working memory functioning on a more specific level. Simple working memory tasks do not require the coordination of multiple processes in working memory. Thus, as tasks become more complex, the working memory system is more generally utilized, whereas simpler tasks may be completed using specific working memory mechanisms.

Similarly, it is helpful to think of the components of the working memory as having general and specific functions. For example the central executive is hypothesized to control the general functioning of the total working memory system. Therefore, the CE is likely to be involved in the performance of complex or general working memory tasks which have high processing demands; and the CE is likely to be involved, although

14

to a lesser extent, in the performance of more specific working memory tasks which have low processing demands. In this way, the CE has a general function within the working memory system. In contrast, the PL and VS are specialized to store phonological and visual material (respectively), and as such these mechanisms have more specific or restricted functions within the working memory system.

Furthermore, it is helpful to understand that the structure and functioning of the individual components of the working memory system have been more or less specified in the literature. The structure of the phonological loop has been extensively researched and its functions have been relatively well specified, whereas the CE, due to the complexity of its functions remains vaguely specified. The structure of the visualspatial sketchpad is less theoretically specified than the the PL, but more specified than the CE (Baddely, 1996, 2002, in press). The following paragraphs describe the individual components of the working memory system in more detail.

Depending on the complexity of a task and the nature of the materials involved, individuals may employ either specific mechanisms (i.e., simple modality-specific storage using the PL or VS) or general mechanisms (i.e., concurrent storage or storage and processing, which also involve the CE) to complete the task. It is also possible that individuals use material from long-term memory to aid in the performance of many complex processing tasks (specifically through the use of the episodic buffer). Researchers have designed tasks that are thought to rely more on working memory mechanisms than on long term memory mechanisms, and tasks that functionally isolate one or more of the specific components of the working memory system (Baddeley, 1986; Daneman & Carpenter, 1980; Pickering & Gathercole, 2003; Smith, 2006).

The involvement of long-term memory in cognitive tasks may be limited by controlling two experimental variables: 1) the duration of the task; and 2) the nature of the materials used in the task. Generally, working memory is thought to operate on material that is held in memory for 2-4 seconds, after which additional encoding in long-term memory is likely to occur. Studies on working memory typically involve immediate recall tasks, which allow only brief rehearsal periods. With regard to experimental materials, it appears that the contributions of long-term memory may also be reduced if the materials used are unfamiliar to the subject, such as abstract shapes (e.g., Japanese Kanji characters or shapes that are not easily labeled verbally, such as black and white matrices), and pseudowords or words in a foreign language (Baddeley, 1986). The specific components of the working memory system may be experimentally isolated by restricting the processing demands of a task, or by manipulating the modality (visual or verbal) of the materials used in the task. The following paragraphs briefly describe the components of working memory and the experimental tasks used in the literature, which are thought to reflect the individual components of the working memory system.

The central executive is thought to control executive processes in working memory, such as the coordination of performance on concurrent tasks, the switching of long-term memory retrieval strategies, monitoring of output, the selective control of attention, and the inhibition of automatic responses and disruptive stimuli (Baddeley, 1996). However, the specific mechanisms of the central executive are vaguely defined, due in part to the complexity of these functions. Baddeley (1986, 2002) describes the central executive as a "theoretical grab bag" or an area of residual ignorance. In other words, the working memory system is assumed to be controlled by some limited capacity

mechanism (attention). Precisely how this attentional control operates is unclear.

Furthermore, there are a number of processes, which are assumed to occur in working

memory that are not completely understood, specified, or operationalized. Over the

course of the development of the working memory construct, general or undefined

mechanisms have been ascribed to the central executive system, while researchers have

chosen to focus "on more tractable problems, such as the phonological loop", which has a

comparably simpler structure (Baddeley, 2002; in press). As specific mechanisms are

theoretically defined and experimentally observed, they are "fractionated" from the

central executive.

The capacity of the central executive is measured by tasks that require control or

monitoring of attention and output, or tasks that involve the performance of concurrent

tasks such as simultaneous storage or simultaneous storage and processing. For example,

in the random generation task, the subject is asked to produce a random sequence of

letters or numbers. Performance on this task depends on the subject's ability to

constantly inhibit the tendency to revert to known sequences (A-B-C; 1-2-3) by switching

retrieval strategies and monitoring his or her output. The extent to which a subject is able

to produce a random sequence in a given time is taken as a measure of his or her central

executive capacity, or the capacity to control processing in working memory (Baddeley,

1986; 1996).

In the listening span task, subjects listen to a series of sentences, answer a

processing question about one of the sentences and then immediately recall the last word

in each sentence (Daneman & Carpenter, 1980; McNamara & Wong, 2003; Pickering &

Gathercole, 2004; Siegel & Ryan, 1989; Swanson & Alexander, 1997; Swanson &

Ashbaker, 2000; Swanson & Sache-Lee, 2001). A visualspatial analog to the listening

span task is the counting span task, which requires subjects to count the number of dots in

a series of sequentially presented arrays, and then to immediately recall the resulting

series of counts (Siegel & Ryan, 1989; Swanson & Alexander, 1997). The backward

digit recall task also requires simultaneous storage and processing, this task requires

subjects to store a verbally presented sequence of digits in working memory and then

verbally recall the sequence in reverse order (Pickering & Gathercole, 2004; Savage,

Frederickson, Goodwin, Patni, Smith, & Tuersley, 2005). Researchers have also used

tasks that require subjects to sort cards into categories while retaining a sequence of

digits, as a measure of central executive capacity (Baddeley, Lewis, Eldridge &

Thompson, 1984; Swanson & Alexander, 1997). Performance on these tasks is thought

to reflect an individual's capacity to simultaneously store and process information. In

other words, tasks used to measure central executive capacity measure and individuals

ability to coordinate multiple simultaneous processes in working memory.

Central executive capacity appears to increase from birth to approximately 15

years of age when adult levels are typically reached (Pickering & Gathercole, 2001;

Alloway, Gathercole, Willis, & Adams, 2003). Neurological studies have linked

executive processes with activation in the frontal lobe area of the brain (Shallice, 1982,

1998). When processing demands are high, the capacity of the CE supports working

memory performance by coordinating the functioning of the total working memory

system. Thus, the capacity of the central executive is taken to represent the capacity of

the total or *general* working memory system because the capacity of the CE limits or

constrains complex working memory functioning (Baddeley, 1986; 1996; 2000). Several

researchers have suggested that some children's decoding problems may stem from deficits in the attentional control functions of the central executive (Swanson & Alexander, 1997; Swanson & Ashbaker, 2000; Swanson, Ashbaker, & Lee, 1996). The CE limits the general capacity of the working memory system. Thus the capacity of the CE can be thought of as being synonymous with general working memory capacity. This synonymy is somewhat problematic, however, because general working memory functioning is dependent to some extent on specific working memory functioning. For example, the backward digit span task measures the ability to maintain two processes simultaneously in working memory (to store a series of digits in the PL, and to transform the series of digits to the reverse). Thus, measures of the CE or general working memory capacity also reflect specific working memory capacity to some extent because the specific storage capacity of the PL supports the more complex function of transformation.

As the model in Figure 3 indicates, the working memory system (1974) is also dependent on two specialized storage-only mechanisms. The working memory system utilizes the specialized storage mechanisms of the phonological loop and the visualspatial sketchpad to complete complex working memory tasks, such as listening span and backward digit recall. Until the episodic buffer hypothesis was proposed, the central executive was assumed to aid in the storage of material in working memory somehow. However, a general storage mechanism related to the central executive was not defined by the 1974 working memory model. The episodic buffer hypothesis represents an attempt to specify and isolate such a general or amodal store in working memory. The episodic buffer hypothesis is described following descriptions of the phonological loop (PL) and the visualspatial sketchpad (VS).

The phonological loop (PL) is a mechanism specialized for the storage of phonological material. The PL is comprised of a phonologically based store capable of maintaining sound sequences for roughly 2 seconds, after which time this material decays unless it is refreshed by an articulatory rehearsal mechanism. The storage capacity of the phonological loop is measured in individuals by their performance on simple verbal short-term memory tasks that do not require simultaneous storage and processing, and which typically involve the immediate recall (2-4 seconds) of aurally presented sequences of items such as letters, numbers, or words. The number of items that can be accurately recalled is referred to as digit span, word span, simple span, or verbal span depending on the nature of the items used (Pickering & Gathercole, 2004; Swanson & Ashbaker, 2000; Vukovic, Wilson, & Nash, 2004). The observation that subjects tend to perform better on span tasks involving unrelated real words compared to span tasks using unrelated pseudowords suggests that the PL likely interacts with linguistic structures in long term memory (Baddeley, 1986). However, the simple structure and limited capacity of the PL would likely restrict the complexity of this interaction.

Evidence from neurologically impaired patients (Shallice & Warrington, 1970) supported the existence of the phonological loop; imaging studies appeared to localize the phonological loop in the left hemisphere and Broca's areas of the brain (Baddeley, 2000). The development of the phonological loop is similar to the development of the central executive – roughly birth to 15 years (Alloway, Gathercole, Willis, & Adams, 2003; Pickering & Gathercole, 2001). Furthermore, it has also been suggested that the PL evolved as a language learning device (Baddeley, Gathercole, & Papagno, 1998). Children with decoding difficulties have consistently demonstrated poor phonological

loop functioning when compared to children with typical decoding ability (Bauer, 1977; Jeffries & Everatt, 2004; Jorm, 1983; Kibby, Marks, Morgan, & Long, 2004; Smith-Spark, Fisk, Fawcett, & Nicolson, 2003).

The visual-spatial sketchpad (VS) component of working memory is specialized for the storage of static visual patterns and spatial sequences. It appears that the sketchpad may be comprised of two separable mechanisms tentatively named the visual cache and the inner scribe (Logie, 1995). The capacity of the visual cache can be measured by presenting subjects with a matrix of a certain size, in which some of the cells are filled in black with remaining cells blank. Subject's are then asked to reproduce this matrix by either pointing or drawing (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; McNamara & Wong, 2003; Pickering & Gathercole, 2004; Swanson & Alexander, 1997; Swanson & Ashbaker, 2000; Swanson & Sache-Lee, 2001; Swanson, 2000; van der Sluis, van der Leij, & de Jong, 2005; Wilson & Swanson, 2001). The largest matrix that can be accurately reproduced immediately (2-4 seconds) is referred to as a subject's visual memory span (or matrix span). Matrix span also increases with age; typical adults are able to distinguish differences between matrices as large as eight cells square (Phillips, 1974). It is not clear how static visual patterns are refreshed in working memory, but it has been hypothesized that some form of conscious visualization is employed (Baddeley, 1999; Logie, 1995).

The capacity of the inner scribe is measured using tasks that require the immediate recall of visually presented spatial sequences. For example, in the corsi block-tapping task, subjects are asked to reproduce a sequence, which has been tapped out on an array of randomly distributed blocks (Pickering & Gathercole, 2004). In a similar task

21

called the dynamic matrices task, subjects are presented with a black and white matrix, of which some of the cells blink (switch color) in a particular sequence. Subjects are then asked to indicate, by pointing, which cells had blinked, and in what order the cells had blinked. In another inner scribe task subjects are asked to reproduce, by drawing or pointing, a path through a maze (Keeler & Swanson, 2001; Pickering & Gathercole, 2004; Swanson & Ashbaker, 2000; Wilson & Swanson, 2001). Visualspatial capacity increases from birth to 15 years as well (Pickering & Gathercole, 2003). As with the phonological loop, the VS may have limited interaction with visual semantic structures in long-term memory (Baddeley, 2002). Although deficits in visualspatial working memory are less commonly observed in children with decoding problems, the fact that word-reading involves static printed letter patters suggests that visualspatial working memory (the visual cache, in particular) may support graphophonic word-reading development at some level.

The independence of the PL and the VS is supported by studies that have shown selective interference patterns in subject performance for concurrent visual and verbal memory tasks. For example, it has been shown that the ability to retain a sequence of letters in working memory is disrupted more by a concurrent verbal working memory task, than by a concurrent visualspatial task when processing demands are controlled. The reverse also appears to be the case (Cocchini, Logie, Della Sala, MacPherson, & Baddeley, 2002; Colle & Welsh, 1976; MacAndrew, Klatzky, Fiez, McClelland, & Becker, 2002; Mayer & Moreno, 1998). The PL and the VS may support each other through the attentional functions of the central executive. For example, if an individual's central executive capacity is high enough, he or she may be able to verbally label

visualspatial stimuli and concurrently maintain both representations in working memory to aid in the recall of visual patterns or spatial locations. Similarly, an individual may visualize a pattern of keys on a phone in order to remember a phone number. However, neither the PL nor the VS contain mechanisms for the integration of visual and verbal material, a working memory function implied in the above examples. Integration in working memory is hypothesized to be a function of the recently proposed episodic buffer component, which is described in the following paragraphs.

The most recent version of the working memory model (Baddeley, 2002), which includes the episodic buffer hypothesis, is presented as Figure 4. The main point of difference is the addition of a modality non-specific store called the episodic buffer. In this model the central executive is relegated to attentional control.
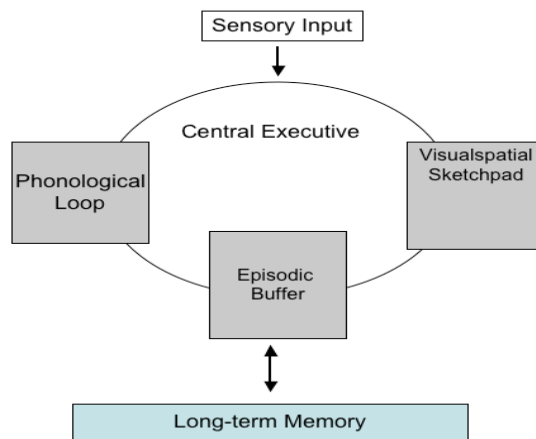
Figure 4. Baddeley's Working Memory Model (2002).

In terms of the general and specific structure of working memory, the episodic buffer is a working memory mechanism, specialized for integration. However, as the EB is concerned with integrating material from the various memory systems, it can be

thought of as a general working memory mechanism also. Because integration is assumed to be an attentionally demanding process, the functioning of the episodic buffer is constrained by the capacity of the central executive. In addition, the episodic buffer may be constrained by the functioning of the PL, the VS and LTM, as these mechanisms may be the source of the material to be integrated by the episodic buffer.

The episodic buffer is hypothesized to be a temporary store (or buffer) capable of accepting material from the phonological loop, the visual spatial sketchpad and long-term memory, which the episodic buffer then combines or integrates to form a multifaceted *episode*. Due to its recent proposal (Baddeley, 2000), the episodic buffer is significantly less theoretically developed than the phonological loop (PL) and the visual-spatial sketchpad (VS). The episodic buffer was proposed to account for phenomena that could not be explained by the functions of the PL or the VS, yet these phenomena shared a common dimension – namely integration and general modality-free storage. For example, the performance advantage of memory tasks involving meaningful sentences over sequences of unrelated words (Baddeley & Wilson, 2002; Gooding, Issac, & Mayes, 2004), the evidence of visual coding in verbal span performance (Logie, Della Sala, Wynn, & Baddeley, 2000), and the ability to construct original mental images based on the integration of material in working memory and long-term memory (Baddeley, 2002), could not be explained solely by the functioning of the phonological loop or the visual spatial sketchpad.

In the previous version of working memory, integrative functions were unspecified and vaguely ascribed to the general functions of the central executive. However, the most current model restricts the CE to attentional control functions

(Baddeley, 2002). Thus, the episodic buffer has been hypothesized to perform the complex storage functions described above. In a way, the episodic buffer can be viewed as the assumed yet unspecified general storage mechanism of the central executive. However, as previously stated, the central executive controls the functioning of the whole working memory system. As such, the PL and VS can also be thought of as *specialized* storage mechanisms of the central executive.

One way that the episodic buffer is hypothesized to support working memory tasks is through the use of long-term memory structures, which serve as a cognitive scaffold (Baddeley 2002). For example, adults typically show a word span of 6 to 8 unrelated words, yet if these words are formed into an unfamiliar yet meaningful sentence of prose, span can increase to 16 words. A sequence of 16 words far exceeds the capacity of the PL, which suggests that the material is being stored by some other mechanism in working memory. The increase in span is thought to reflect the ability of the episodic buffer to integrate semantic structures from long-term memory with the material in the phonological loop (the words presented), which acts as a structural scaffold for the memory task (Baddeley & Wilson, 2002). Also, when subjects were prevented from using the phonological loop in the simple span task (through a technique called articulatory suppression), a decrement in performance is observed, but this decrement is significantly less than 100% (Larsen & Baddeley, 2003), which also suggests that the span task is being supported by some other mechanism (Baddeley, in press).

The observation of visual similarity effects for verbally presented letters also supports the episodic buffer hypothesis (Logie, Della Sala, Wynn & Baddeley, 2000). When subjects were verbally presented with lists of letters and words with a similar

visual depiction (e.g., fly, dry, cry, hew, new, few), recall for these lists was poorer than when the lists are comprised of words with more distinct spellings (e.g., guy, sigh, lie, who, blue, ewe). This suggests that subjects are employing the visualspatial sketchpad in this verbal recall task in addition to using the phonological loop. However, the visualspatial sketchpad has been shown to be ill-suited for serial recall, and to be based more on pattern complexity (Phillips, 1974), which again suggests that the material is being integrated and held in working memory by some other mechanism capable of using both visual *and* verbal codes.

In addition, working memory also appears to require a creative component to account for common cognitive feats that cannot be accomplished by the phonological or visual stores alone. For example, it is possible to imagine an elephant wearing a purple tu-tu, singing the aria to Madame Butterfly (Baddeley, 2002). Although this event is not likely to have occurred in reality, it is possible to construct this episode in working memory, and in significant detail. Images of blue oranges, and singing spoons can also be constructed by combining phonological and visual material from present experience (working memory) and parts of long-term memory material, although the complete image has never been experienced in reality (Baddeley, 2002, in press).

As the episodic buffer is hypothesized to integrate material from several memory systems (PL, VS, LTM), the tasks used to measure episodic buffer functioning must necessarily differ according to the memory systems involved. The ability to integrate LTM and the PL may be reflected by the immediate prose recall task, which requires subjects to immediately recall a meaningful sentence (Alloway, Gathercole, Willis, & Adams, 2003; Baddeley & Wilson, 2000; Gooding, Issac, & Mayes, 2005). Performance

on the prose recall task can be taken as a measure of episodic buffer capacity by itself or it may be compared to recall for a sequence of unrelated words of equivalent length (word span).

Evidence from patients with neurological impairment supports the existence of a mechanism that is independent from the phonological loop that supports the prose recall task (Baddeley & Wilson, 2000; Gooding, Issac, & Mayes, 2005). These individuals have a greatly reduced span for unrelated words, have extreme difficulty learning new material, yet show normal recall for unfamiliar prose. This suggests that the episodic buffer is supporting the prose recall task for these individuals, by enabling them to use knowledge in long-term memory that has not been affected by their impairment. Furthermore, structural analysis of the working memory system suggests that the prose recall task varies independently from the CE, the PL, and the VS (Alloway, Gathercole, Willis, & Adams, 2003). The development of immediate prose recall is roughly ages 3 to 11, which is a slightly shorter developmental period than the other components of working memory, which also suggests that prose recall is separable from the PL.

Smith (2006) measured the development of the ability to integrate material from the visual spatial sketchpad (unfamiliar static visual patterns – Japanese Kanji characters) and material in the phonological loop (verbally presented pseudowords) using a modified paired associate learning task, which required immediate recall and one-time presentation of stimuli. The use of unfamiliar shapes and words, the single presentation format, and the immediate recall aspect of this task fit the theoretical description of a working memory task. The cross-modal associations required for performance on this task are also consistent with the theoretical function of the episodic buffer. Smith found cross-

modal binding ability to increase between the ages of three and seven. Furthermore, this developmental pattern appears to correspond to the graphophonic stage of word reading development. In this study two tasks were used to represent the functioning of the episodic buffer (EB1 and EB2). The two tasks, EB1 and EB2, were used to control for the possibility that cross modal material which has been bound in working memory (the graphophonic pair) may be recalled by two different methods -verbally (EB1), or by pointing (EB2). In other words, subjects' recall of the material may also be prompted by presentation of either the visual component (EB1) or the verbal component (EB2) of the cross-modal material being stored by the episodic buffer.

In summary, the working memory construct is a model of temporary information storage and processing. The components of the working memory system interact to assist individuals in the performance of complex cognitive tasks. The working memory construct is far from complete in its ability to specify the mechanisms involved in short-term cognitive processing, however the working memory model has enjoyed a substantial amount of explanatory power (Baddeley, 2003; Baddeley, Gathercole, & Papagno, 1998; Barrouillet & Lapine, 2005; Jarrold, Baddeley, & Philips, 2002; Kane, Hambrick, & Conway, 2005; Kibby, Marks, Morgan, & Long, 2004; Keeler & Swanson, 2001; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; McGurk, Coleman, Harvey, Reichenberg, White, Friedman, Parrella, & Davis, 2004; Pickering & Gathercole, 2004; Rasmussen & Bisanz, 2005; Swanson, Saez, Gerber, & Leafstedt, 2004; Swanson & Sasche-Lee, 2001). In addition, research supports the relation between working memory functioning and decoding ability (Bauer, 1977; Howes, Bigler, Burlingame, & Lawson, 2003; Jeffries & Everatt, 2004; Jorm, 1983; Seigel & Ryan, 1989; Strattman & Hodson,

2005; Swanson, Trainin, Necoechea, & Hammil, 2003). The episodic buffer hypothesis further specifies the working memory model and provides a theoretical framework within which one type of processing, the association of visual and phonological material (i.e. working memory cross-modal binding or graphophonic association in working memory), can be examined. Furthermore, since it appears that children in the early elementary years are learning to associate printed letter patterns and spoken word sounds, and that during this time children may use these stored graphophonic associations to read words graphophonically; it seems reasonable to suggest that a child's episodic buffer functioning is related to his or her ability to read words graphophonically in the early elementary years. The purported relationship between the episodic buffer and decoding ability is depicted below as Figures 5 and 6.

Child with Deficient EB Development	Child with Typical EB Development
/K-A-T/ & "CAT" /H-A-T/ & "HAT"	/K-A-T/ & "CAT" /H-A-T/ & "HAT"
CE PL /K-A-T/ — VS "CAT"	CE PL /K-A-T/ — VS "CAT"
EB /k-.-t/ + "cat"	EB **/K-A-T/+"CAT"**
LTM /.-.-t/ - "cat" /h-a-t/- ….	LTM **/K-A-T/ - "CAT"** **/H-A-T/- "HAT"**
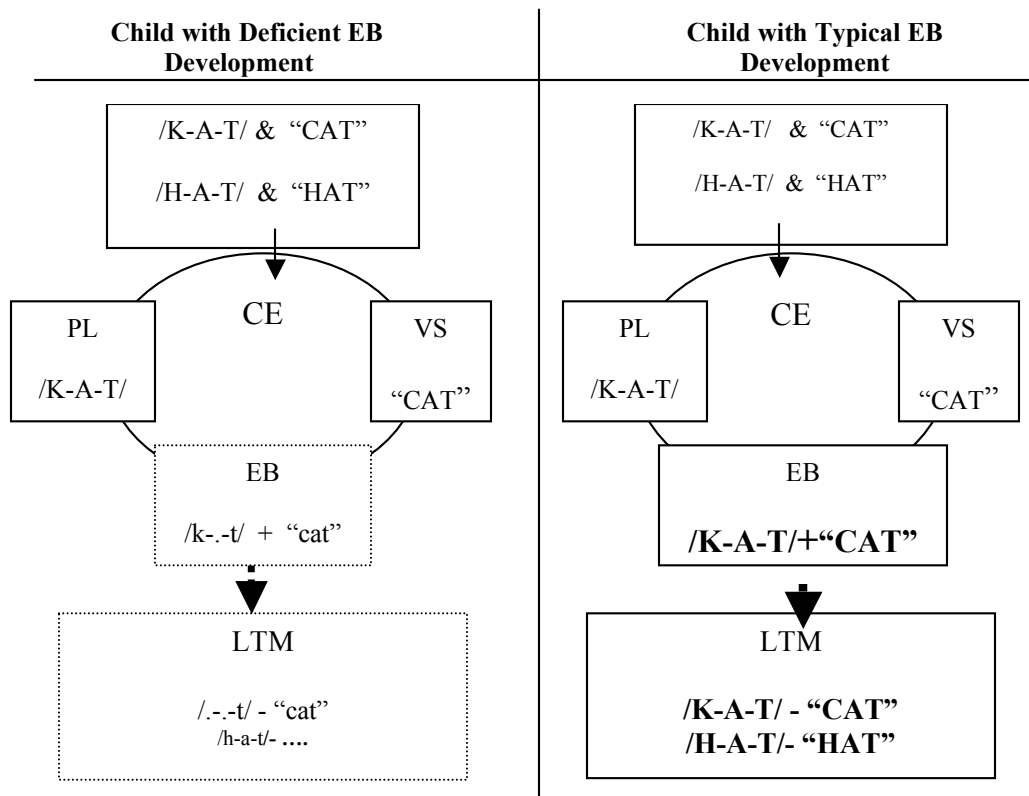
Figure 5. The Relationship Between the EB and the Establishment of a Robust Graphophonic Store in LTM.

The graphic in Figure 5 shows how EB capacity may constrain the establishment of a robust store of graphophonic associations in LTM during general word-reading instruction. During general word-reading instruction (specifically during explicit phonics instruction), children are presented with sound and printed letter pattern pairs, which they are directed to attend to and associate (/KAT/-"CAT", /HAT/-"HAT"). The child with typical EB development is able to efficiently bind wordsounds and printed letter patterns in working memory, which may, in turn, result in the child being better able to store (encode) these graphophonic pairs in LTM (the complete and bolded letter/sound pairs), and establish a robust store of graphophonic associations in LTM. The child with deficient EB capacity, however, is less able to bind sounds and printed letter patterns in working memory during reading instruction. As a result such a child may be comparably less able able to store (encode) these graphophonic pairs in LTM (Partial, incomplete and smaller letter/sound pairs), and establish a robust store of graphophonic associations in LTM.

Figure 6 shows how the establishment of a robust store of graphophonic associations in LTM may affect a child's ability to read words during the act of reading itself. During reading activities, children are presented with a printed letter pattern ("CAT"). In order to decode the word correctly they must then recall the sounds associated with this letter pattern (/KAT/). The child with typical EB development has been able to efficiently bind graphophonic pairs in working memory during reading instruction, and has, as a result, been able to establish a robust graphophonic store in LTM. The contents of this store allow the child with typical EB development to decode the presented written word correctly. The child with deficient EB development, however,

experiences a relative dearth of quality graphophonic pairs in LTM, which, in turn, impairs his or her ability to decode words during reading activities.

Child with Deficient EB Development	Child with Typical EB Development

RESPONSE = …

"CAT" is presented

PL
…

CE

VS
"CAT"

EB

LTM

/.-.-t/ - "cat"

/h-a-t/- ….

RESPONSE = /k-a-t/

"CAT" is presented

PL
/K-A-T/

CE

VS
"CAT"

EB

/K-A-T/+"CAT"

LTM

/K-A-T/ - "CAT"

/H-A-T/- "HAT"
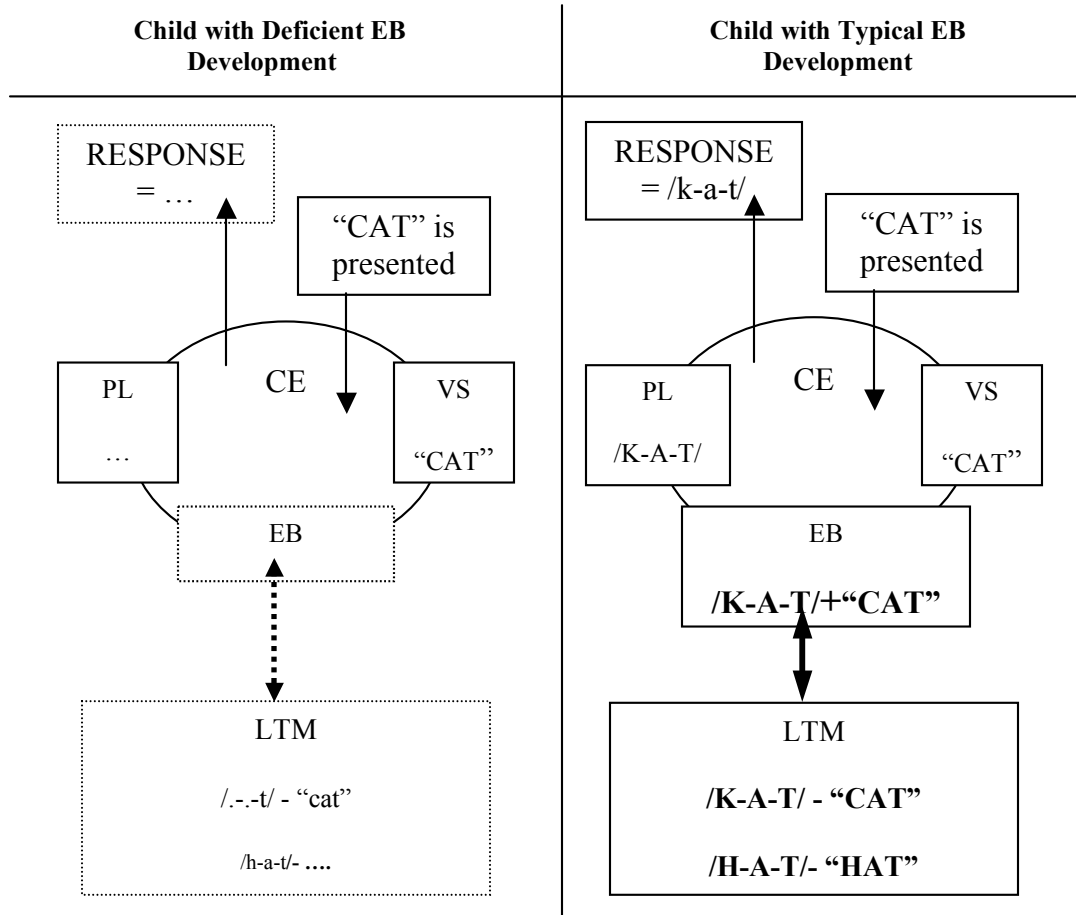
Figure 6. The Relationship Between the Establishment of a Robust Graphophonic Store in LTM and Decoding Ability.

Background and Need

The ability to decode individual words, quickly and accurately, is a critical reading skill for children to acquire in the elementary grades. The development of reading comprehension skills in the elementary years and beyond is thought to depend on a child's emerging ability to read isolated words with little cognitive effort (Ehri, 2000;

Stanovich, 2000). Being able to decode many words easily, allows a child to devote his or her cognitive capacity to understanding the meaning of words and larger bodies of text during reading activities and general instruction, therefore enabling a child to learn from text (Stanovich, 2000). Ultimately, if a child does not learn to read, he or she is more likely to drop out of school, to be limited to low paying jobs, and is at a higher risk of youth and adult incarceration (Burrell & Warboys, 2000; IDA, 2005; Quinn, Rutherford, Leone, Osher, & Poirier, 2005; Wagner, Newman, Cameto, Garza, & Levine, 2005). One of the initial stages of word-reading development, graphophonic word reading, occurs in the early elementary grades (Chall, 1983; Ehri, 1998; Ehri, & McCormick, 1998). Research has suggested that early elementary decoding ability affects later reading achievement (Stanovich, 1986). Thus, progress in graphophonic word-reading ability in the early elementary years is important if not critical to a child's success in school and adult life.

Currently, over 50% of children in the U.S. public schools (over 25 million children) are reading below grade level (Loomis & Bourque, 2001; NCES, 2003, 2005). A significant percentage of these children are still in the early elementary grades (Rathbun & West, 2004). These children are also likely to be poor readers in future grades, which may lead to more general academic difficulties, a cascade of academic failure referred to as the "Mathew Effect" (Stanovich, 1986), whereby children who have difficulty reading tend to read less, and therefore learn to read less, and so on, until they are significantly behind the achievement levels of their peers.

Without effective intervention, these children are likely to have difficulty responding to text-based instruction across the general curriculum (Chall, 1983; Ehri,

2000; Stanovich, 2000). In the second and third grades, the curriculum begins to require that children understand, and begin to critically analyze, text-based material in many academic subjects (CDE, 2005A). Coincidentally, most children who are identified as having a reading disability are identified in the early elementary years (Wagner, Cameto, & Newman, 2003; Wagner, Newman, Cameto, & Levine, 2006). Fortunately, research suggests that early intervention has a positive impact on decoding ability (Bhattacharya & Ehri, 2004; Blachman, Schatschneider, Fletcher, Francis, Clonan, Shaywitz, & Shaywitz, 2004; Castiglioni-Spalten & Ehri, 2003; Ehri, Nunes, Stahl, & Willows, 2001; Ehri & Stahl, 2001; Gaskins, Ehri, Cress, O'Hara, & Donnelly, 1997; Hatcher, Hulme & Snowling, 2004; O'Shaughnessy & Swanson, 2000). Thus, it is important to understand the source of a child's decoding problems in the early elementary years so that his or her difficulties may be ameliorated before these difficulties become pervasive and intractable (Snow, Burns, & Griffin, 1998; USDOE, 2005). Furthermore some researchers have suggested that decoding problems are best understood in terms of their underlying cognitive mechanisms (Bell, McCallum, & Cox, 2003).

There is substantial research on the relationship between decoding problems and working memory. Children with severe decoding problems are consistently shown to have deficient phonological loop capacity (Bauer, 1977; Jeffries & Everatt, 2004; Jorm, 1983; Kibby, Marks, Morgan, & Long, 2004; Smith-Spark, Fisk, Fawcett, & Nicolson, 2003). Some researchers have suggested that children with decoding problems also present deficits in the general functions of the working memory system (i.e., the central executive), (Swanson, 2000; Swanson & Alexander, 1997; Swanson & Ashbaker, 2000; Swanson & Sachse-Lee, 2001). However, there is no consensus regarding which

working memory system (specific or general) is more important in graphophonic word-reading development. In addition, the bulk of the literature is based theoretically on the previous working memory model, which does not include the episodic buffer hypothesis. It is not clear how the unaccounted for variance in decoding ability associated with the episodic buffer would have affected the results of these previous studies. The episodic buffer is hypothesized to interact with the other mechanisms in working memory. Thus, it is reasonable to suggest that the episodic buffer shares variance with these other components (PL, VS, CE). Furthermore, if episodic buffer functioning is related to graphophonic word-reading development, the determination of this relationship may clarify the relationship between graphophonic word-reading development and total working memory system. Some of the variance shared among the CE, PL, VS, and decoding ability may be attributable to the episodic buffer.

Working memory cross-modal binding ability may be specifically related to graphophonic word-reading development in the early elementary years. The development of working memory cross-modal binding ability during the early elementary years may enable children to form associations between units of speech sound (phonemes) and printed letter patterns (graphemes) during reading instruction. Efficient cross-modal binding (graphophonic binding) in working memory may facilitate the establishment of a robust store of graphophonic units in long-term memory. During the act of reading children may rely on the contents of this graphophonic store to help them decode complex or unfamiliar words (Ehri, 1998; 2000).

The graphophonic word-reading stage typically occurs during the first to second grades (Chall, 1983; Ehri, 1998; Ehri, & McCormick, 1998). Windfuhr and Snowling

(1998) found that performance on a paired associate learning task involving abstract visual shapes and pseudowords corresponded with this time frame and that performance on this task is related to decoding ability during the early elementary years. It is reasonable to suggest that the initial binding of these sounds and symbols occurs in working memory. In an unpublished dissertation by Smith (2006), working memory cross-modal binding ability was found to increase from ages three to seven. This developmental pattern is similar to the paired associate learning task described above, which also corresponds to the graphophonic word-reading stage. The only significant difference between the paired associate learning task and the task used by Smith is that in the paired associate task, subjects are allowed to practice the associations repeatedly. The Smith task used an immediate recall technique with a single presentation of associated pairs. In other words, the paired learning task used by Windfuhr and Snowling involved encoding in long-term memory, while the cross-modal binding task used by Smith was limited to the working memory system. These similarities suggest that the two tasks are related functionally.

The Smith study did not find a significant relationship between working memory cross-modal binding ability and graphophonic word-reading. However, her study was focused on grammar development and, as such, could not conclusively determine the relationship between cross-modal binding ability and word-reading. Although graphophonic word-reading was examined in relation to cross-modal binding ability, there were three methodological issues that undermined the validity of the result. First, the study was based on two samples, one older and one younger. Both samples were measured on working memory cross-modal binding ability, which yielded the apparent

developmental pattern of working memory cross-modal binding ability. However, only the word-reading scores for the older children in the sample were reported . Secondly, the older sample was mostly comprised of readers whose ability was significantly above average. The sample had a mean standard word reading score of 114.64 and a standard deviation of under 12 points (the mean for the scale is 100). Finally, this study did not adequately address the other components of the working memory system. Established measures of the PL, VS and CE were not included in the study.

A further source of evidence supporting the hypothesis that working memory cross-modal binding ability is related to graphophonic word-reading ability in the early elementary years comes from research on the remediation of early elementary word-reading difficulties. This research suggested that word-reading instruction that explicitly addressed the connections between the sounds within spoken words and the letters that represent these sounds was effective for struggling readers in the early elementary years (Bhattacharya & Ehri, 2004; Castiglioni-Spalten & Ehri, 2003; Ehri, Nunes, Stahl, & Willows, 2001; Ehri & Stahl, 2001; Gaskins, Ehri, Cress, O'Hara, & Donnelly, 1997). This suggests that this type of word-reading instruction may facilitate cross-modal binding ability in working memory and that interventions designed in this way may compensate for deficient working memory cross-modal binding ability in children with decoding difficulties.

In the task of learning to read graphophonically, the cross-modal binding function of the episodic buffer is clearly implicated. Initial binding in working memory of word sounds and printed letter patterns influences the strength with which these graphophonic associations are encoded in long-term memory (Craik, 1983). The development of

graphophonic word-reading ability may depend on the establishment of a store of graphophonic associations in long-term memory (Ehri & McCormick, 1998). The mechanism that has been proposed to be responsible for working memory cross-modal binding ability is the episodic buffer, which, in its most theoretically conservative construction, provides a storage mechanism for the association (binding or integration) of material from multiple sources in working memory to occur (Allen, Baddeley, & Hitch, 2006; Baddeley, 2000, 2002, in press; Baddeley & Wilson, 2002; Gooding, Issac, & Mayes, 2004; Zhang, Zhang, Sun, Li, Wang, He, & Hu, 2004). However, there is no study that has directly or adequately examined how working memory cross-modal binding ability is related to graphophonic word-reading ability in the early elementary years.

In summary, there is a need to identify the cognitive systems that support graphophonic word-reading development in the early elementary years. This need comes from two sources, from within the child, as early word-reading ability will eventually affect his or her own quality of life, and from without, as the school system and society are tasked with remediating or accommodating those who cannot read. Research has suggested that the working memory system is related to decoding ability. However, the understanding of this relationship is incomplete. The manner in which graphophonic word-reading develops in the early elementary years, the apparent developmental pattern of working memory cross-modal binding ability during the same time, and the nature of effective graphophonic word-reading instruction suggest that working memory cross-modal binding ability (an episodic buffer function) may support the acquisition of graphophonic word-reading skills in the early elementary years. However, this

conjecture had not been conclusively determined, nor has it been sufficiently examined. Therefore, the purpose of this study was to determine the relationship between working memory cross-modal binding ability and graphophonic word-reading ability in a sample of first and second graders with a wide range of reading ability. The results of this study may contribute to the theoretical understanding of the working memory construct. The results of this study may also contribute to the understanding of the relationship between graphophonic word-reading development and the working memory system, and how word-reading difficulties in the early elementary years can be ameliorated.

Significance of the Study

This study is significant for two reasons. First, this study examined a cognitive mechanism that may support learning to decode words in the early elementary grades (graphophonic word-reading, decoding). The first and second grades represent a critical point for children who are learning to read words (Ehri, 2000). Thus the identification of cognitive abilities that support graphophonic word-reading development during the early elementary years may lead to a more complete understanding of how children learn to decode words. This may, in turn, contribute to the design of more effective instruction for children with typical word-reading development, and the development of effective interventions for children who are having difficulty learning to read words in the early elementary years.

Working memory appears to be susceptible to training (Klingberg, Fernell, Olesen, Johnson, Gustafsson, Dahlstrom, Gillberg, Forssberg & Westerberg, 2005; Swanson, 2000). Thus it is possible that children who have been identified as having reading-related working memory deficits in the early elementary years could be exposed

38

to training interventions that focus on the remediation of these underlying working memory deficits. For example, in the area of math achievement, a research group called the Mind Institute has developed a computer program aimed at stimulating children's visualspatial processing capacity. This intervention is purported to have strong positive effect on math achievement (The Mind Institute, 2005). Perhaps similar interventions can be designed to stimulate the components of working memory which are related to reading ability. In other words, if graphophonic word-reading ability is found to be related to episodic buffer functioning in the early elementary years, then children in kindergarten and early first grade, who have been found to have word-reading and working memory deficits, could be exposed to working memory training interventions, which may allow them to benefit more from reading instruction. Furthermore, in the case of children who do not respond to such interventions, an understanding of the cognitive deficits that contribute to their difficulties may enable educators to provide special educational supports during reading instruction, that address the cognitive source of a child's problems in learning to read words graphophonically, thus facilitating his or her word-reading development. As the working memory model is further specified, teachers may design instructional accomodations that address the specific working memory deficits that are related to a child's academic problems.

Learning to read words graphophonically is a complex cognitive ability that is supported by a collection of underlying cognitive process (Swanson, Trainin, Neccoechea, & Hammil, 2003). Some of these mechanisms may be contained within the working memory construct. Thus, the determination of the relationship between the integrative functions of the episodic buffer and graphophonic word-reading development

may help to complete our understanding of working memory with regard to graphophonic word-reading development, which may further our understanding of word-reading development and how word reading failure may be remediated or accommodated.

Although not the primary purpose of this study, the results of this study may also contribute to the theoretical development of the working memory construct by investigating a relatively unexamined mechanism in working memory, the ability to integrate phonological and orthographic material. There is a growing body of literature on the relationship between the working memory system and higher order cognitive abilities (Kane, Hambrick, & Conway, 2005), various cognitive difficulties (Jarrold, Baddeley, & Philips, 2002; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; McGurk, Coleman, Harvey, Reichenberg, White, Friedman, Parrella, & Davis, 2004; Pickering & Gathercole, 2004), mathematical ability (Barrouillet & Lapine, 2005; Keeler & Swanson, 2001; Rasmussen & Bisanz, 2005), language (Baddeley, 2003; Baddeley, Gathercole, & Papagno, 1998; Swanson, Saez, Gerber, & Leafstedt, 2004), and word-reading (Bauer, 1977; Howes, Bigler, Burlingame, & Lawson, 2003; Jeffries & Everatt, 2004; Jorm, 1983; Kibby, Marks, Morgan, & Long, 2004; Seigel & Ryan, 1989; Strattman & Hodson, 2005; Swanson, Trainin, Necoechea, & Hammil, 2003; Swanson & Sasche-Lee, 2001). However, the working memory construct is still undergoing development (Baddeley, in press) and several cognitive mechanisms which are hypothesized to occur within the working memory system have been proposed but not completely specified (Baddeley, 1996; 2002).

The episodic buffer, in particular, is the first significant modification to the working memory construct in the roughly 30 years since its initial proposal, and is

currently under experimental investigation (Allen, Baddeley, & Hitch, 2006; Alloway,

Gathercole, Willis, & Adams, 2003; Baddeley, 2000; Gathercole, Pickering, Ambridge,

& Wearing, 2004). However, there has been very little research which has specifically

examined the cross-modal binding function of the episodic buffer. Thus, this study

contributes to the theoretical specification and experimental operationalization of the

episodic buffer by examining how the cross-modal binding mechanism of the episodic

buffer is related to the other mechanisms in working memory (the central executive, the

phonological loop and the visual-spatial sketchpad).

Research Questions

1. What is the relationship between cross-modal binding ability (EB) and the other components of working memory in a sample of first and second graders?
2. What is the relationship between the PL, VS, CE, and EB components of working memory and graphophonic word-reading ability in a sample of first and second grade readers with a wide range of reading ability?
3. What is the relationship between cross-modal binding ability (EB) and graphophonic word-reading ability in a sample of first and second grade readers with a wide range of reading ability, when general working memory capacity, and phonological and visual storage capacity are controlled in the analysis?

Definition of Terms

Cross-Modal Binding Ability (EB): The ability to associate or integrate sounds and static

non-verbal visual patterns in working memory. This capacity is operationalized

in this study by the PAIRS cross-modal binding task. In the PAIRS cross-modal

binding task subjects are presented with a cross-modal pair consisting of a

pseudoword and a particular abstract visual pattern (a character from the Japanese

Kanji orthography); then subjects are immediately asked to either recognize the

character from an array of target and distractor stimuli, upon presentation of the associated pseudoword; or they are asked to verbally produce the target pseudoword upon presentation of the associated static visual pattern. Cross-modal binding ability is thought to reflect the functioning of the episodic buffer (EB) component of the working memory construct. Two tasks, EB1 and EB2, were used to capture two aspects of the episodic buffer's cross-modal binding mechanism. The tasks are functionally identical except that in the EB1 task the test item is visual with a phonological target response, and in the EB2 task the test item is phonological with a visual target response.

Chronological Age: The age of an individual in years.

Decoding (WRDEC): A method of reading words that uses the using the letter-sound correspondences between spoken and written words. The term decoding is used interchangeably with the term graphophonic reading ability.

Elaborative Processing: Complex processing of material in working memory.

Encoding: Storage of material in long-term memory.

Episodic Buffer (EB): An hypothesized component of the working memory model responsible for the integration of material from multiple sources (PL, VS, LTM). The episodic buffer may be comprised of several submechanisms specialized for integration between the various memory mechanisms (PL,VS,LTM). However, in this study only the cross-modal binding mechanism of the episodic buffer was examined (the integration of material from the PL and VS). Thus, in this study episodic buffer was used interchangeably with cross-modal binding ability. The acronym EB refers to both terms unless otherwise noted.

General Working Memory Capacity (CE): The extent to which an individual is capable of

maintaining several storage processes concurrently in working memory, or the

extent to which an individual is capable of maintaining several concurrent

processes in working memory. This capacity is operationalized in this study by

the backward digit recall task which requires subjects to store a sequence of digits

and simultaneously transform the sequence upon recall. General working

memory capacity is primarily dependent on the central executive mechanism of

the working memory system, and as such, the central executive is used

synonymously with general working memory capacity and represented by CE.

General Word-Reading Ability: In this study general word reading ability is defined as

the ability to read words in isolation by any strategy.

General Word-Reading Instruction: Any and all of the various classroom activities

directed primarily at teaching children to learn to read words (i.e., word-reading

instruction in general).

Grapheme: The smallest meaningful graphic unit in the English orthography. For

example, letters (a, b, c) and letter groups (tion, sh, est).

Graphophonic Processing Ability: The ability to establish connections between

phonemes and graphemes. Although graphophonic processing may be an

important component of graphophonic reading ability, the two terms are not

synonymous.

Graphophonic Store: Knowledge stored in long-term memory of associations between

   wordsounds and lettern patterns in the English language.

Graphophonic Unit: A language unit comprised of an associated sound/symbol pair (also

   called an orthographic unit).

Hierarchical Regression: A statistical method similar to stepwise regression, whereby the

   Researcher determines the order of entry of predictors in a multiple regression

   equation.

Integration: The association or binding of cognitive material from sensory input and/or

   long-term memory.

Learning: The encoding of material in long-term memory.

Orthography: The written form of a language (the set of characters, or letter groups or

   words).

Orthographic Processing Ability: The ability to attend to and manipulate visual

   (orthographic) material. This ability is operationalized in the literature by tasks

   such as the orthographic choice task which requires subjects to identify which of a

   pair of words is a *real* word; for example, *rane* vs. *rain.*

Phoneme: The smallest meaningful phonological unit in the English language, for

   example the sounds */sh/* and */ch/* in the words *shout* and *child*, respectively.

Phonological Processing Ability: The ability to attend to and manipulate phonological

   material. Phonological processing is not limited to the working memory system,

   and is operationalized in the literature by phonological awareness and

   manipulation tasks, such as phoneme deletion, phoneme elision, phoneme

   segmentation, spoonerisms and pig-latin.

Phonology: The word sounds that make up a spoken language (the set of *legal*

phonemes).

Pseudoword: A phonetically pronounceable, yet false word.

Retrieval: The act of bringing material from long-term memory into working memory so

that it may be processed or used in the performance of cognitive tasks

Verbal Short-term Memory Capacity (PL): The extent to which an individual is able to

maintain a phonological sequence (a sequence of sounds) in working memory.

This capacity is operationalized in this study by the pseudoword repetition task,

which requires subjects to retain a sequence of word-like sounds, and verbally

recall the sequence in the original order of presentation. Verbal short-term

memory capacity is thought to reflect the functioning of the phonological loop

component of the working memory construct.

Visual Short-Term Memory Capacity (VS): The extent to which an individual is able to

maintain a static non-verbal visual pattern in working memory. This capacity is

operationalized in this study by the Visual Patterns Test, which requires subjects

to immediately recall a partially filled black and white matrix of given size, by

filling in a blank matrix of similar size. Visual short-term memory capacity is

thought to reflect the functioning of the visual cache mechanisms of the

visualspatial sketchpad component of the working memory construct.

Working Memory: The memory system responsible for the storage and manipulation of

visual and verbal material for brief periods of time (2-4 seconds). Working

memory is sometimes referred to as short-term memory in order to distinguish it

from long-term memory, although working memory involves processing as well

as simple short-term memory storage.

Working Memory Tasks: Tasks that require the storage and/or manipulation of visual and

verbal material for 2-4 seconds, and that are limited in their reliance on

knowledge structures in long-term memory.

CHAPTER II: REVIEW OF THE LITERATURE

The general purpose of this study was to examine the relationship between working memory functioning and graphophonic word-reading ability in the early elementary years. Although a significant amount of research regarding the relationship between working memory and word-reading ability exists in the literature, there is very little research directly examining how working memory cross-modal binding ability is related to the acquisition of graphophonic word-reading skills. Working memory cross-modal binding ability is hypothesized to be a function of the episodic buffer (EB), and may play an important role in determining the efficiency with which children are able to establish detailed and sophisticated associations between speech sounds and the letters that represent these sounds during general word-reading instruction in the early elementary years. Thus, the specific purpose of this study is to determine the unique variance shared between working memory cross-modal binding ability and graphophonic word-reading ability in children in the first and second grades. A secondary purpose of this study was to investigate the relationship between cross-modal binding ability and the established components of working memory (e.g., the PL, VS, CE). As the episodic buffer is a recent addition to the working memory construct, the mechanisms of the episodic buffer and their relation to the previously specified mechanisms of the working memory construct are not yet understood.

Consider the task confronting the child who is learning to read words in elementary school, and the underlying cognitive mechanisms that would reasonably be employed in the performance of this task. During basic general word-reading instruction, a child is presented with phonological material and static visual material (word sounds

and printed letter patterns, respectively). These materials must be attended to and analyzed in working memory. The child must then form associations between particular sounds and particular static visual patterns (letter groups), which are subsequently stored in long-term memory (storage in long-term memory is called encoding). Finally, at some later time, the child is presented with a particular group of printed letters and required to retrieve and produce the word sound associated with this group of letters. Thus, learning to read words can be viewed as a complex memory task, whereby graphophonic (letter/sound) associations are formed in working memory, encoded in long-term memory, and subsequently retrieved from long-term memory. The components of this complex memory task involve phonological and visual storage, cross-modal association (or cross-modal binding), attentional control, and retrieval, which are reasonably performed using the phonological loop, the visualspatial sketchpad, the episodic buffer, and the central executive components of the working memory system. It is also reasonable to suggest that the encoding of visual and verbal material in long-term memory during reading instruction, and therefore the ability to retrieve this material during reading instruction, depends on the general capacity of an individual's working memory system. The following section reviews the literature that supports this conjecture.

Research has suggested that individuals who use more sophisticated processing strategies in working memory during the encoding of material perform better on retrieval tasks of the same material than those who use more rudimentary encoding strategies (Craik & Lockart, 1972). Assuming that an individual has knowledge of sophisticated processing strategies, an individual's ability to employ elaborated encoding strategies

may be constrained by their general working memory capacity, and logically by the previous reasoning, the use of complex processing strategies would also be constrained by the capacity of the specific mechanisms of the working memory system. Individuals with comparatively high working memory capacity should be better able to coordinate and simultaneously employ several basic processing strategies during general word-reading instruction. Thus, the capacity of a child's working memory system (on the general and specific levels) during the early elementary years would limit the sophistication with which he or she is able to process sounds and printed letter patterns during general word-reading instruction, which in turn, constrains a child's ability to employ complex processing strategies during general word-reading instruction.

For example the word-sounds presented during word-reading instruction must be held temporarily in working memory so that they may be subjected to processing in even the most superficial manner, suggesting the involvement of the phonological loop. Likewise, the letter patterns presented during word-reading instruction must also be stored temporarily in working memory, presumably by the visual cache mechanism of the visualspatial sketchpad. The capacity of an individual's central executive may also be important during word-reading instruction, as these multiple storage processes must be coordinated, while the material being stored is processed.

There are three general types of processing that appear in the literature as important in word-reading acquisition: phonological processing, orthographic processing, and graphophonic processing. Phonological processing is defined as the ability to attend to and manipulate phonological material in working memory, and operationalized as phonological awareness tasks (e.g., phonemic segmentation, deletion, blending, and

49

manipulation). Orthographic processing is somewhat more difficult to operationalize than phonological processing because of the fact that while most children can produce phonological responses required by phonological awareness tasks, the production of orthographic material (visual representations of language) involves factors such as motor coordination that may place additional constraints on task performance which are not necessarily related to the ability to attend to, and manipulate, visual material in working memory. In addition, the mechanisms of visual processing are somewhat more elusive and underspecified than those hypothesized to be involved in phonological processing. As a result, orthographic processing ability is often measured by tasks that reflect orthographic knowledge, such as the orthographic choice task where subjects are required to identify which of a pair of phonologically equivalent words is actually a real word (Swanson & Alexander, 1997). Graphophonic processing or graphophonic awareness (Ehri, 1999) refers to the ability to match up graphemes (letter groups) and phonemes (word sounds) within individual words. The paired associate learning task provides a related paradigm, and performance on this task has been found to be related to graphophonic word-reading ability (Windfuhr & Snowling, 2001). It is reasonable to suggest that these three types of processing are important in learning to read words, and that the working memory system plays and important role in phonological, orthographic, and graphophonic processing.

Phonological processing has been found to be related graphophonic word reading ability in the early elementary years (Wagner & Torgesen, 1987; Wagner, Torgesen, Rashotte, Hetch, Barker, Burgess, Donahue, & Garon, 1997). Measures of phonological processing (called phonological awareness and manipulation tasks) are thought to

represent basic cognitive skills that facilitate the acquisition of the graphophonic principle in written language. The requirements of these tasks range in complexity, from blending sounds to make words (phonemic blending), to removing and transposing the sounds within pairs of words (i.e., the spoonerisms task).

In the phonemic blending task children are presented with individual phonemes (i.e., cuh-ah-tuh) and asked to give the word formed when these sounds are blended together (i.e., "cat") (Swansnon & Alexander, 1997). In phonemic segmentation tasks, children are presented with a spoken word (i.e., "cat") and are asked to speak the individual sounds that comprise the word (i.e., cuh-ah-tuh). In phonemic deletion tasks children are presented with a word and required to speak the sound produced when either the first, middle or final sound is removed (i.e., removing the first sound in "cat" produces the word "at"), (Swanson & Alexander, 1997). An example of the more complex phonemic manipulation tasks is called the spoonerisms task, where children are presented with a pair of words and asked to transpose the initial or final sounds in these words. For example, when presented with the words "sad cat", the child should respond, "cad sat" (Savage, Frededrickson, Goodwin, Patni, Smith, & Tuersley, 2005). In theory, children who perform well on phonological processing tasks are better able establish connections between letter groups and the sub-word units of speech. In other words, the ability to deconstruct and manipulate spoken words makes learning to decode words easier because instead of learning say 10,000 whole words, children can use the knowledge that the sounds within words (phonemes) are represented by smaller groups of letters (graphemes), which number only 30 to 40 in the English language. For example the words "man", "can", and "ban" all share the same middle and final sound, /a/ and /n/.

In addition, being able to attend to the phonological sub-word units in speech allows children to establish connections between the individual letters and letter groups within words and the sounds that these letters represent.

Poor phonological processing is thought to impede the encoding of detailed phonological representations in long-term memory, which, in turn, constrains a child's performance on tasks that require the use of phonological representations such as the decoding of words. Deficits in phonological processing are consistently found in children with decoding problems (Mann, Cowin, & Schoenheimer, 1989; Strattman & Hodson, 2005; Wagner & Torgesen, 1987; Wagner, Torgesen, & Rashotte, 1994; Wagner, Torgesen, Rashotte, Hecht, Barker, Burgess, Donahue, & Garon, 1997). In terms of the working memory system, an individual's performance on phonological processing tasks may rely in some part on his or her phonological loop capacity by the simple fact that phonological material must be held in working memory while the operations described above are performed. This conjecture is supported in the literature, as word and digit span measures are moderately correlated with phonological processing in children in the first through fourth grades (Wagner, Torgesen, & Rashotte, 1994; Wagner, Torgesen, Rashotte, Hecht, Barker, Burgess, Donahue, & Garon, 1997). In addition, children with decoding problems are consistently shown to perform poorly on word and digit span measures when compared to typical word-readers (Bauer, 1977; Jorm, 1983; Kibby, Marks, Morgan, & Long, 2004). Phonological short-term memory has also been referred to as a component of the general phonological processing construct (McDougall, Hulme, Ellis, & Monk, 1994). The results of these studies suggest that the phonological loop component of working memory is related to graphophonic word-

reading ability at some level, if only through the support the PL provides for phonological processing. However, the same research yields correlations between decoding and verbal span measures in the low range, and some researchers have suggested that the functioning of the general working memory system (e.g., the central executive) is also important in graphophonic word-reading ability. This is reasonable considering the fact that the working memory system is comprised of interdependent components which are difficult to isolate. Furthermore, when phonological processing tasks are analyzed in detail the involvement of a general working memory system is also implicated.

In addition to storage demands, phonological awareness and manipulation tasks require that phonological material be processed simultaneously in working memory. This is especially so in the case of the more complex phonological manipulations tasks such as the spoonerisms task. In fact, measures of general working memory capacity have shown a moderate correlation with phonological processing tasks and decoding (Alloway, Gathercole, Willis, & Adams, 2004; Swanson, Trainin, Necoechea, & Hammill, 2003). Several studies have also suggested that central executive capacity is related to decoding ability even when controlling for verbal short-term memory (Swanson & Alexander, 1997; Swanson & Ashbaker, 2000; Swanson & Howell, 2001).

The relationship of the visualspatial sketchpad and graphophonic word-reading ability is more implied in the literature, than directly implicated. Children with decoding problems are often found to perform comparably to typical word-readers on measures of visualspatial working memory. Thus, studies on severe decoding problems have rarely focused on this component of working memory. However, although children with

decoding difficulties are often shown to perform comparably to children with typical word-reading development on measures of visualspatial short-term memory, some researchers suggest that children with word-reading problems suffer more general orthographic processing deficits (Eden, Stein, Wood, & Wood, 1995; Meyler & Breznitz, 2005). These findings implicate the involvement of the visualspatial sketchpad on some level, however the relationship has not been specified sufficiently for discussion. Orthographic processing measures also show moderate correlations with decoding ability across many independent samples (Swanson, Trainin, Necoechea, & Hammill, 2003).

The research on the relationship between graphophonic word-reading ability and the integrative mechanisms of the episodic buffer (EB) is virtually non-existent. This is likely due to the recentness of the proposal of the episodic buffer and the current lack of theoretical specification of its mechanisms. The episodic buffer is hypothesized to be capable of integrating material from the phonological loop, the visualspatial sketchpad, and long-term memory. However, it has not been established whether these functions are controlled by a single mechanism, or whether the EB can be further fractionated into several mechanisms according to the type of material to be integrated. In spite of this, the episodic buffer hypothesis has begun to appear in the literature on working memory, word-reading and grammar development (Alloway, Gathercole, Willis, & Adams, 2003; Smith, 2006), this research has suggested a link between the episodic buffer and word-reading development. In addition, a recent study on the relationship between paired-associate learning and word-reading development adds support to the hypothesis that working memory cross-modal binding ability is related to word-reading development (Windfuhr & Snowling, 2001). Furthermore, studies on effective word-reading

instruction have also supported the connection between children's ability to associate word sounds and letter patterns during reading instruction, which would reasonably involve the working memory system, and in turn, the episodic buffer (Bhattacharya & Ehri, 2004; Castiglioni-Spalten & Ehri, 2003; Ehri, Nunes, Stahl, & Willows, 2001; Ehri & Stahl, 2001; Gaskins, Ehri, Cress, O'Hara, & Donnelly, 1997).

Alloway and collegues (2003) performed a structural analysis of the working memory system using a sample of children aged six to nine. This study included the prose recall task, which is taken to be a measure of the episodic buffer's capacity to integrate material from the phonological loop and semantic structures in long-term memory. This study did not examine the relationship between the working memory system and graphophonic word-reading, however, it did suggest a model in which the prose recall task loaded on an independent factor, separate from measures of the CE, PL, and VS. Although not providing direct evidence for the independence of working memory cross-modal binding ability, this result supports the validity of the episodic buffer hypothesis as an independent fourth component of working memory.

Windfuhr & Snowling (2001) examined the relationship between a paired associate learning task and decoding ability in children of similar age to the Alloway et. al. study, and found that the ability to *learn* associations between pseudowords and abstract visual shapes uniquely correlated with decoding ability. This is not surprising, since learning to read words is in a sense a paired associate learning task, albeit on a grand scale. However, this study is significant because by using stimuli that were unfamiliar to subjects, the involvement of long-term memory is limited. In fact, the only difference between the task used in the study by Alloway and colleagues and a proper

working memory cross-modal binding task (such as the one used by Smith, 2006), is that paired associate learning involves repeated presentation of stimuli. The subjects participating in this task were actually learning or encoding visual/verbal associations in long-term memory and so the task extends beyond the working memory system. However, it is reasonable to suggest that the initial binding of these materials occurs in working memory, and that because the materials were unfamiliar to the participants, the task relies to some large extent on working memory cross-modal binding ability. In other words, the paired associate learning task employed by Windfuhr and Snowling may represent a working memory task that is supported by repeated exposure to the material to be associated. Similar to the everyday working memory task of remembering a phone number while looking for a phone, except that a second person is supporting the task by repeating the phone number every few seconds while you are searching for the phone.

Smith (2006) examined working memory cross-modal binding ability in children ages three to ten using an experimental task similar to that of Windfuhr and Snowling, except that she refined the task by presenting pseudowords and abstract visual stimuli (Japanese Kanji characters) only once and requiring immediate recall or recognition of associated pairs of these stimuli. In this way the measure further reduced the opportunity for subjects to encode the material in long-term memory, thus resulting in a more *pure* working memory task. Furthermore, the measure is more closely related to the experience of a child learning to read words, as Kanji characters resemble letters more than do abstract shapes. The results of this study are informative, however inconclusive. Smith found that working memory cross-modal binding ability increased dramatically between the ages of three to seven, after which no further development was observed up

to age 10. This developmental pattern is markedly different from that of the other components of working memory which appear to increase steadily from ages three to 15, but closer to the developmental pattern of the prose recall task suggested by Alloway and colleagues (3 to 11). Interestingly, the development of working memory cross-modal binding ability does, however, coincide very closely with the time when children appear to develop graphophonic reading skills (Ehri & McCormick, 1998). Although Smith found that working memory cross-modal binding ability did not contribute significantly to decoding ability, this result deserves reexamination for several reasons.

First, the study was focused on grammar development, and although the data from which the developmental pattern of working memory cross-modal binding ability (WMC-MBA) was inferred was based on children ages three to 10, reading scores were only available for children ages 6 to 10 (a much smaller sample). In addition, those children with available reading scores were, for the most part above average readers with a mean standard score of 114.64 (SD 11.49) on a standardized measure of word-reading whose scale has a mean of 100. Thus it is not clear whether similar correlations between working memory cross-modal binding ability and decoding ability would be obtained in a sample that included a wider range of reading ability. It is possible that these children were homogeneous in their working memory functioning which would make shared variance between working memory and decoding ability difficult to detect. Furthermore, the experimental procedures of the study did not include established measures of the phonological, visualspatial, or executive components of the working memory system. Smith did include measures of unimodal integration. However, these measures are of questionable validity. The literature has not explicitly defined how material in a single

domain is integrated in working memory (Allen, Baddeley, & Hitch, 2006). The prose

recall task may be more reflective of the integration of material in the verbal modality.

As such, it is not clear how the inclusion of established measures reflecting PL, VS, and

CE capacity would affect the observed correlations between working memory cross-

modal binding ability and graphophonic word-reading during the early elementary years.

Thus, the specific purpose of the current study wss to examine how working memory

cross-modal binding ability is related to graphophonic word-reading ability in a sample of

readers with a wide range of word reading ability in the first and second grades. This

relationship has not been adequately determined in the literature on word-reading

development and word-reading failure. The following paragraphs summarize the line of

reasoning which supports the hypothesis that working memory cross-modal binding

ability is related to graphophonic word-reading development in the early elementary

years.

Summary

Recent research has supported the existence of a fourth component of working

memory capable of integrating or binding material from multiple sources within the

cognitive system, and that this component may have a developmental pattern which

corresponds to the ages when children are in the early elementary grades and learning to

read words graphophonically. In its most general conception, learning to decode words is

learning to associate or bind certain sounds with certain static visual patterns. Research

has also suggested that phonological and orthographic storage and processing in working

memory are related to decoding ability, as are attentional capacity and control. Word

word-reading instruction in the early elementary classroom may involve rapid

presentation of complex phonological and orthographic material, and this instruction typically occurs amidst a variety of competing stimuli. However, regardless of adequate capacity and functioning in the mechanisms that may support these processes (e.g., the PL, VS, & CE), ultimately successful acquisition of graphophonic word reading skills depend on the ability to associate phonological and orthographic material together in durably bound graphophonic (or orthophonic) pairs. Thus, working memory cross-modal binding ability is, in a sense, the keystone of graphophonic word-reading development. Without this basic binding ability, phonological and orthographic processing ability remain isolated, and sounds and letter patterns remain unconnected.

Children in the first through second grades, who have experienced typical episodic buffer development, may become increasingly efficient at binding the sounds within words (called phonemes) and the printed letter patterns that are used in the English orthography to represent these sounds (called graphemes) during word-reading instruction, to the point where graphophonic binding may occur relatively automatically. As a result, these children may be able to establish many sophisticated and durable graphophonic units (sound/symbol pairs) in long-term memory during word-reading instruction with decreasing effort as they progress through the early elementary grades. As such, they are able to employ these graphophonic units with increasing sophistication in the decoding of complex and unfamiliar words while learning to read, and during reading activities.

If children do not experience typical development in cross-modal binding ability during the early elementary years, they may be impaired in their ability to form graphophonic units in working memory, and to efficiently encode these units in long-

term memory. The resulting lack of strongly bound and detailed graphophonic units in long-term memory could then impede such children's progress in graphophonic word-reading, as they would be at a disadvantage compared to their typically developing peers in using learned graphophonic units during word-reading instruction and during reading activities. Children with a relatively deficient store of graphophonic associations in long-term memory would have more difficulty decoding complex and unfamiliar words than their typically developing peers, because they would have fewer graphophonic units in long-term memory available to help them. The quality of these graphophonic units may also be poorer in children with deficient working memory cross-modal binding ability (e.g., these associations may not extend to the phonemic and graphemic units within words). In other words, these children would be limited to decoding words using fewer graphophonic units, or to using the associations of whole spoken and printed words, whereas their typically developing peers would be able to access similar spelling patterns within words.

For example, the working memory impaired child would be forced to encode the graphophonic pairs for "hot" and "plot" individually whereas the unimpaired child could take advantage of more sophisticated graphophonic knowledge, in this case the sub-word unit "ot" could be used to decode many words such as "hot", "got", "plot", "lot", and so on. Intervention studies support this line of reasoning by suggesting that children with decoding problems benefit from instruction that directs them to make explicit connections between English phonology and orthography at the subword level during word-reading instruction (Bhattacharya & Ehri, 2004; Castiglioni-Spalten & Ehri, 2003; Ehri, Nunes, Stahl, & Willows, 2001; Ehri & Stahl, 2001; Gaskins, Ehri, Cress, O'Hara,

& Donnelly, 1997). The effectiveness of explicit graphophonic word-reading instruction may derive from the fact that instruction of this type compensates for a lack of working memory cross-modal storage ability. When instruction explicitly directs a child to associate a particular sound with a particular letter pattern, the specific pair in question is re-established or refreshed in the episodic buffer and prevented from decaying before the pair has been encoded in long-term memory. Thus explicit graphophonic instruction aids struggling readers in the establishment of the critical graphophonic store in long-term memory, by decreasing the effort children must expend to maintain graphophonic units in working memory.

Explicit phonics instruction may help children who have no working memory deficiencies by supporting their existing working memory functioning during instruction. During explicit phonics word-reading instruction children with typical episodic buffer development may be relieved of storage demands placed on the episodic buffer, and the processing demands the general working memory system. This "free capacity" can then be devoted to increasing the sophistication with which they are able to processes phonological and orthographic material in working memory during word-reading instruction and general reading activities. Thusly, working memory cross-modal binding ability (the episodic buffer) may help children with no memory problems to benefit further from word-reading instruction.

Thus, the results of this investigation may provide researchers and educators with a more complete understanding of the critical cognitive factors which determine a child's success in word-reading during the early elementary years. This understanding can potentially be translated into improved screening and diagnostic measures that seek to

determine the source of an individual child's current reading problems, or the likelihood

of a child's future reading success. A more complete understanding of the cognitive

factors related to word-reading development could also contribute to the development of

effective specialized word-reading instruction for children in the general enrollment, and

to the development of more effective word-reading interventions and accommodations

for children with special educational needs.

CHAPTER III: METHOD

This correlational study examined the relationship between working memory functioning and graphophonic word-reading ability or decoding. A substantial amount of research has been directed at the understanding of this relationship, however, the working memory model has been recently modified to include a new component called the episodic buffer. One of the mechanisms ascribed to the episodic buffer is called cross-modal binding ability, which is hypothesized to allow individuals to bind verbal material from the phonological loop and visual material from the visualspatial sketch pad into an associated pair in working memory prior to encoding in long-term memory. In light of the recent theoretical modification of the working memory model, a re-examination of the relationship between working memory and graphophonic word-reading ability is warranted as it is unclear how or whether the episodic buffer interacts with graphophonic word-reading ability. In other words, the addition of the episodic buffer may or may not add to the explanatory or predictive power of the working memory construct with regard to decoding. Specifically, this study examined the unique variance shared between the cross-modal binding mechanism of the episodic buffer and graphophonic word-reading ability. In addition, this study explored the relationship among the hypothesized episodic buffer component of working memory and the phonological loop, the visual spatial sketchpad, and the central executive components of working memory. These relationships were examined by analysis of the intercorrelation matrix produced by these variables, and by hierarchical regression. The analyses in this study were performed using SPSS version 11 for MAC OSX, and are described in the following sections.

Variables

This correlational study examined the relationships among five variables: general working memory capacity (CE), short-term phonological storage capacity (PL), short-term visual storage capacity (VS), working memory cross-modal binding ability (EB), and one criterion variable, decoding. The CE, PL, VS, and EB were used as predictors in this study. General working memory capacity (a measure of central executive capacity – CE) is operationalized as the ability to retain and attend to a verbally presented sequence of numbers, and then immediately produce the sequence in reverse order. This task is commonly referred to as the backward digit recall task Short-term verbal storage capacity (a function of the phonological loop –PL) is operationalized as the ability to retain a sequence of speech sounds (nonwords) in working memory for a brief period of time, and then verbally produce the sequence in the order presented. This task is referred to as verbal or nonword span. Short-term visual storage capacity (a function of the visualspatial sketchpad –VS), is operationalized in this study as the ability to retain a static visual pattern (a black and white partially filled matrix of specified size), and then reproduce this matrix by filling in a blank matrix of the same size with pencil and paper. The task is called the visual patterns test. Cross-modal binding ability is operationalized as the ability to retain an associated pair of visual and verbal material (a function of the episodic buffer –EB), and to verbally recall, or recognize by pointing, one member of the pair upon presentation of the other member of the pair. The criterion variable, decoding, was operationalized as the ability to read printed English regular and non-high frequency words in isolation (one at a time) and aloud.

64

Instrumentation

Five instruments were used in this study to measure verbal (PL) and visual (VS)

short-term memory, central executive capacity (CE), working memory cross-modal

binding ability (EB), and graphophonic word-reading ability (WRDEC). Appendix B

contains samples of stimulus items for each measure. Except for the working memory

cross-modal binding measure, all measures have appeared in the literature in original or

adapted form, as valid measures of the various components of working memory

(Pickering & Gathercole, 2001; Seigel & Ryan, 1989; Swanson & Alexander, 1997;

Swanson & Ashbaker, 2000; Wilson & Swanson, 2001). All measures were administered

according to the guidelines set forth by the instrument developers.

Decoding (WRDEC)

The WRAT-4 reading subtest is a straightforward test of general word-reading

ability. Participants were individually presented with a visual list of 15 letters and a

mixture of 40 decodable, high frequency, and irregular words of increasing difficulty,

which they were then asked to read aloud. Standard scores were computed using the total

number of words read correctly. An earlier version of this measure (WRAT-3) appears

often in the literature (Seigel, & Ryan, 1989; Swanson & Alexander, 1997; Swanson &

Ashbaker, 2000; Wilson & Swanson, 2001) and is reported to have acceptable reliability

and validity. The test manual reports high coefficient alphas (.88 - .95) for children ages

five to eight, and moderate to strong correlations with the California Achievement test

(r =.72), the Stanford Achievement Test (r = .87), and the California test of Basic skills (r

= .69) (Wilkinson & Robertson, 2006). For children reading at typical first and second

grade levels, administration takes approximately five minutes. In order to increase the

sensitivity of this measure, irregular and high frequency words were removed in the final analysis leaving a list of words that were decodable using graphophonic sound/letter correspondences. The ability to read the words on the resulting list more accurately reflects decoding ability, and thus this measure was used to represent the criterion variable (WRDEC) in the final analyses. Standard scores derived from the total number of words read from the complete WRAT-4 (WRSTD) wordlist were used for descriptive purposes only.

Central Executive Capacity (CE)

Central executive capacity was measured using the backward digit recall task from the Working Memory Battery for Children (Pickering & Gathercole, 2003). This task is a relatively simple measure of general working memory capacity compared to measures such as the listening and counting tasks described previously. The backward digit recall task is similar to a simple span task (also described previously) except that participants were asked to recall and verbally produce sequences of verbally presented digits (e.g., 3-7-2) that increase in length. However, unlike the simple span task, they were asked to recall the sequences in reverse order, which required participants to simultaneously store and transform the material in working memory. The length of the longest sequence correctly recalled was the subjects span score. Transformation of the to-be-remembered sequence places higher demands on the working memory system than the simple digit or nonword span task, which may be accomplished using only the phonological loop. The reliability of this measure is reported to be in the moderate range (r=.53) for the age group included in this study (Pickering & Gathercole, 2001).

Phonological Short-Term Memory (PL)

Simple phonological storage in working memory was measured using the pseudoword repetition task, from the Working Memory Battery for Children (Pickering & Gathercole, 2003). The pseudoword repetition task is similar to the word span task in that the participants heard increasingly long sequences of nonwords. The participants were then asked to repeat the sequences in the order presented. The length of the longest sequence recalled was the participants' nonword span. The pseudoword repetition task was chosen instead of the more common digit or word span task because by using unfamiliar pseudowords, any incidental involvement of long-term memory is limited. The reliability for this measure is reported to also be in the moderate range (r =.68) (Pickering & Gathercole, 2001).

Short-Term Visual Storage (VS)

Simple visual storage in working memory was measured using the visual patterns test developed by Della Sala, Gray, Baddeley, & Wilson (1997). In this task, participants were presented with partially filled black and white matrices that increased in size and in the number of filled cells. Participants were then asked to recall the presented matrix by filling in a blank matrix printed on paper, with a pencil. The numerical average of the number of filled cells in the last three correctly recalled matrices was the participants' matrix span. Because black and white matrices are not easily associated with verbal labels or previously experienced visual phenomena (as would shapes of common everyday objects, and some abstract shapes), the influence of the phonological loop and long-term memory are limited. Variations of the visual patterns test have been used by several researchers to measure short-term visual storage capacity (McNamara & Wong,

2003; Pickering & Gathercole, 2004; Swanson, 2000; Swanson & Ashbaker, 2000;

Swanson & Sache-Lee, 2001;Van der Sluis, Leij, & de Jong, 2005; Wilson & Swanson,

2001).

Working Memory Cross-Modal Binding (EB)

Working memory cross-modal binding ability (EB) was assessed using two tasks

from a measure developed by Smith (2006), called the PAIRS working memory task.

This measure has not been standardized, however, the tasks required by the measure are

consistent with theoretical descriptions of working memory construct and the

hypothesized episodic buffer; and it has been extensively piloted using young children by

the instrument developer (Smith, 2006). The PAIRS working memory task is similar to a

paired associate learning task. However, the fact that pseudowords and abstract visual

shapes (Japanese Kanji characters) were employed limits the use of long term memory

structures to aid in performance. Also, unlike traditional paired associate *learning* tasks,

which through repeated exposure to stimuli measure the ability to encode associated pairs

in long-term memory, the PAIRS working memory task presented to-be-remembered

stimuli only once, and required immediate recall. These differences significantly limit

the performance on the PAIRS task to the working memory system. No reliability data is

available for this instrument, however, the task appears to substantially limit long-term

memory involvement and functionally resembles the cross-modal binding mechanism

hypothesized to be contained within the episodic buffer construct. As stated previously,

the terms *working memory cross-modal binding* and *episodic buffer* were used

interchangeably in this study, and represented by EB.

Two tasks comprise the cross-modal binding measure. In the first task (EB1), subjects are presented with sequences of sound/symbol pairs that increase in length. Within two seconds, subjects are presented with the symbol of one of the presented sound/symbol pairs, and asked to verbally produce the associated sound. The stimulus portion of the second cross modal binding task (EB2) is the same as in the first task, however, after the presentation of the sound/symbol sequences, the subjects hear the sound of one of the presented sound/symbol pairs and is required to select the symbol associated with this sound from a 2x2 array of similar symbols. The length of the longest sequence in which the target nonword or picture was correctly recalled or identified is the participant's cross-modal span.

Participants

The sample consisted of 55 children in the first and second grades in a large elementary school in Southern California. This sample size is less than the 90 recommended by Tabachnik & Fidel (2007). Although consent was received for approximately 150 children, data from four participants were unuseable and the remaining 31 participants could not be included due to absences, scheduling conflicts, and/or general time constraints imposed by the district.

The total enrollment of the school was 1068 children in kindergarten through the sixth grade. Three hundred and thirteen children were in the first and second grades. The ethnic composition of the school was 96.4% Hispanic, 3.1% Asian, 0.4% Pacific Islander, and 0.1% African American. The percent of enrollment receiving free or reduced priced meals was 92.7 %. All teachers at the school were fully credentialed, with an average of

15.1 years of teaching experience. The average class size for the first and second grades

was 19.5 students per class.

Of the 55 children that participated in this study, 44 children were in the first

grade and 11 were in the second grade. The mean age for the entire sample was 7.19

years, with a range of 2.84 (6.33-9.17). Only eight children were eight years or older,

with 85.5% of the sample 7.83 years or younger. All the children in the sample were of

Hispanic origin. Twenty-three females, and 27 males participated in the study.   The

sample had a mean standard score of 109.33 with a standard deviation of 17.39 on the

WRAT-4 Word Identification subtest. Vision and hearing was in the normal range for all

participants in the study.

<div align="center">Procedure</div>

The participants in this study were administered the instruments in a single testing

session conducted by the primary researcher and two assistants (graduate students from

the California State University at Fullerton), lasting approximately 35 minutes. Testing

sessions took place at the children's school site and after the regular school day. Three

children were tested per session over 21 days from late February to early March. Testing

was conducted according to the following general procedure.

Consent forms were mailed to the parents of all of the first and second graders at

the school where the study was conducted (N=315). Approximately 150 signed consent

forms were returned. Of the 150 children for whom written consent was obtained, ninety

children (45 first graders and 45 second graders) were randomly selected. However, it

was only possible to collect data for all 5 measures from 55 children. Four children were

eliminated because they appear not to understand the directions of the tasks presented.

The remaining 31 children could not be tested due to absences, scheduling conflicts and general time constraints imposed by the district.

An assessment schedule was constructed to determine which children were to be assessed on a given day. On each day of testing, the parents of the children scheduled to be tested were called by the primary researcher, notifying them that their child was scheduled to be tested on that day, and asking their permission to keep their child after school. This phone call ensured that the parents were not inconvenienced by the conduct of the study and provided them an opportunity to directly ask the researcher questions about the study.

On most testing days, six children stayed after school to participate in a 90 minute story reading activity led by a teacher at the school, using a book selected by the school's reading specialist. On some days fewer than six children were able to stay after school. During the reading activity, the researcher and two assistants "pulled-out" three children at a time for individual testing in a quiet room near the room where the story reading activity is taking place. The researcher and two assistants each administered two of the instruments described above. For example, while the researcher administered the cross-modal binding measures, the first assistant administered the WRAT-4 reading subtest measure and the visual patterns test, and the second assistant administered the nonword recall and backward digit recall measures. Prior to the actual data collection, research assistants were trained to administer their respective tests in training sessions with the primary researcher, were asked to review the manual extensively on their own, and to administer their respective tests to children with in the age range of the study sample.

In each session, testing proceeded in a round robin fashion until three children had been administered the four working memory measures and one word-reading measure. After the first three children were administered the variable measures, they were returned to the story reading activity and the second group of three children were pulled out for testing. In order to eliminate testing effects, children were randomly assigned the order of their testing with each test administrator, and each test administrator rotated the order of administration of each of the tests they administered. In this way, each individual child was equally likely to be administered the set of measures in random order.

Data Analysis and Research Questions

Before performing the analyses the data were treated in the following manner. First, a subset of graphophonically decodable words was derived from the WRAT-4 word list. Second, a composite was formed from participants' span scores on the episodic buffer measures. Third, scores on all measures were converted to z scores. These treatments are described below.

Although all of the words on the WRAT-4 were administered to participants, the WRAT-4 is not a sensitive measure of decoding ability. The WRAT-4 contains both high frequency and irregular words in addition to words that are graphophonically decodable. For this reason, a sublist of eight graphophonically decodable words was selected. This allowed two scores to be derived from the data: 1) a standard score for general word-reading ability (WRSTD), and 2) a score for graphophonically decodable words only (WRDEC). The words selected were the first eight decodable words on the total list of words on the WRAT-4, omitting decodable words that were also high

frequency according to the Dolch and the Fry lists of high frequency words (Literacy Connections, 2007). The list of decodable words is presented in Appendix B.

Secondly, in order to obtain a measure for episodic buffer functioning, the two cross-modal binding tasks were formed into a composite (EB) comprised of the mean of subjects span scores for the cross-modal binding task with visual recall (EB2) and verbal recall (EB1). As EB1 and EB2 are both assumed to reflect episodic buffer capacity (the correlation between EB1 and EB2 is .23, p<.05), the composite EB represents episodic buffer functioning in this study. In an ancillary analysis (see Appendix A), EB1 and EB2 were treated as separate variables. In addition, an analysis was performed on all data obtained only from children in the 1st grade (see Appendix A). Finally, all scores were transformed into z-scores to meet the normality assumption required for the correlational and regression analyses performed in this study.

The first research question asked by this study was: (research question 1) what is the relationship between cross-modal binding ability and the other components of working memory in a sample of first and second graders? This question is somewhat exploratory in nature. For purposes of theoretical specification, it is useful to understand how the mechanisms within the working memory system are related to each other. In the case of the episodic buffer it is not clear if the cross-modal binding in working memory is dependent on the capacity of the modality specific stores of the PL and VS. Nor it is clear how attentionally demanding cross-modal binding is, which would be partially revealed by the shared variance between cross-modal binding ability and measures of the various components of working memory. In order to examine these questions, a bivariate intercorrelation matrix was formed from the z-scores of the CE, PL, VS, and EB. All

73

correlations were performed using 1-tailed tests of significance. Because all the tasks administered in this study are assumed to represent related cognitive abilities, the direction of the correlation coefficients was expected to be in the positive direction.

The second and third questions asked by this study were: (research question 2) what is the relationship among all the components of working memory and graphophonic word-reading ability in a sample of first and second grade readers with a wide range of reading ability, when a measure of working memory cross-modal binding ability is included; and (research question 3) what is the relationship between cross-modal binding ability and graphophonic word-reading ability in a sample of first and second grade readers with a wide range of reading ability, when general working memory capacity, and phonological and visual storage capacity are controlled in the analysis? These questions were answered by examining the bivariate intercorrelation matrix formed by the z-scores of the working memory and word-reading measures used in this study. In addition, the working memory measures were hierarchically regressed onto the WRDEC measure. The final regression equation produced by this method was used to answer question number 2, and the change in the magnitude of the regression coefficient when the EB is added to the regression was used to answer question 3.

Hierarchical regression is similar to forward stepwise regression in that predictors are entered into the regression equation in a stepwise fashion, or sequentially. Technically, the difference between stepwise and hierarchical regression is that, in stepwise regression, the order of entry of the predictors is determined by the analysis with the strongest predictors entered into the regression equation first. In hierarchical regression, the researcher determines the order of entry of the predictors in order to

examine how the coefficient of regression is effected by the addition of specific predictors to the regression equation. Another subtle difference between stepwise and hierarchical regression is how the results of the analysis are interpreted. Typically, in stepwise regression, the goal of the analysis is to specify a regression equation that includes only the strongest predictors. Thus, relationships between variables are inferred from the final regression equation yielded after all predictors have been tested. In hierarchical regression, the goal is to determine the unique variance associated with a particular predictor (the last predictor entered), regardless of whether this predictor has a stronger or weaker statistical relationship to the criterion than other predictors being considered. In this way, hierarchical regression is a method of determining relationships between the criterion and a particular predictor, while achieving statistical control for previously entered predictors.

In hierarchical regression, the regression coefficient (R) and its square (R^2) are examined each time a new predictor is added to the regression. The squared regression coefficient represents the total amount of variance shared between all the predictors in the regression equation and the criterion. Therefore, the change in R^2 (ΔR^2) at each step in the regression represents the unique variance shared between the criterion variable and the last predictor entered (see Appendix C for a hypothetical example of hierarchical regression).

Several researchers have used hierarchical regression to examine the relationship between a variety of variables including working memory and word-reading ability (Smith, 2006; Strattman & Hodson, 2005; Swanson & Alexander, 1997; Swanson &

Ashbaker, 2000; Swanson & Howell, 2001). In this study, CE, PL and VS were all

entered at the first step of the regression; EB was entered at the second step.

Protection of Human Subjects

All requirements and procedures set forth by the University of San Francisco,

Department of Psychology, IRPBHS Review Board have been observed in order to

protect the participants (including children, parents, school personnel) from any harm,

discomfort or disruption that may result from participation in research studies. The

primary researcher is of Hispanic descent and fluent in spoken and written Spanish, and

so he was able to communicate the goals of the study to children and parents, as well as

address any concerns these individuals may have had. All names were immediately

changed to numbers on all protocols, and all materials were kept in a locked cabinet with

the primary researcher retaining the only key. Only the primary researcher, and three

research assistants who have been trained in the procedures used in this study, and the

ethical issues involved in using human subjects in research studies, have had access to the

materials used in this study and the knowledge yielded by its conduct. No child or parent

showed any signs of physical or mental distress as a result of the conduct of this study.

Explicit procedures and consent documents are found in Appendix D).

Summary

The purpose of this correlational study was to examine the relationship between

episodic buffer functioning and decoding ability in a sample of 55 children in the first

and second grades with a wide range of reading ability. In order to determine this

relationship three questions were put to the data. First: how is the episodic buffer related

to the CE, VS, and PL? Second: what is the correlation between the total working

memory system and decoding ability? Third: what amount, if any, of the variance shared between the working memory construct and decoding ability, is attributable to the episodic buffer?

The measures in this study reflected the four components of the working memory model (CE, VS, PL, EB) and decoding ability (WRDEC). The first research question tests the episodic buffer hypothesis. Working memory theorists suggest that a discrete mechanism called the episodic buffer (EB) exists within the working memory system. In its most conservative construction, the EB is assumed to be responsible for cross-modal binding, which is an attentionally demanding process. Therefore, the cross modal binding measure can be assumed to reflect the functioning of the episodic buffer, and one would expect a particular pattern of correlation between the EB and the existing components of working memory. If the EB is independent from the VS and PL (i.e., if it performs some function the PL and VS cannot), the correlation between the EB and the PL, and between the EB and the VS should be low. On the other hand, the correlation between the EB and the CE should be relatively stronger.

The answer to the first question is necessary to answer the second and third questions in this study. The general purpose of this study is to understand why some children have difficulty learning to decode words, which may lead to interventions that prevent decoding problems in children. The working memory model provides a theoretical framework within which the development of decoding ability can be examined in terms of the cognitive sub-mechanisms that underlie decoding. The previous working memory model (Baddeley & Hitch, 1974) was limited in its ability to explain reading ability. The addition of episodic buffer component may significantly

77

increase the explanatory power of the working memory construct with regards to decoding ability. Hierarchical regression of working memory measures onto a decoding measure with the EB entered last will determine whether this is in fact the case, and to what degree.

CHAPTER IV: RESULTS

The purpose of this study was twofold. First, this study examined how working memory cross-modal binding ability (EB) was related to simple visual (VS) and phonological (PL) storage, and attentional capacity (CE) in working memory. Secondly, this study examined how working memory cross-modal binding ability (EB) was related to graphophonic word-reading ability (WRDEC) in a sample of first and second grade children with a wide range of reading ability. The first of these questions was intended to increase the understanding of the working memory construct. The episodic buffer is a recent hypothesis in the working memory construct and as such, it has not been examined extensively in the literature. Examining the correlations between measures of the existing working memory model and the episodic buffer could shed light on the nature and viability of the episodic buffer. The second purpose of this study was to examine the cross-modal binding mechanism of the episodic buffer as related to graphophonic word-reading (decoding) skills in children, and to determine if any variance in graphophonic word-reading is uniquely shared with the episodic buffer. The following section describes the results of this study, and is organized according to the research questions posed by this study. Table 1 below presents the descriptive statistics for all the variables in this study, including age, grade, and WRSTD and WRDEC scores.

Standard scores on the WRAT-4 have a mean of 100. The children who participated in this study were above average (mean = 109.33), with a standard deviation of 17.39. Recall that the participants in the Smith (2006) study had an average standard score of 114.64 and a standard deviation (SD=11.49). Thus, although the participants in

the current study were of comparable reading skill to those in the Smith study (only 40%

of the sample had standard scores below 114), the current sample had a much larger

Table 1. Descriptive Statistics: N=55

	Range	Min	Max	Span	Mean	Std. Dev.
Age in years	2.84	6.33	9.17	-	7.19	.68
Grade	1	1	2	-	1.20	.40
WRSTD	82	60	142	50-180	109.33	17.39
WRDEC	8	0	8	8	5.62	2.09
CE	2	1	3	0-6	2.33	.51
VS	3.70	2.00	5.70	0-24	3.47	.89
PL	3	1	4	0-6	1.67	.70
EB	2.5	1	3.5	0-6	2.22	.72

standard deviation, reflecting a wider range of ability than in the Smith study. Standard

scores on the WRAT-4 ranged from 60 (far below average) to 142 (far above average).

Table 2 presents the correlations (with p-values in parentheses) between the

criterion WRDEC, the EB, PL, VS, and CE. Although many correlational studies control

for age in their analyses, these studies typically include participants with a wide age

range (Alloway, Gathercole, Willis, & Adams, 2003; Smith, 2006; Swanson &

Alexander, 1997; Swanson & Ashbaker, 2000; Swanson & Howell, 2001). The age

range in this study was truncated (6.33 – 9.17), with only one child 9 years or older. For

this reason, age was not considered to be an important covariate in this study, and thus,

age was not considered in the analysis. The following section presents the results

according to the research questions posed by this study.

Table 2. Intercorrelations Among Working Memory Measures: N=55

	WRDEC	CE	VS	PL
CE	.22* (.050)	---	---	---
VS	.25* (.031)	.28* (.018)	---	---
PL	.39** (.002)	.26* (.030)	.33** (.007)	---
EB	.40** .001	.40** (.001)	.12 (.193)	.24* (.041)

* significant at or beyond the p<.05 level, one tailed.
**significant at or beyond the p<.01 level, one tailed

Research Question 1. What is the relationship between cross-modal binding ability (EB) and the other components of working memory in a sample of first and second graders?

Table 2 shows that the bivariate z-score correlation between the VS and PL was in the moderate range (.33, p=.007). The correlation between the CE and the PL was .26 (p=.030). The correlation between the CE and the VS yielded a moderate relationship (r=.28, p=.018). The EB was moderately correlated with the CE (.40, p=,001) and less so with the PL (.24, p=.041), but not significantly correlated with the VS (r=.12, p=.193). These results suggest that the EB shared a significant amount of variance with the CE and with the PL, although less so. However, the amount of shared variance between the EB and VS was very small and not significant. These results are discussed Chapter Five.

Research Question 2. What is the relationship between the PL, VS, CE, and EB

components of working memory and graphophonic word-reading ability in a sample of

first and second grade readers with a wide range of reading ability?

Table 1 shows that the sample had a mean general word-reading ability (WRSTD)

standard score of 109.33 (SD = 17.39), with a range of 82 (min=60, max=142) standard

score points. Which is slightly above average (mean = 100) As stated above, participants

scores on the complete WRAT-4 reading subtest (WRSTD) were used for descriptive

purposes. In this study, the criterion (decoding-WRDEC) was measured by the total

number of words participants were able to read from the restricted wordlist (decodable

words only). The correlation between EB and WRDEC was in the high moderate range

(.40, p=.001).   When z-score transformations of age, CE, PL, VS and EB were

simultaneously regressed onto the z-score transformation of WRDEC the coefficient of

regression (R) is equal to .51 with R^2 = .26. The ANOVA for the regression was found to

be significant (p=.004). Standardized coefficients (Beta: β) for CE, PL, VS and EB are: -

.013, .27, .13, and .33, respectively. The βs associated with the PL and EB were also

significant (p=.048 and p=.019 respectively), however the βs associated with the CE

(p=.924) and VS (p=.326) were not. These results suggest that the working memory

functioning shares a substantial amount of variance with decoding ability. These results

are discussed in chapter five.

Research Question 3.What is the relationship between cross-modal binding ability (EB) and graphophonic word-reading ability in a sample of first and second grade readers with a wide range of reading ability, when general working memory capacity, and phonological and visual storage capacity are controlled in the analysis?

Table 3 presents the results of the hierarchical regression of age, CE, VS, PL and EB onto WRDEC. The ANOVAs for step 1 (CE) and step 2 (VS) of the regression were not significant. However, the ANOVAs for step 3 (PL, p=.024) and step 4 (EB, p=.019) of the regression were significant. The EB was found to explain an additional 8.7% (p<.05) of the variance in WRDEC. These results strongly suggest that the EB explains additional variance in decoding ability, over and above the variance explained by the CE, VS, and PL. In other words, the current model of working memory (Baddeley, 2002) has greater exaplanatory power than the previous version of working memory (Baddeley & Hitch, 1974).

Table 3. Results of Hierarchical Regression of Working Memory onto WRDEC : n =55

Step	Variables Entered	R	R^2	ΔR^2	Sig.
1	CE	.224	.050	---	.101
2	VS	.299	.090	.040	.139
3	PL	.420	.128	.087	.024*
4	EB	.513	.263	.087	.019*

To summarize, the correlations between all of the working memory measures (EB, CE, PL and VS) were in the moderate to high moderate range except for the correlation between the EB and the VS which was very low. In addition, when regressed simultaneously onto the decoding measure (WRDEC) the working memory measures

explained approximately 26% of the variance in WRDEC. Furthermore, when regressed

hierarchically onto WRDEC, the EB explained an additional 8.7% of the variance in

WRDEC, after the entry of the CE, VS, and PL. These results are discussed in Chapter

Five.

CHAPTER V: DISCUSSION AND RECOMMENDATIONS

Discussion

The results of this study suggest that the episodic buffer component of the working memory system is related to graphophonic word-reading ability. Further, the episodic buffer component explains a significant portion of variance in graphophonic word-reading, heretofore unaccounted for by the working memory system. The evidence for these findings is presented in the following section in terms of the research questions posed by this study.

The first question asked by this study concerned the relationship between working memory cross-modal binding ability (EB) and the CE, PL, and VS. As previously stated, the working memory model has been recently modified (Baddeley, 2002). The episodic buffer was proposed in order to specify a general (amodal) storage mechanism within the working memory system whereby visual and verbal material could be integrated. The first question was intended to establish the relationship between cross-modal binding ability and working memory functioning. As the episodic buffer is a recent addition to the working memory construct, the relationship between the EB and the CE, VS, and PL was unknown. This question, therefore addressed the validity of the episodic buffer hypothesis, which had not been substantially established experimentally.

Working memory is a multi-component cognitive system responsible for the storage and processing of material over brief periods of time (Baddeley, 2002). The working memory model has helped researchers to understand a variety of cognitive phenomena (Baddeley, 2003; Baddeley, Gathercole, & Papagno, 1998; Barrouillet & Lapine, 2005; Bauer, 1977; Howes, Bigler, Burlingame, & Lawson, 2003; Jarrold,

Baddeley, & Philips, 2002; Jeffries & Everatt, 2004; Jorm, 1983; Kane, Hambrick, & Conway, 2005; Keeler & Swanson, 2001; Kibby, Marks, Morgan, & Long, 2004; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; McGurk, Coleman, Harvey, Reichenberg, White, Friedman, Parrella, & Davis, 2004; Pickering & Gathercole, 2004; Rasmussen & Bisanz, 2005; Seigel & Ryan, 1989; Strattman & Hodson, 2005; Swanson, Saez, Gerber, & Leafstedt, 2004; Swanson & Sasche-Lee, 2001; Swanson, Trainin, Necoechea, & Hammil, 2003). The VS and PL are modality specific stores (visualspatial and aural, respectively), yet previous studies have suggested the possibility of a multimodal store in working memory (Baddeley, 2002; Baddeley & Wilson, 2002; Gooding, Issac, & Mayes, 2004; Logie, Della Sala, Wynn, & Baddeley, 2000). Thus, the episodic buffer was proposed to expand the explanatory power of the working memory construct. The specific functioning of the episodic buffer (Allen, Baddeley, & Hitch, 2006) and the details of the relationships between the episodic buffer and the CE, VS, and PL (Alloway, Gathercole, Willis, & Adams, 2003) are currently the focus of research.

Allen and colleagues (2006) examined whether binding in a single modality (visual) is attentionally demanding. The results suggested that binding in a single modality is not attentionally demanding which further suggests that visual binding in working memory is not accomplished via the episodic buffer. Alloway and colleagues (2003) used factor analysis to determine whether the prose recall task (assumed to reflect the functioning of the episodic buffer –integration between the PL and long-term memory) loaded on a separate factor than the CE, VS, and PL. Alloway and colleagues found that the prose recall task did, in fact load on a separate factor from the CE, VS, and

86

PL, supporting the validity of the episodic buffer as an independent working memory component. Question 1 of this study examined whether the intercorrelations between the EB, CE, VS, and PL were consistent with the episodic buffer hypothesis with regard to cross-modal binding.

One of the specific mechanisms ascribed to the EB is the integration of visual and verbal material, which is an attentionally demanding process. The intercorrelations in Table 2 suggest that cross-modal binding in working memory draws on the capacity of the CE, and is related to the PL, but is independent of the VS. The CE and EB were moderately correlated (.40, p=.001), which suggests that, for this sample, children with higher general working memory capacity have higher cross modal binding ability. This, in turn, suggests that cross-modal binding is attentionally demanding, since children with lower general working memory capacity were able to bind cross-modal material less effectively. This is consistent with the theoretical definition of the episodic buffer (Baddeley, 2002). However, the correlations between the components of the working memory construct are reported to be significantly lower than those observed in this sample. Pickering & Gathercole (2001) found that the CE had a low correlation with the VS (r.25, p<.05) and the PL (r=.15, p=ns). The high magnitude of the correlation coefficients in this study may be explained by the fact the sample in this study was much lower than the recommended sample size for correlational studies using six measures.

The correlation between the EB and the PL was low (r=.24, p=.041). Recall that the PL measure (nonword recall) and the EB measure (binding nonwords to abstract visual images) shared an audio component. Thus, it may be that verbal material is first held in the PL and then fed into the EB. This suggests that the EB capacity may depend

on the capacity of the PL. This finding does not fully support the independence of the EB and the PL, but the fact that the correlation between the EB and the PL was low suggests some degree of independence between these components. In other words, if the cross-modal binding tasks employed the PL exclusively then the correlation between cross-modal binding and nonword recall would have been stronger. Thus it appears that the Pl supports the EB. The small but nonsignificant correlation between the EB and the VS (r=.12, p=.193) strongly supports the EB hypothesis. However, the PL and VS were moderately correlated (r=.33, p=.007), which is not consistent with the working memory model. Pickering and Gathercole found that the PL and VS had a very weak correlation (r=.03, p=ns).

The cross-modal binding task (EB) requires that subjects remember a sequence of distinct images paired with particular sounds. It is possible that an individual could maintain both sequences at once in order to complete the task (the sequence of sounds in the PL and the sequence of images in the VS). However, this is unlikely for two reasons. First, it is unlikely that children in the first grade would have the capacity to utilize such a complex strategy without being prompted to do so. More importantly though, is the fact that research has suggested that the visual spatial sketchpad does not appear to support serial recall of static visual patterns (Phillips, 1974). This raises the question of how these children were able to retain up to as many as five items presented sequentially. Thus, the weak correlation between the EB and the VS strongly suggests that participants in this study were employing some other mechanism besides the VS to perform the cross-modal binding tasks.

The weak relationships between the EB and the VS, and between the EB and the PL, suggests that some other mechanism, capable of storing a sequence of visual/verbal pairs, enabled the participants in this study to complete the cross-binding task. This finding is also consistent with the episodic buffer hypothesis (Baddeley, 2002), which suggests that cross-modal binding is accomplished by a component separate from the PL and VS, and that this process is attentionally demanding.

The second question posed by this study was intended to determine the total explanatory power of the working memory construct with regard to graphophonic word-reading ability. When regressed onto graphophonic word-reading ability, the revised working memory construct (CE, PL, VS and EB) explained over 25% of the variance in graphophonic word-reading ability (R=.51, p<.01). There are very few studies in the literature that have regressed all of the components of working memory onto decoding ability. However, a recent meta-analysis by Swanson and colleagues (2003) suggested that, averaged across many studies, the correlation between the previous working memory model and graphophonic word-reading ability was in the moderate range (.33-.40). Thus, the addition of the episodic buffer appeared to increased the explanatory power of the working memory construct considerably.

The increase in shared variance between the revised working memory model and decoding ability was expected. Prior to the proposal of the EB, working memory lacked the ability to explain complex cognitive processes (e.g. those involving integration across domains (i.e. visual and verbal). The addition of the EB allows cognitive tasks to be deconstructed to a greater degree. The negative β associated with the CE is problematic,

89

however, this coefficient is very small (β=-.013) and the p-value (p=.924) which suggests that it may not be a reliable estimate.

The final question posed by this study examined how much explanatory power was exclusively related to the EB with regard to graphophonic word reading ability (WRDEC). The hierarchical regression suggested that the episodic EB was exclusively associated with over 8% of the variance in graphophonic word-reading ability. Smith (2006) found that cross-modal binding ability explained an additional 5% of the variance in decoding ability, however this result was not found to be significant at p<.05 (p-values were not reported). It is possible that this nonsignificant result was due to a small sample size. The Smith study included only 46 participants. In addition, the participants in the Smith study spanned a larger age range (6-11 years) than the current study (6-9), and over 30% of Smith's sample were age 9 years or older. In the current study, only one child was 9 years old. The results of the Smith study suggested that development in cross-modal binding ability plateaus at 7 years of age. Thus, that part of the sample that corresponded to the age range in the current study (6-8) was very small, which may have made the unique variance between cross-modal binding and decoding difficult to detect. In other words, the results of the Smith study suggested that cross-modal binding ability (EB) ceased to develop after age 7 or 8. Thus, it is possible that the EB is not as important after this age. That is to say that, after ages 7 or 8, other mechanisms may be more important in helping children to decode words.

Thus, it appears that the EB shares a significant amount of variance with decoding ability in children in the first and second grades. This finding strongly suggests that the episodic buffer is a critical support mechanism for children who are learning to read

graphophonically in the early elementary years. Children are first exposed to formal reading instruction in the early elementary years. During reading instruction children are presented with printed letter patterns and spoken words. These visual and verbal pairs must be associated (or bound together) and transferred into long-term memory, so that at some later time, when a particular letter pattern is presented, the correct spoken word can be retrieved. It is likely that several cognitive mechanisms support this process, many of which may occur in working memory. It is possible that an increase in episodic buffer capacity in the first and second grade is crucial to the process of learning to read, by allowing children to make basic connections between word sounds and printed letter patterns. Graphophonic association (EB) may work in concert with phonological and orthographic processing development, but as previously stated, if children are not able to associate the orthography and phonology of the English language, these elements remain unconnected (or poorly connected), thereby preventing the retrieval of the correct word sound upon presentation of a particular letter pattern.

Conclusions

The most significant finding in this study was the dramatic increase in the explanatory power of the working memory construct with regard to graphophonic word-reading ability. The episodic buffer appears accounted for an additional 8.7% of the variance in graphophonic word-reading ability. This finding is a significant contribution to the knowledge of the cognitive mechanisms that support early elementary word-reading ability. Prior to the specification of the episodic buffer hypothesis, the working memory construct explained a low to moderate amount of variance in decoding ability. When the episodic buffer is included, the relationship between working memory and

graphophonic word-reading ability approaches the strong level. The results of this study

also support the validity of the episodic buffer hypothesis and the validity of PAIRS

cross-modal binding task as a measure of one of the hypothesized functions of the

episodic buffer. The episodic buffer was roughly consistent with theoretical

expectations, and the resulting relationship with graphophonic word-reading ability was

consistent with the rationale of this study.

<div align="center">Recommendations for Future Research</div>

Future research should be directed at exploring the relationship between the

revised working memory model and phonological and orthographic processing. As

discussed previously in this study, it is possible that phonological awareness and

manipulation tasks reflect the functioning of the working memory system. Prior to the

proposal of the episodic buffer hypothesis the working memory system was limited in its

ability to explain how phonological and orthographic material is manipulated in working

memory. The PL and VS can only explain how this material is stored. With the

inclusion of the episodic buffer hypothesis, a more sophisticated understanding of

manipulation of verbal and visual material in working memory is possible. In addition,

research should be conducted on the relationship between graphophonic word-reading

ability and episodic buffer capacity in children identified as having reading disability, and

how this relationship may be different from children with poor reading ability who are

not identified as having disability, and typical readers. Furthermore, as the children

participating in this study were all of Hispanic descent, it is not clear how a similar study

using children of Anglo or Asian descent might result. Future research should be

<div align="center">92</div>

directed at examining whether the relationship between episodic buffer functioning and graphophonic word-reading ability is mediated by primary language status.

On a theoretical level, future research should also be directed at further specifying the functions of the episodic buffer. The episodic buffer is also hypothesized to integrate material from long-term memory, and as such, the episodic buffer may be specifically related to how material is retrieved from long-term memory. It is possible that the rapid automatic naming task (RAN), (Swanson, et al., 2003) reflects the efficiency with which material is retrieved from long-term memory. In addition, research suggests that the RAN task is related to word-reading ability. Thus it is possible that the episodic buffer is comprised of several sub-mechanisms. When these sub-mechanisms are specified, the episodic buffer may prove to exert more influence on graphophonic word reading ability by determining the efficiency with which children are able to retrieve graphophonic associations from long term memory during graphophonic word-reading activities.

Finally, more research should be conducted with adult participants using the dual task paradigm, in order to further specify the relationship of the episodic buffer and the PL and VS. For example, precisely how attentionally demanding is working memory cross-modal binding ability? Also, is material stored in the PL and VS and then fed into the episodic buffer; or is this material primarily stored within the episodic buffer and subsequently stored in the PL and VS for specialized tasks. These questions remain unresolved.

Practitioner Recommendations

The results of this study imply several practitioner recommendations. First, educators should be aware that episodic buffer capacity appears to be related to

graphophonic word-reading ability. In terms of word-reading instruction, some children may need more extensive presentation of associated phonological and orthographic material during word reading instruction than others. Children with relatively deficient episodic buffer capacity may benefit from repeated exposure to smaller phonological and orthographic units during word reading instruction than children with higher episodic buffer capacity. The repeated exposure of smaller units of material may alleviate the demands placed on the episodic buffer during reading instruction, thus allowing children to encode graphophonic units in long-term memory with more efficiency.

In addition, it is possible that computer based instructional tools can be developed that address individual children's working memory deficits (deficits in the episodic buffer specifically) by precisely manipulating the duration with which graphophonic material is presented and adjusting the length of the graphophonic units presented, according to individuals' working memory profile. Furthermore, the findings of this study suggest that children in the preschool and early elementary years may benefit from exercises that stimulate the episodic buffer. For example, young children may benefit from rapid visual/verbal naming and recall games, which may stimulate episodic development prior to their receiving formal word-reading instruction. Finally, the working memory construct may be sufficiently specified at this point to serve as a diagnostic measure for future word-reading problems.

Limitations

The results of this study may be limited by the following factors. First, the sample size was significantly smaller than that which is recommended for correlational studies that include more than two variables. It is possible that the results of this study

may have been different if a larger sample were used. Some of the correlations approached significance. Also, the children in this study were all English language learners with varying levels of English language proficiency. It is not clear how this may have effected the results of this study. Results may have been different if a more heterogeneous sample had been employed. These issues may limit the generalizability of the findings in this study to other populations.

Summary

The ability to read individual words in isolation is a critical academic ability for children in the early elementary years. Future success in school and adult life is based on the ability to read individual words with substantial ease and accuracy. As children master word-reading ability, they are increasingly able to understand and analyze large bodies of complex text, and thus they are increasingly able to learn from text and achieve academically. Research has identified several cognitive processes thought to be related to word-reading ability, including phonological and orthographic processing, and working memory. However, the working memory construct has been recently modified to include the episodic buffer, a mechanism which enables individuals to combine (bind or associate) material from multiple memory sources.

Learning to read words graphophonically is in essence the ability to associate sounds and symbols into bound graphophonic units. These sound/symbol pairs are encoded in long-term memory and then used to learn to read new and complex words, as well as in the act of decoding itself. The encoding of graphophonic units in long-term memory may initially depend on the ability to form graphophonic associations in working memory. Thus, episodic buffer capacity may be related to graphophonic word-reading

development by constraining a child's ability to efficiently form graphophonic associations in working memory, thereby determining the establishment of a large and durable store of graphophonic association in long-term memory, and in turn, constraining decoding ability.

Research has suggested that the development of cross-modal binding ability coincides with word-reading development in the early elementary years (Smith, 2006), and that reading instruction which makes explicit connections between sounds and symbols in the English language are effective (Bhattacharya & Ehri, 2004; Castiglioni-Spalten & Ehri, 2003; Ehri, Nunes, Stahl, & Willows, 2001). This suggests that the episodic buffer is involved in early word-reading development and that interventions of the above type may support the cross-modal binding mechanism of the episodic buffer during word-reading instruction. However, there is very little research that has examined this possible relationship.

The findings of this study are roughly consistent with the episodic buffer hypothesis and suggest that episodic buffer development supports early elementary graphophonic word-reading development. These findings may help to provide researchers and educators with a more complete understanding of graphophonic word-reading development and the possible causes of word-reading problems in children in the early elementary years. Furthermore, the findings of this study may allow other researchers to explore the yet unspecified functions of the episodic buffer and the working memory system.

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Appendices

A. Ancillary Analyses

Two ancillary analyses were performed to answer additional questions which emerged during data analysis. In the first analysis the two cross-modal binding tasks (EB1 and EB2) were treated separately and the three research questions posed by this study were then put to these data. In the second analysis the data were restricted to only those children who were in the first grade and the three research questions were also put to these data.

Table 4. Descriptive Statistics (with EB1 & EB2): N=55

	Range	Min	Max	Span	Mean	Std. Dev.
Age in years	2.84	6.33	9.17	-	7.19	.68
Grade	1	1	2	-	1.20	.40
WRSTD	82	60	142	50-180	109.33	17.39
WRDEC	8	0	8	8	5.62	2.09
CE	2	1	3	0-6	2.33	.51
VS	3.70	2.00	5.70	0-24	3.47	.89
PL	3	1	4	0-6	1.67	.70
EB1	2	1	3	0-6	1.87	.72
EB2	4	1	5	0-6	2.56	1.10

Table 4 presents the same data as in Table 1 with the single difference being that instead of the EB composite, the individual EB tasks (EB1 and EB2) are shown instead. Recall that in the EB1 task sets of sound/symbol pairs are presented to the participant. The number of pairs in each set increases at each level of difficulty. In the recall phase, the participant is presented with a visual stimulus (the visual component of the sound/symbol pair) and is asked to respond with the corresponding verbal component.

107

The EB2 task differs from the EB1 task in the modality of the recall phase. In the EB2 task, the participant is presented with a phonological stimulus (the phonological component of the sound/symbol pair), and then asked to select by pointing the corresponding visual component from an array of distractor items. Table 4 suggests that the participants in this study found the EB1 (mean = .72) task slightly more difficult than the EB2 task (mean = 1.10). The standard deviation for EB2 (SD=2.56) was larger than the standard deviation for EB1 (1.87) indicating a greater amount of variability in the sample in terms of performance on the EB2 task than on the EB1 task. The apparent difference in task difficulty between EB1 and EB2 may be due to the fact that the EB1 task require a verbal response. The pseudowords used in the EB1 task may have been difficult to articulate. The EB2 task only required pointing.

The research questions asked by this study were revisited using the EB1 and EB2 as separate variables. Table 5 presents the intercorrelation matrix used to examine research questions one and two. The statistics reported in Table 5 are the bivariate correlations between the all the measures used in this study with p-values given in parentheses. These results are described and discussed below.

Table 5. Intercorrelations Among Working Memory Measures: N=55

	WRDEC	CE	VS	PL	EB1
CE	.22* (.050)	---	---	---	---
VS	.25* (.031)	.28* (.018)	---	---	---
PL	.39** (.002)	.26* (.030)	.33** (.007)	---	---
EB1	.37** (.003)	.22 (.057)	.11 (.219)	.14 (.159)	---
EB2	.28* (.019)	.39** (.002)	.09 (.264)	.22 (.052)	.23* (.044)

* significant at or beyond the p<.05 level, one tailed.
**significant at or beyond the p<.01 level, one tailed

108

Research Question 1. What is the relationship between cross-modal binding ability (EB1 and EB2) and the other components of working memory in a sample of first and second graders?

Table 5 shows that the correlation between the CE and EB1 approached significance (p=.057) with r=.22. The moderate correlation between the CE and EB2 (r=.39), however, was significant (p=.002). These results are difficult to interpret. If the EB2 task was more challenging for students than the EB1, one would expect a stronger correlation between EB2 and the CE. A more difficult task would seem to require more attentional resources than a less difficult task. These results suggest that some other factor other than task difficulty confounded the results. The correlation between EB1 and the CE is similar to the correlation between the CE and the PL (r=.15, p<.05), and between the CE and the VS (r=.24, p<.05) as reported by Pickering and Gathercole (2001), but the difference in the correlations between EB1 and the CE and between EB2 and the CE suggests some confounding factor.

The weak correlations between the VS and EB1 (r=.11, p=.219) and between the VS and EB2 (r=.09, p=.264) suggest that the participants in this study were not depending on the VS to complete either cross-modal binding task, which is consistent with the results in Chapter IV. The correlation between the PL and EB1 (r=.14, p=.159) was weak and nonsignificant. The correlation between the PL and EB2 (r=.22, p=.052) was also weak (but considerably higher than that between the PL and EB1) and approached significant. These results suggest that the participants in this study were not relying on the PL to complete the cross-modal binding tasks (EB1 and EB2), which is consistent with theory. However, the difference between the correlations between the PL and EB1 and EB2 is problematic. The PL and EB1 shared a verbal component. In light

of this, it would be reasonable to expect that the correlation between the PL and EB1 would be stronger than the correlation between the PL and EB2. This was not observed. The correlation between EB1 and EB2 (r=.23, p=.044) was also weaker than would be expected between two tasks purported to reflect the functioning of a single cognitive mechanism.

The results both support and contradict the episodic buffer hypothesis. The participants in this study did not appear to rely on the PL and the VS to complete either cross-modal binding task, however closer examination of the intercorrelation matrix in table 5 reveals somewhat problematic relationships between the working memory measures used in this study. In general, these results are difficult to interpret.

2. What is the relationship between the PL, VS, CE, and EB1 and EB2 components of working memory and graphophonic word-reading ability (WRDEC) in a sample of first and second grade readers with a wide range of reading ability?

Table 5 shows that EB1 (r=.37, p=.003) and EB2 (r=.28, p=.019) were moderately correlated with WRDEC. The higher correlation between EB1 and WRDEC is not surprising as the EB1 task more closely resembles the act of reading, than does the EB2 task. Both correlations are significant supporting the general hypothesis that cross-modal binding ability is related to decoding ability in the first and second grades.

When the z-score transformations of age, CE, PL, VS and EB1 were simultaneously regressed onto the z-score transformation of WRDEC the coefficient of regression (R) is equal to .52 with $R^2 = .27$. The ANOVA for the regression was found to be significant (p=.003). Standardized coefficients (Beta: β) for CE, PL, VS and EB1 are:

.05, .11, .29, and .31, respectively. The βs associated with the PL and EB were also significant (p=.029 and p=.016 respectively), however the βs associated with the CE (p=.699) and VS (p=.406) were not.

When the z-score transformations of age, CE, PL, VS and EB2 were simultaneously regressed onto the z-score transformation of WRDEC the coefficient of regression (R) for the equation (r=.46 with $R^2 = .21$) is slightly smaller than when EB1 was included in the working memory model. However, the amount of shared variance between the model of working memory with EB2 included is also considerable and significant. The ANOVA for the regression was found to be slightly less significant (p=.019) than in the previous equation in this analysis. Standardized coefficients (Beta: β) for CE, PL, VS and EB2 (.05, .11, .29, and .31, respectively) were similar to the equation including the EB1. In similar fashion to the regression using EB1, the β's associated with the EB2 (p=.16) and PL (p=.040) were significant. The βs associated the CE (p=.699) and VS (p=.406) were not significant. These results suggest that when either EB task is included in the working memory model, working memory explains a considerable amount (21-27%) of the variance in decoding ability in this sample.   This suggests that both task are tapping some aspect of cross-modal binding, and that this ability underlies early elementary decoding ability. It is interesting to note that when EB1 was included in the working memory model the regression of working memory onto WRDEC yielded a higher coefficient of regression than when both EB1 and EB2 were formed into a composite.

Research Question 3.What is the relationship between cross-modal binding ability (EB)

and graphophonic word-reading ability in a sample of first and second grade readers

with a wide range of reading ability, when general working memory capacity, and

phonological and visual storage capacity are controlled in the analysis?

Table 6 presents the results of the hierarchical regression of age, CE, VS, PL and EB1 onto WRDEC. The ANOVAs for step 1 (CE) and step 2 (VS) of the regression were not significant. However, the ANOVAs for step 3 (PL, p=.018) and step 4 (EB1, p=.003) of the regression were significant. The EB1 was found to explain an additional 9.1% of the variance in WRDEC.

Table 6. Results of Hierarchical Regression of Working Memory onto WRDEC : N =55

Step	Variables Entered	R	R^2	ΔR^2	Sig.
1	CE	.224	.050	---	.101
2	VS	.299	.090	.040	.139
3	PL	.420	.177	.087	.024*
4	EB1	.518	.268	.091	.016*

Table 7 presents the results of the hierarchical regression of age, CE, VS, PL and EB2 onto WRDEC. Similar to the regression in Table 6, the ANOVAs for step 1 (CE) and step 2 (VS) of the regression were nonsignificant. Surprisingly, step 3 (EB) for the regression was also nonsignificant. However, the ANOVAs for step 3 (PL, p=.024) of the regression were significant. Thus, EB2 was not found to explain any additional variance in WRDEC for this sample.

Table 7. Results of Hierarchical Regression of Working Memory onto WRDEC : n =55

Step	Variables Entered	R	R^2	ΔR^2	Sig.
1	CE	.224	.050	---	.101
2	VS	.299	.090	.040	.139
3	PL	.220	.177	.087	.024*
4	EB2	.455	.207	.030	.175

These results suggest that the EB explains additional variance in decoding ability, over and above the variance explained by the CE, VS, and PL. In other words, the current model of working memory (Baddeley, 2002) has greater exaplanatory power than the previous version of working memory (Baddeley & Hitch, 1974). However, it appears that EB1 was responsible for all of the additional power of the revised working memory model, and that the inclusion of EB2 in the regression lowered the magnitude of the coefficient of regression. These inconsistent results may be explained by age range of the sample and the fact that second graders were included in the sample, but not in equal numbers as were the first graders.

The sample used in this study was comprised of 44 first graders and 11 second graders. Although the mean age of the sample was 7.19 years, one child was 9.17 years of age. This single child may have represented an outlier in the sample. More importantly, the second graders in the sample had received almost a full academic year of additional reading instruction. It is possible that that the second graders in the sample may have employed more sophisticated decoding strategies than the children in first grade. Furthermore, recall that the results of the Smith study (2006) suggest that EB development slows significantly at around seven years of age. It is possible that this

113

study yields different results when the sample is restricted to only children in the first grade. In order to explore this possibility a second set of analyses (similar to the analyses above) were performed on the data from children in the first grade.

Table 8. Descriptive Statistics (with EB1 & EB2; 1st Grade Only): N=44

	Range	Min	Max	Span	Mean	Std. Dev.
Age in years	2.34	6.33	8.67	-	6.97	.51
WRSTD	74	60	134	50-180	107.68	17.10
WRDEC	8	0	8	0-8	5.25	2.15
CE	2	1	3	0-6	2.20	..46
VS	2.70	2.00	4.70	0-24	3.23	.74
PL	3	1	4	0-6	1.55	.66
EB1	2	1	3	0-6	1.87	.72
EB2	4	1	5	0-6	2.41	1.18

Table 8 presents the same data as in Table 4 for the first graders in the sample. These data suggest that the first graders in this study found the EB1 (mean = 1.80) task slightly more difficult than the EB2 task (mean =2.41). The standard deviation for EB2 (SD=1.08) was larger than the standard deviation for EB1 (.73) indicating a greater amount of variability in the sample in terms of performance on the EB2 task than on the EB1 task. As metioned above, the apparent difference in task difficulty between EB1 and EB2 may be due to the fact that the EB1 task requires a verbal response. The pseudowords used in the EB1 task may have been difficult to articulate. The EB2 task only required pointing.

The research questions asked by this study were revisited using the EB1 and EB2 as separate variables. Table 9 presents the intercorrelation matrix used to examine research questions one and two. The statistics reported in Table 9 are the bivariate

correlations between the all the measures used in this study with p-values given in

parentheses. These results are described and discussed below.

Table 9. Intercorrelations Among Working Memory Measures: N=44

	WRDEC	CE	VS	PL	EB1
CE	.06 (339)	---	---	---	---
VS	.09 (273)	.02 (.443)	---	---	---
PL	.29* (.027)	.16 (.151)	.20 (.102)	---	---
EB1	.37** (.007)	.13 (.207)	-.04 (.409)	.19 (112)	---
EB2	.20* (.093)	247 (.053)	-.14 (.191)	.14 (.191)	.25* (.048)

* significant at or beyond the p<.05 level, one tailed.
**significant at or beyond the p<.01 level, one tailed

Research Question 1. What is the relationship between cross-modal binding ability (EB1 and EB2) and the other components of working memory in a sample of first and second graders?

Table 9 shows that the weak correlation between the CE and EB1 was

nonsignificant (p=.207). The moderate correlation between the CE and EB2 (r=.25),

however, approached significance (p=.053). The magnitude of these correlations are

more aligned with the range of correlations reported by Pickering and Gathercole (2001)

for the components of the working memory model. However, the small sample size

likely prevented the detection of a significant relationship between the EB1, the EB2 and

the CE.   Similarly, in the sample of first graders EB1 appears to be the more difficult

task.

The correlation between the CE and the PL (r=.16, p=.151) is similar to the

correlation (r=.15, p<.05) reported by Pickering and Gathercole (2001), however this

correlation in the first grade sample was far from significant. The correlation between

the CE and the VS was weak and non significant (r=.02, p=.443). This result is not close

to the correlations (r=.24, p<.05) reported by Pickering and Gathercole (2001). The

correlation between EB1 and EB2, however, was slightly stronger (r=.25, p=.048) in the

restricted sample (only first graders) than in the total sample (r=.23, p=.044).

The weak, negative and nonsignificant correlations between the VS and EB1

(r=-.04, p=.409) and between the VS and EB2 (r=-.14, p=.187) again suggest that the

participants in this study were not depending on the VS to complete either cross-modal

binding task. This result is consistent with the results in Chapter IV. The correlation

between the PL and EB1 (r=.19, p=.112) and between the PL and EB2 (r=.135, p=.191)

were in the range that might be expected from these components, but these relationships

were not found to be significant. However this also suggests that the participants in this

study were not using the PL to complete the EB1 and Eb2 tasks.

These results suggest two possible explanations. The results may support the

episodic buffer hypothesis by showing that the EB operates with considerable

independence from the PL and VS. However, although stronger on average than the

relationship between EB1 and EB2 and the PL and the VS, the weak and nonsignificant

relationship between Eb1 and EB2 and the CE is unexpected as cross-modal binding in

working memory is thought to be attentionally demanding (Baddeley, 2002; in press).

These results are difficult to interpret. However, there is very little research in the

literature concerning the episodic buffer, with which to guide the interpretation of these

data.

2. What is the relationship between the PL, VS, CE, and EB1 and EB2 components of working memory and graphophonic word-reading ability (WRDEC) in a sample of first grade readers with a wide range of reading ability?

Table 9 shows that EB1 (r=.37, p=.007) was moderately correlated with WRDEC, but that the correlation between EB2 and WRDEC (r=.20, p=.093) was weak and nonsignificant. The higher correlation between EB1 and WRDEC is again not surprising, as the EB1 task more closely resembles the act of reading, than does the EB2 task.

When the z-score transformations of age, CE, PL, VS and EB1 were simultaneously regressed onto the z-score transformation of WRDEC in a sample of first graders, the coefficient of regression (R) was equal to .44 with R^2 = .19. The ANOVA for the regression approached significance (p=.073). Standardized coefficients (Beta: β) for CE, PL, VS and EB1 were: -.01, .06, .22, and .33, respectively. Only the β associated with EB1 was fount to be significant (p=.029).

When the z-score transformations of age, CE, PL, VS and EB2 were simultaneously regressed onto the z-score transformation of WRDEC for a sample of first graders, the coefficient of regression (R) for the equation (r=.34 with R^2 = .12) is considerably smaller than when EB1 was included in the working memory model. However, the amount of shared variance between the model of working memory with EB2 included is also considerable and approached significance. The ANOVA for the regression was found to be nonsignificant (p=.286). Standardized coefficients (Beta: β) for CE, PL, VS and EB2 were found to be -.02, .44, 1.64, and 1.16 (respectively). In this regression none of the βs were found to be significant. It appears, through this and the

previous regression analyses, that the task presented by EB1 is tapping a cognitive

mechanism which underlies decoding ability in children in the first and second grades.

Research Question 3.What is the relationship between cross-modal binding ability (EB)

and graphophonic word-reading ability in a sample of first grade readers with a wide

range of reading ability, when general working memory capacity, and phonological and

visual storage capacity are controlled in the analysis?

Table 10 presents the results of the hierarchical regression of age, CE, VS, PL and

EB1 onto WRDEC for the restricted sample. The ANOVAs for step 1 (CE) and step 2

(VS) of the regression were not significant. However, the ANOVA for step 3 (PL,

p=.078) approached significance and the ANOVA for step 4 (EB1, p=.029) was

significant beyond the .05 level. The EB1 was found to explain an additional .19% of

the variance in WRDEC.

Table 10. Results of Hierarchical Regression of Working Memory onto WRDEC : N =44

Step	Variables Entered	R	R^2	ΔR^2	Sig.
1	CE	.064	.004	---	.679
2	VS	.112	.013	.008	.556
3	PL	.295	.087	.075	.078
4	EB1	.439	.193	.106	.029*

Table 11 presents the results of the hierarchical regression of age, CE, VS, PL and

EB2 onto WRDEC. Similar to the regression in Table 10, the ANOVAs for step 1 (CE),

step 2 (VS) and step 4 (EB) of the regression were nonsignificant. The ANOVA for step

118

3 (PL, p=.078) approached significance, however. Similar to the previous analyses with the full sample, EB2 was not found to explain any additional variance in WRDEC for this sample.

Table 11. Results of Hierarchical Regression of Working Memory onto WRDEC : N=44

Step	Variables Entered	R	R^2	ΔR^2	Sig.
1	CE	.064	.004	---	.679
2	VS	.112	.013	.008	.556
3	PL	.295	.087	.075	.078
4	EB2	.343	.118	.031	.252

The results of these ancillary analyses are inconclusive. Although some significant relationships were identified, the small sample size made some effects difficult to detect. However, it does appear that the EB1 task (and the EB2 to a lesser extent) reflects some independent mechanism that supports decoding ability in the first and second grade. Further research is necessary to fully understand how the episodic buffer interacts with the working memory system.

B. Instrumentation

1. Word list from the WRAT-4 word-identification subtest (green form):

A, B, O, S, E, R, T, H, U, P, I, V, Z, J, Q
See, Red, Milk, Was
Then, Jar, Letter, City
Between, Cliff, Listen, Wrap
Plot, Grunt, Sour, Huge

2. Graphophonically Decodable Words Taken from the WRAT-4 Wordlist

Milk, Was, Jar, Cliff
Wrap, Plot, Grunt, Humidity

3. Sample Stimulus list from the pseudoword repetition subtest of the Working Memory Test Battery for Children:

lotch
meck, targ,
chot, paj, dal
loob, kell, tam, dorj

4. Sample digit set for the backward digit recall subtest of the Working Memory Test Battery for Children:

2, 3
5, 4
3, 4, 5
2, 7, 1, 4

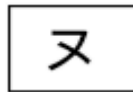5.Sample matrices from an adapted version of the Visual Patterns Test (taken from Swanson & Sasche-Lee, 2001).
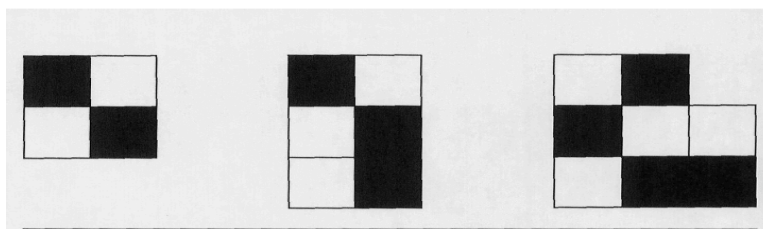
6. Sample of stimulus items from the working memory cross-modal binding task of the
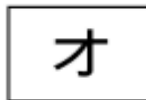   PAIRS task set:

Cross-modal tasks

Stimulus items: (For both cross-modal tasks, the child was presented with nonword-image
pairs)

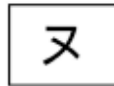Pair 1:

ㄋ

tʃudof

Pair 2:

才

vaɪvik

Cross-modal task with verbal recall:

Test phase: (Then the child was presented with the test item and asked which word went with the test image.)

Test image

ヌ

Cross-modal task with visual recognition:

Test phase: (The child was shown the response array and asked which image went with the test word. The experimenter pointed to each item in the array while asking about the paired items.)

Test word
vaɪvik

Response array

| ト | ヌ |
| サ | オ |

C. Example of Hierarchical Regression

For puposes of explanation, Table 12 presents an hypothetical example of the hierarchical regression technique as it may appear in the literature. The goal of this particular analysis is not to determine how CE, PL, and VS are related to word-reading ability together, but whether or not the inclusion of VS as a predictor causes R^2 to increase to a significant degree. If this is the case, this would suggest that VS shares unique variance with the criterion (word-reading ability -WR).

Table 12. Example Hierarchical Regression

Order of Entry	Predictor Variables	R^2	ΔR^2	Sig.
1	CE	.32	--	.005
2	PL	.44	.12	.01
3	VS	.45	.01	.25

Table 12 depicts the change in the coefficient of regression after each predictor (measures of working memory) are regressed hierarchically onto word-reading ability. The final regression is written as WR = CE + PL + VS, however the point of interest in this analysis lies not in the final regression equation but in the change in the regression coefficient (ΔR^2) after VS is entered into the equation. In Table 2, the predictor CE, is entered first. The resulting R thus represents the simple bivariate correlation between WR and CE, and R^2 for this step represents the variance shared between these two variables. At each step in the proceeding regression, an F-test is conducted to test the significance of the resulting correlation coefficient. The ΔR^2 is not applicable at this step. The second predictor variable (PL) is entered into the regression equation at step 2.

At the second step, the coefficient of regression (R) and its square (R^2) naturally increase,

reflecting the added influence of the second predictor (if the second predictor is

completely unrelated to the criterion R and R^2 would remain the same). Therefore, the

change in R (Δ R) represents the unique influence of the second predictor. In other

words, at step 2 in the regression, Δ R represents the bivarivate correlation between the

criterion (WR) and the second predictor (PL), after controlling for the first predictor

(CE). At step 2, Δ R^2 represents the unique variance shared between the second predictor

and the criterion. Finally the third predictor (VS) is entered at step 3. Although Δ R^2 is

greater than zero, the result is not siginificant. Thus, VS does not appear to share

variance with WR, outside of any variance VS may share with CE and PL.

D. IRBPHS Approved Consent Materials

PARENT LETTER (English)

Eduardo Sanchez, Graduate Student
University of San Francisco
February, 2007

      This letter is to introduce myself and inform you of a proposed research project, which will include your child's elementary school. Your principal, Mr. or Mrs. _____, has agreed to participate in this study, and I would like your permission for your child to be included in this study.

      I am an experienced teacher. I have taught children at various grade levels who present a variety of academic abilities, and I am currently working on my doctorate degree in education at the University of San Francisco. I am interested in finding ways to support children who are learning to read in the first and second grades. In particular, I am interested in how memory helps children learn to read words.

      Reading is a critical skill in modern society, and it is especially important that children learn to read in the early elementary grades, because of the increasing academic challenges of the later grades. Therefore, it is very important to learn about ways to academically support children who are learning to read in the first and second grades. I have developed a research study that will examine how memory is related to reading ability.

      In this study children will be given a series of memory and reading tests that will occur in a single session lasting approximately 35 minutes. These sessions will take place after school during a story-reading activity. The story-reading activity will last approximately 90 minutes and will take place at your child's elementary school.

      The memory tests will simply present the child with either spoken or visual material, which he or she will then be asked to repeat or identify. The reading tests will consist of a typical list of isolated words, which the child is asked to read out loud. The story-reading activity will be led by a graduate student from California State University at Fullerton, School of Education and will use a book selected by the reading specialist at your school. The reading and memory tests will be administered by myself and two graduate students from California State University at Fullerton, School of Education.

      The names of children will be immediately changed to numbers on all papers, and all materials will be kept in a locked cabinet with the primary researcher retaining the only key. All information concerning individuals, and the name of the school and district will be kept strictly confidential. I will send you a summary of the results when the study is completed. This study will not interfere with nor disrupt your child's regular school instruction in any way.

      I hope you will allow your child to participate. Your cooperation will be greatly appreciated. If you agree, please sign the enclosed form and return it via regular mail using the pre addressed envelop enclosed. If you have any further questions, please feel free to call me at 714-278-8269, or email me at esanchez@fullerton.edu.

Sincerely, Eduardo Sanchez

CARTA PARA LOS PADRES (Español)

Eduardo Sánchez
Estudiante Graduado
Universidad de San Francisco
Febrero, 2007

Esta carta es para presentarme a usted, y a la vez informarle de un estudio de investigación que incluye la escuela de su niño (a). El director (a), _____ esta de acuerdo en participar en este proyecto, y yo quisiera obtener su permiso para incluir a su niño (a) en este estudio.

Yo soy un maestro con experiencia. He enseñado a niños (as) de diferentes grados escolares y que presentan varias habilidades académicas. Actualmente estoy completando mi doctorado en educación en la Universidad de San Francisco. Yo estoy muy interesado en el descubrimiento de métodos que puedan ayudar a niños (as) de primer y segundo grado que estén aprendiendo a leer.   Muy en especial, yo estoy interesado en demostrar como la memoria ayuda a los niños (as) a aprender a leer palabras.

La lectura es una habilidad crítica en la sociedad moderna, y es especialmente importante que los niños (as) aprendan a leer en los primeros años de la escuela elementaría debido a los desafíos académicos que se presentan en los últimos grados de la escuela elementaría. Por lo tanto, es extremadamente importante aprender métodos que le puedan dar apoyo académico a los niños (as) que estén aprendiendo a leer en el primero y segundo grado escolar. Yo he desarrollado un estudio de investigación que examinara como la memoria se relaciona con la capacidad de la lectura.

En este estudio, se le dará a los niños (as) una serie de pruebas de memoria y de lectura, estos pruebas ocurrirán en una sola sesión de aproximadamente 35 minutos. Estas sesiones se darán al fin del día escolar durante una actividad de lectura. Cada actividad de lectura durará aproximadamente 90 minutos, y se efectuará en la escuela de su niño (a).

Las pruebas de memoria simplemente se le presentaran al niño (a) con material verbal y visual, que entonces pedirá que el niño lo repita o los identifique. La prueba de lectura consistirá en una lista de palabras y se le pedirá al niño (a) que los lea en voz alta. La actividad de lectura será conducida por un estudiante graduado de la Escuela de Educación de la Universidad de California en Fullerton. El estudiante graduado utilizará un libro seleccionado por un especialista de lectura de la escuela de su niño (a). Las pruebas de memoria y lectura serán administradas por mi mismo y por dos estudiantes graduados de la Escuela de Educación de la Universidad de California en Fullerton.

Los nombres de los niños que participe en el estudio serán cambiados inmediatamente por números de identificación, en todos los documentos. Estos documentos son confidenciales y serán guardados muy cuidadosamente en un gabinete con llave, y yo tendré la única llave siempre conmigo. Toda información perteneciente a los participantes, el nombre de la escuela y distrito serán terminantemente mantenidos en forma confidencial. Cuando este estudio este terminado, yo les enviaré un resumen de los resultados. Este proyecto no interferirá o interrumpirá la instrucción regular de su niño de ninguna manera.

Espero que usted permita que su niño(a) participe. Su cooperación será apreciada grandemente. Si esta de acuerdo, por favor firme los documentos incluidos y los envía por correo usando el sobre con estampilla de correo que esta incluido con los documentos. Si usted tiene alguna pregunta, me puede llamar al siguiente numero de teléfono: 714-278-8269, o enviándome un correo electrónico a esanchez@fullerton.edu.

Sinceramente, Eduardo Sanchez

PARENT CONSENT FORM (English)

Title of the Study: Working Memory Cross-Modal Binding and Decoding Ability
             in First and Second Grade Children

Researcher's Name: **Error! Contact not defined.**, doctoral student, University of San
Francisco

       I give my consent for my child to participate in this study of memory and reading
ability. I understand that my child will be given several tests of short-term memory and
one test of word-reading ability.

       I also understand that my child's name will never be used on any reports or
records. Each child's name will be immediately changed to a number on any written
work or data sheet. Neither the principal nor any teacher will be given information about
any individual child's performance. Complete confidentiality will be maintained. All
parents will receive a summary of the results of the study.

       I understand that the purpose of this study is to gain more understanding of the
ways to support children who are learning to read in the first and second grades.

Date _____

Parent/Guardian Signature _____

Signature of Researcher _____

PERMISO DE LOS PADRES (Español)

Titulo del Estudio: Atascamiento Cruz-Modal de la Memoria y la Capacidad
de la Lectura En Niños (as) en el Primero y Segundo
Grado Escolar

Nombre del Investigador: Eduardo Sánchez, estudiante doctoral, Universidad de San
Francisco

Doy mi consentimiento para que mi niño (a) participe en este estudio de investigación relacionado con la memoria y la capacidad de la lectura. Entiendo que a mi niño (a) de le darán varias pruebas de memoria y una prueba de la habilidad de leer palabras.

También entiendo que el nombre de mi niño (a) nunca será utilizado en ningún informe o archivo. El nombre de cada niño(a) será cambiado inmediatamente a un número de identificación en cualquier trabajo escrito o hoja de datos. Ni se le dará al director (a), ni a ningún profesor, la información sobre el funcionamiento individual de cada niño (a) que participe en este proyecto. Toda información será mantenida en una forma totalmente confidencial. Todos los padres de los niños (as) participantes recibirán un resumen de los resultados del estudio.

Entiendo que el propósito de este estudio es para obtener un mejor entendimiento de métodos que puedan ayudar a los niños (as) de primero y segundo grado escolar que estén prendiendo a leer.

Fecha _____

_____
Escriba su nombre en letra de molde

_____
Firma de los padres o guardianes legales del niño (a):

_____
Firma del Investigador

CONSENT TO BE A RESEARCH SUBJECT (English)

A. Purpose of the Study

Mr. Eduardo Sanchez from the University of San Francisco is doing a study of the relationship between memory and reading ability in the first and second grades, in which my child is being asked to participate.

B. Procedures

If I agree to allow my child to be in the study, the following will occur:

1. My child will be given a series of memory tests.
2. My child will be given one test of reading

These tests will be administered in one testing session lasting approximately 35 minutes. The testing session will occur during an after school story-reading activity, and will take place at my child's school site.

C. Risks and Discomforts

1. This study will ask children to recall visual and verbal information, or to read a list of words, both of which are common occurrences in everyday life, so no unusual discomfort should be involved in these tasks.
2. The testing sessions will take approximately 35 minutes, which may be a long time for some children to remain attentive. This may be uncomfortable for some children. However children will be given breaks at any sign of discomfort or fatigue, as noted by the researcher.
3. Confidentiality: All study records will be kept as confidential as possible. My child's name will be changed to a number on all data sheets. No individual names will be used in any reports or publications about this study.

D. Benefits

My child may benefit from the experience of participating in a research study for a large university. In addition, my child may benefit from participating in the story-reading activity. No other direct benefits will be made to me, or my child.

The study will benefit teachers and students in general by contributing to the understanding of reading in the early elementary years.

E. Alternatives

I am free to choose not to let my child participate in this study, with no negative effect to my child or me.

F. Costs

There is no cost for participation in this study, except for the time children will participate.

G. Reimbursement

There is no reimbursement for participating in this study.

H. Questions

If I have any questions about this study, I may call Eduardo Sanchez 714-278-8269, or email him at esanchez@fullerton.edu.

If I have any questions or comments about participation in this study, I should first talk to the researcher (Eduardo Sanchez). If for some reason, I do not wish to do this, I may contact IRBPHS, which is concerned with protection of volunteers in research projects. I may reach the IRBPHS office between 8:00 AM and 5:00 PM, Monday to Friday, by calling (415) 666-2416, or by writing to the IRBPHS, Psychology Department, University of San Francisco, 2130 Fulton Street, San Francisco, CA, 94117-1080.

I. Consent

I have been given a copy of this consent form to keep.

PARTICIPATION IN RESEARCH IS VOLUNTARY. I am free to refuse permission for my child to be in this study, or to withdraw at any point.

_____
Date

_____
Parent/Guardian Signature

University of San Francisco

CONSENTIMIENTO PARA PARTICIPAR EN UN ESTUDIO DE

INVESTIGACION

A. Propósito del Estudio

El Señor Eduardo Sánchez de la Universidad de San Francisco esta haciendo un estudio sobre la relación entre la memoria y la capacidad de la lectura en el primero y segundo grado escolar, en el cuál se pide la participación de mi niño (a).

B. Procedimientos

Si yo estoy de acuerdo con permitir que me hijo (a) participe en este estudio, se hará lo siguiente:

1. Darán a mi niño (a) una serie de pruebas de la memoria.
2. Darán a mi niño (a) una prueba de la lectura.

Estas pruebas serán hechas en una sesión que durará aproximadamente 35 minutos. La sesión ocurrirá durante una actividad de lectura después del día escolar y se harán en la escuela de mi niño (a).

C. Riesgos y Inconvenientes:

1. Este estudio requiere que los niños (as) recuerden información verbal y visual, o que lean una lista de palabras, que son muy comunes en nuestra vida diaria. Así, que ningún inconveniente fuera de lo común esta relacionado con este procedimiento.
2. Las sesiones de las pruebas tomarán aproximadamente 35 minutos, lo cual puede ser para algunos niños un plazo de tiempo muy largo para permanecer atentos. Esto puede ser incómodo para algunos niños (as). Sin embargo, se les dará a los niños (as)un descanso tan pronto como el investigador observe cualquier signo de incomodidad o fatiga.
3. Confidencialidad: Todos los expedientes del estudio serán guardados de una manera muy confidencial. El nombre de mi niño (a) será cambiado a un número en todas las hojas de datos. En ninguno de los reportes o publicaciones acerca de este estudio se utilizará ninguno de los nombres de los participantes

D. Ventajas

Quizás mi niño (a) se beneficie de la experiencia de participar en un estudio de investigación hecho por una universidad grande. Además, puede ser que mi niño

(a) se beneficie por participar en la actividad de lectura. No habrá ningún otro beneficio para mí o para mi niño (a).

El estudio beneficiará a profesores y a estudiantes en general, porque contribuirá al entendimiento de la lectura en los primeros años de la escuela elementaría.

E. Alternativas

Soy libre de elegir que mi niño (a) no participe en este estudio, sin ningún efecto negativo para mí o a mi niño (a).

F. Gastos

No hay ningún gasto relacionado con la participación de mi niño (a) en este estudio, a la excepción del tiempo empleado para que los niños(as) participen.

G. Reembolso

No hay reembolso por participar en este estudio.

H. Preguntas

Si tuviera cualquier pregunta sobre este estudio, yo puedo llamar a Eduardo Sánchez al número de teléfono 714-278-8269, o puedo enviarle un correo electrónico a esanchez@fullerton.edu.

Si yo tengo preguntas o comentarios sobre la participación en este estudio, yo debo primero hablar con el investigador (Eduardo Sánchez). Si por alguna razón, no deseo hacer esto, me puedo poner en contacto con la oficina de IRBPHS, la cual se encarga de la protección de voluntarios en estudios de investigación. Puedo llamar a la oficina del IRBPHS entre las horas de 8:00 AM hasta 5:00 PM de lunes a viernes (415-666-3416), o por correo a: IRBPHS, Psychology Department, University of San Francisco, 2130 Fulton Street, San Francisco, CA, 94117-1080.

I. Consentimiento

He recibido una copia de esta forma del consentimiento para retener en mis archivos.

LA PARTICIPACION EN ESTUDIOS DE INVESTIGACION ES COMPLETAMENTE VOLUNTARIA.
Tengo libertad de negarle permiso a mi niño (a) o de cancelar su participación este estudio en cualquier momento.

_____   _____
Fecha   Firma del Padre o Guardián Legal

                                           _____
                                           Firma del Investigador