EXAMINING THE NATURE OF THE ASSOCIATION BETWEEN PHONOLOGICAL MEMORY AND EARLY READING DEVELOPMENT

BY

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ABSTRACT

Considerable research has been conducted examining the contribution of early phonological memory (PM) skills on later reading ability, whereas little has investigated whether early reading performance influences later PM, or whether there is a bi-directional relationship between these variables. A secondary dataset was used, containing a sample of 54 children tested across three time points during the fall of first grade (Time 1), spring of first grade (Time 2), and spring of second grade (Time 3), to assess the nature of the relationship between reading performance and PM. (Two simple PM measures were used in this study: pseudoword repetition and word span.)

The main purpose of this study was to determine whether there is a relationship between PM and reading performance, and if so, in which direction. Hierarchical regression analyses indicated that early PM does not predict later reading, nor does early reading account for later PM development. However, correlational analyses showed a significant relationship between early reading and later PM, but did not point to a relationship between early PM and later reading achievement. Growth curve modeling analyses were used to test the second hypothesis, that reading performance would influence growth in PM development. Results from these analyses did not provide evidence in support of such a relationship. Lastly, a series of hierarchical regression analyses were conducted to explore whether shared variance exists between the two PM measures included in this study, and whether one is a better early predictor of later reading acquisition. These findings demonstrated shared variance between the PM measures, but did not reveal that either measure predicted reading.

The results from this study are discussed regarding the importance of the PM measure used and the necessary point in time, or in reading acquisition, when participants should be tested. In addition, the basis of the lack of a relationship between early PM and later reading is discussed, along with the findings that early reading corresponds with later PM development. Limitations and proposed future directions for research also are presented.

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DEDICATION

This dissertation is dedicated to the students with whom I will have the opportunity to assist as a school psychologist. It is my hope that all children may find an avenue for educational success through the guidance and support of student and adult mentors.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLE PAGE

CHAPTER 1

INTRODUCTION

For nearly four decades, the association between literacy and phonological memory (PM; i.e., the temporary storage of phonologically coded information in working memory) primarily has been investigated in a unidirectional order. Specifically, a central question that has stirred considerable examination is: “Does early performance in PM predict later reading acquisition?” Researchers have conducted longitudinal and experimental projects in the attempt to answer this question, but have reported inconsistent findings. Precisely, a number of studies provide evidence in support of a positive relationship between early PM and later reading performance (e.g., Alloway & Alloway, 2010; Baddeley & Gathercole, 1992; Baddeley, Gathercole, & Papagno, 1998; Brady, Poggie, & Rapala, 1989; Gathercole & Baddeley, 1993b; Gathercole, Alloway, Willis, & Adams, 2006; Perfetti, 1985; Seigneuric & Ehrlich, 2005), while other work does not display such a relationship (e.g., Sprugevica & Hoien, 2003; see Savage, Lavers, & Pillay, 2007 for review; Wagner, Torgesen, & Rashotte, 1994). The conflicting results may be explained by variation of several factors between studies, namely the use of a variety of PM measures, both simple and complex measures, exercised to represent the same PM construct, as well as participants of varying ages across studies.

This relationship in reverse, that is, the role of early literacy development on later PM skills, has received less attention. Recently, Nation and Hulme (2011) were among the first researchers to examine this relationship. Their results indicated that reading ability at age six accounted for significant variance in PM (measured by pseudoword repetition) at age seven. Yet, when they assessed the relationship conducted in reverse (i.e., the role of early PM on later reading performance), they found non-significant results, unlike the findings from other research (e.g., Gathercole & Baddeley, 1993b). These main findings demonstrate the continued variability in results regarding early PMs effect on reading success, and introduce the potential influence of reading on later PM development. This evidence is suggestive that it would be worthwhile to investigate further the direction of the relationship between reading performance and PM during the period of early reading acquisition.

Thus, the main aim of this project was to examine the relationship between reading performance and PM over time to determine whether a correspondence between these domains is evident and, if so, to ascertain the direction of influence. A second goal was to examine the growth of PM and assess whether reading performance influences this growth. These aims were analyzed using a secondary data set with children tested three times from the fall of first grade to the spring of second grade. In addition, because there are variations in phonological memory measures that may contribute to differences in outcomes, this project explored the relationship between the two PM measures and whether one predicted reading performance better than the other.

Justification for and Significance of the Study

Association between Reading Achievement and Phonological Memory

The relationship between orthographic abilities and phonological processes, with a focus on PM, has been examined for quite some time. The link with phonological processes was established initially by evidence that reading performance was positively correlated with verbal memory for a series of words, but not with nonverbal memory as measured by a nonverbal spatial task (Mann & Liberman, 1984). These early findings indicate that reading ability is related specifically to phonological processes in memory, not to memory abilities in general. Other evidence also has shown that phonological processes, specifically PM, are early predictors of reading development.

Phonological Memory as a Predictor of Reading Development, a Unidirectional View

As mentioned earlier, the examination of the role of PM as a predictor of later reading performance has been studied extensively (e.g., Al Otaiba & Fuchs, 2002; Gathercole & Baddeley, 1993b; Gathercole, 1995; Puolakanaho et al., 2008). Longitudinal studies have illustrated that early pre-reading PM skills predict later reading progress. For example, Gathercole and Baddeley's (1993b) study examined the effect of PM ability for four-year old pre-readers in relation to their later reading performance at the age of eight. Fixed-order multiple regression analyses showed that pre-reading pseudoword repetition performance accounted for significant variance in later reading performance, even after controlling for vocabulary knowledge when the participants were four-years old.

Findings from Bull, Espy, and Wiebe's (2008) study indicated that early PM ability, measured by digit span, tested among 88 preschool students, predicted reading performance three years later when the students were in their third year of primary school. Growth curve modeling results demonstrated that for every increase in verbal span length of one digit, there was about a three-point inflation in the reading score at the final wave of testing. Evidence from this study also showed a positive relationship between reading performance and PM at each wave reading was evaluated, beginning when the children were age 5 until age 7. Recently, Elwér (2014) found that PM, measured by the verbal memory subtasks within the WRAML, at pre-kindergarten was a significant positive predictor of reading comprehension in grades 2, 4, 8, and 9. Specifically, results from logistic regression analyses indicated that weak early PM skills were a predictor of later reading comprehension impairment (Elwér, 2014). The author reported that weak PM skills adversely impact a child's ability to comprehend text, especially for comprehension questions that require an inferential and a semantic understanding.

In addition, early reading intervention studies have examined early predictors of reading success, with PM being one variable of particular interest. Prediction studies have found that early phonological skills when children are just beginning to learn to read, such as phonological awareness and PM, predict later reading group differences (e.g., Al Otaiba & Fuchs, 2002; Badian, 1998; Piquard-Kipffer & Sprenger-Charolles, 2013; Preßler et al., 2014; Puolakanaho et al., 2008). Although these studies confirm that a relationship between reading performance and PM exists, and that PM may be a contributor to later reading success, as stated earlier other findings show little to no relationship between these variables.

Lack of a Relationship between Reading and Phonological Memory

Although a sizable body of research points in the direction of a positive relationship between early PM development and later reading acquisition, other studies find a lack of a relationship. There are several prediction studies that have not shown that PM predicts later reading performance. In 2003, Sprugevica and Hoien reported the power of early phonological skills (measured by PM, phonological awareness, and rapid naming) for predicting later reading performance with a group of approximately 55 kindergarten students who were tested at four different time points up to the middle of second grade. Regression analyses revealed that phonological awareness was the only predictor of reading performance at two time points during first grade and at the middle of second grade. Moreover, growth analyses corroborated the findings, with phonological awareness being the only phonological factor that accounted for significant variance on the slope of word reading development.

Similarly, Soltani and Roslan (2013) found that PM, measured by pseudoword repetition, did not contribute additional variance in reading performance beyond that of phonological awareness. These authors concluded that although PM does not explain the variance in reading performance alone, it does contribute to word decoding ability through the domain of phonological awareness. Another study, conducted by Wagner et al. (1994), documented non-significant results between early PM skills, measured by a composite score of digit span and listening recall, and later reading performance. In addition, structural equation modeling showed that kindergarten PM abilities did not predict first-grade reading, nor did first-grade PM predict second-grade reading performance (Wagner et al., 1994).

A study by Gathercole et al. (2006) analyzed the relationship between a composite of PM skills (i.e., digit span, word span, and word list matching) and reading performance. Additional variables were assessed, including working memory (i.e., backward digit span, counting span, and listening recall) and phonological awareness. With a sample of 46, nine-year old, poor readers, a significant relationship was not found between PM and reading achievement. Working memory, including verbal and nonverbal memory tasks, however, explained significant variance in reading performance (Gathercole et al., 2006). The authors suggested that the relationship between PM, measured by verbal short-term memory tasks, and reading performance is generally through the role of phonological awareness. This relationship, the authors discussed, is more likely to be demonstrated during pre- or early reading acquisition (Gathercole et al., 2006).

Thus, research regarding PM as a predictor of reading performance has had variable outcomes. Despite the efforts to investigate whether a unidirectional relationship exists, several factors have been used inconsistently (i.e., PM measure, sample size, and age of the participants), complicating an interpretation of the relationship. It also is unclear whether these variables are associated in the reverse direction, that is, whether early reading performance and is linked with later PM. Because little work has focused on the influence of reading development on PM, further research is warranted to understand the nature of a possible correspondence between reading and PM relate.

The Role of Reading on Phonological Memory

Over the course of several years, less research has analyzed the development of PM as a result of educational experiences and reading acquisition. One of the first to question the nature of this relationship was Wagner (1974) who discussed that memory does not just increase as a result of maturation, as once believed, but is enhanced by educational experiences, such as schooling and learning. Specifically, PM has been found to increase over the course of learning to read, especially between the ages of four to eight years old, from pre-reading to reading (Gathercole, Willis, Emslie, & Baddeley, 1991). Narrowing in on literacy development, attainment of phonological skills and learning to read has been suggested to boost both visual memory (e.g., a child is shown a visual span of digits and is required to immediately recite the string of digits once the visual item is removed) and auditory memory (e.g., digit, word, and sentence spans) (Ellis, 1990). Other researchers have proposed that reading experience facilitates the processes of speech perception and production (Morais, Cary, Alegria, & Bertelson, 1979) and in turn strengthens verbal memory (Donald, 1993).

In order to ascertain the role of educational experiences on phonological processes, the abilities of illiterate and ex-illiterate adults have been studied, as mentioned earlier. Drawing on Wagner’s suggestion that memory may improve as a result of educational factors, Morais, Bertelson, Cary, and Alegria (1986) studied the differences between groups of Portuguese illiterate and ex-illiterate adults on performance on an immediate recall task pertaining to a series of pictures. By comparing illiterate adults with others from the same rural background who in adulthood had recently received reading instruction, it was possible to examine whether learning to read affects phonological processes and memory capacity. The researchers found that the group of ex-illiterates recalled more than the illiterate adults on a memory task, and performed better on a phonological awareness measure.

Later, another study was conducted with adult illiterates and literates from similar sociocultural backgrounds to examine performance on memory tasks including pseudoword repetition and word pair association (i.e., a task requiring participants to remember five pairs of semantically similar words and five pairs of phonologically similar words) (Reis & Castro-Caldas, 1997). As expected, results indicated that the adult illiterates were far less accurate in pseudoword repetition than the literate control group. They also had significantly more trouble remembering the phonologically similar word pairs than they did remembering the semantically similar word pairs. Reis and Castro-Caldas concluded that learning to read enhances phonological processes, such as the knowledge of grapheme-phoneme correspondences that help accurate repetition of novel phonological stimuli.

Most recently, Kosmidis, Zafiri, and Politimou (2011) investigated the performance of ex-illiterates compared to illiterates on forward digit-span (i.e., a verbal task) and forward spatial-span (i.e., a visuospatial task that requires a participant to retain an order of block tapping in memory). Similarly, their findings showed that the illiterate participants did more poorly on forward digit-span than did the ex-illiterates; however, no effect of schooling or literacy was indicated on the forward spatial-span measure. Thus, it is plausible that the absence of literacy experience, and concomitantly weaker phonological processing abilities, is a factor in the poorer performance of the illiterate participants on the digit-span task.

Yet, despite this awareness that PM may be influenced by educational experiences, such as exposure to print, it is surprising to find that few articles have been published looking at the role of reading progress on PM. Conti-Ramsden and Durkin (2007) examined literacy skills, measured at age eleven, as a predictor of PM skills (measured by pseudoword repetition) at the age of fourteen with a group of adolescents with specific language impairment. They found that early word reading performance predicted unique variance in pseudoword repetition at fourteen years of age. The authors suggested that PM skills are a consequence of literacy skills. Poor reading abilities, they argued, may cause a decline or pause in PM, affecting performance on a task such as pseudoword repetition.

More recently, Nation and Hulme (2011), discussed previously, reported a one-year longitudinal study beginning with six-year old participants to examine the relationship between reading performance (based on a decoding measure and a fluency measure) and PM (assessed with a pseudoword repetition task); their focus was on the role of reading on PM development, however they analyzed this relationship in reverse, as well. SEM results indicated that age six reading progress predicted growth in PM skills by age seven, beyond oral language skills (such as vocabulary knowledge, a variable that has been found to contribute to the relationship between reading and PM), and in addition to the autoregressor effect of earlier pseudoword repetition, that was the strongest predictor of later PM. Yet, findings did not reveal a significant relationship when these variables were analyzed in reverse—the role of early PM skills on later reading performance. Nation and Hulme concluded that learning to read an alphabetic writing system assists with the development of segmental phonemic representations that in turn increase the functional capacity of PM.

These results are important because they explicitly show that reading development influences the operation of PM beyond the contribution made by vocabulary knowledge, as well as beyond the autoregressive effect of earlier PM skills. Thus, there are conflicting results in the field; research indicating that PM is a predictor of reading, that PM is not related to reading, and that PM is a consequence of reading. The differences in results across studies are likely due to several factors (e.g., age of the participants, orthography, or sample size) including the measure of PM used.

Does the Measure of Phonological Memory Matter?

The examination of the relationship between reading performance and PM has been conducted now for several years. Yet, the results across studies are mixed. Differing results may be due to several factors, like the measure of PM that is selected. When taking a close look at the studies that have assessed the relationship between reading and PM, the measure of PM has varied.

Specifically, researchers have used a variety of complex verbal span tasks, called verbal working memory (WM), which refer to tasks involving both phonological storage and manipulation, and simpler verbal span tasks, called verbal short-term memory (STM), that require temporary phonological storage before immediate recall (Baddeley, 2012). Examples of verbal WM tasks include listening recall (Alloway & Alloway, 2010; Gathercole et al., 2006; Gathercole & Pickering, 2000; Seigneuric & Ehrlich, 2005; Siegel & Ryan, 1989; Swanson & Howell, 2001), backward digit span (Bull et al., 2008; Gathercole et al., 2006), and counting span (Case, Kurland, & Goldberg, 1982; Gathercole et al., 2006). Verbal STM tasks that measure PM are digit span, word span, or letter span (Sprugevica & Hoien, 2003), and pseudoword repetition (Gathercole & Baddeley, 1993b; Nation & Hulme, 2011). Several measures have been designed to target the same interest, assessing the level to which PM ability contributes to reading acquisition. As such, researchers have found inconsistent results.

In general, findings have supported a more consistent positive relationship between reading acquisition and PM, when the PM task is complex, involving both storage and verbal manipulation abilities (e.g., Alloway & Alloway, 2010; Gathercole et al., 2006; Seigneuric & Ehrlich, 2005). Studies that have used simpler PM tasks, involving temporary storage and immediate verbal recall, have reported less consistent results, with some showing a positive relationship between reading performance and PM (e.g., Al Otaiba & Fuchs, 2002; Gathercole & Baddeley, 1993b; Mann & Liberman, 1984) and others indicating little to no association (e.g., Gathercole et al., 2006; Wagner et al., 1994; see Savage et al., 2007 for review).

A meta-analysis on verbal memory measures reports that the relationship between reading and verbal memory *span* tasks (e.g., letter/digit/word span) is moderate at best, and sometimes non-significant (Savage et al., 2007). It is suggested that these measures may tap top-down lexical processes and rely heavily on vocabulary knowledge. Pseudoword repetition, on the other hand, which is an immediate non-word repetition task, is suggested to require phonological processing abilities more than it does top-down processes, and therefore may link more closely with reading performance than a span task. However, many studies have found significant results between reading and PM (e.g., Alloway et al., 2005; Gathercole & Baddeley, 1993b; Man & Liberman, 1984), while others have not found such a relationship (Gathercole et al., 2006, Sprugevica & Hoien, 2003; Wagner et al., 1994). Therefore, it is important to further explore a variety of measures of PM when examining the direction of the relationship between reading and PM in order to investigate which method provides more salient results, if at all.

This Study

The main purpose of this dissertation was to examine the direction of the relationship(s) between reading performance and PM. Specifically, the study focused on whether early PM predicted later reading, whether early reading predicted later PM, whether this relationship was bi-directional, or whether, in fact, an association between the two constructs would not be observed. Gathercole and Baddeley (1993b) reported a causal relationship between early PM with participants who were four-year old pre-readers, and later reading when the participants were eight. More closely related to this project, however, is the work by Nation and Hulme (2011) that documented a significant relationship between early reading and later PM, but no relationship in reverse. Similar to this study, the participants in Nation and Hulme's (2011) study were first tested at the age of six. Based on this research, it was hypothesized that the relationships between reading and PM would be bi-directional, although with a stronger association between early reading performance and later PM.

The second purpose was to examine whether reading performance accounted for PM growth. It was hypothesized that reading performance would predict PM growth (Nation & Hulme, 2011). Lastly, this study explored the use of different PM measures, which included two immediate recall tasks, pseudoword repetition and word span, and compared results of each analysis to see which measure, if any, was a better predictor of reading performance. Because the inclusion of both PM measures allowed for comparison, this study examined the extent to which they shared variance and whether the demands of one corresponded more closely with reading ability.

These goals were tested with a group of young students attending an elementary school in the Northeastern region of the United States. The students were assessed on measures of reading, vocabulary, and PM across three time points: fall of first grade, spring of first grade, and spring of second grade. Secondary data analyses were conducted.

CHAPTER 2

METHODOLOGY

Participants

The dataset contained data from 76 first-grade students during fall 2003, the first testing time (i.e., Time 1). This initial sample of students consisted of 37 girls and 39 boys, with an age range of six to seven years (*M* = 6 years, 3 months, *SD* = 3.3 months). The children were attending the first grade in an elementary school in New England and spoke English as their native language. In spring 2004 (i.e., Time 2), 65 students remained for testing. Within this group, 32 students were male and 33 were female.

Table 1
Demographic Information Regarding Participants who Remained in the Study (n = 54) and those who Dropped Out (n = 22)

	Time 1 Age		Time 2 Age		Time 3 Age		Gender	
Participants	M	SD	M	SD	M	SD	M	F
Remained (n = 54)	6.44	0.34	7.06	0.34	8.05	0.34	28	26
Dropped Out (n = 22)	6.41	0.32	7.02	0.33	8.03	0.32	11	11

At the end of the study, only 54 (28 male and 26 female students) of the original 76 children were still available for testing during the spring of their second grade (i.e., Time 3). Refer to Table 1 for a summary of the demographic information regarding the final sample (n = 54) of participants who were included in the present project compared to those who dropped out (n = 22). A post-hoc power analysis was conducted in G*power 3.15 to determine the power of this study with the provided sample size. The power analysis revealed that a sample size of 54 participants provided a medium effect size of $f^2 = 0.19$, with a post-hoc power of 0.80 and $\alpha = 0.05$. A conservative effect size estimate using a small effect size of $f^2 = 0.02$ yielded a post-hoc power of 0.13 and $\alpha = 0.05$.

A group differences analysis was used to examine whether the students who dropped out of the study differed in any ways from those who remained (see Table 2 in the results section). All participants passed an audiometric hearing screening before taking part in the assessments during each of the three time points.

Informed Consent

Informed consent was obtained from all parents of the students who participated in the study. The students provided their assent to participate before testing at all three time points.

Measures

A broad set of measures was administered in the original study. For the proposed study, analyses used data for a subset of measures. Each student was given three standardized measures of reading, one standardized measure of expressive vocabulary knowledge, and two experimental measures of phonological memory. Raw scores were calculated for each measure and used in the analyses in order to more easily detect change over time. For each measure requiring verbal production, any pronunciation difficulties with specific phonemes by participants were noted and, for individual children, not marked as an error for stimuli with phonemes the child was unable to produce accurately. For example, if a student had trouble accurately pronouncing the phoneme /l/ and mispronounced it as the phoneme /y/, this production difficulty was not marked as an error on test items.

Reading Performance was measured using the Word Identification, Word Attack, and Passage Comprehension subscales of the *Woodcock Reading Mastery Tests, Revised* (*WRMT-R*; Woodcock, 1998). The *WRMT-R* is a comprehensive individual assessment of reading achievement. Every item within each subscale is scored as either a 1 (correct response) or a 0 (incorrect response). A composite score was used in the data analyses to represent reading performance. The reading composite total score ranged from 0 to 219.

The Word Identification subscale is a measure of word recognition and consists of 106 words. This subtest requires participants to read words that become increasingly complex and less frequent in English. Testing is continued until six consecutive words are not read correctly. The total score on this measure ranges from 0 to 106, and is based on the number of correct words read aloud by the participant.

The Word Attack task includes 45 novel pseudowords arranged in order of difficulty. Each participant is asked to read the words aloud until the individual fails to respond to or correctly pronounce six consecutive items. The total score on this measure ranges from 0 to 45 and are based on the number of peudowords accurately read aloud by the child.

The Passage Comprehension subscale from the WRMT-R was used to measure reading comprehension. This subscale requires children to read a maximum of 68 short texts ranging from single sentences to complex paragraphs and respond to each by filling in a blank embedded in the text. Testing is discontinued after the participant fails to correctly respond to six consecutive items. This measure's total score ranges from 0 to 68 and is based on the number of correct sentence comprehension responses.

Vocabulary was measured using the Picture Vocabulary subtest from the *Woodcock-Johnson III Tests of Achievement* (Mather & Woodcock, 2001). Picture Vocabulary measures oral language development and lexical knowledge. To administer this measure, the examiner presents a series of pictures, one at a time, to the participant. The participant is asked to name the picture presented. The items become increasingly less frequent. The total score based on the total number of correct answers, ranges from 0 to 44.

Phonological Memory was measured using two verbal-STM tasks: A pseudoword repetition task and a word span task. The pseudoword repetition task contained 30 items that varied in length from two to six syllables and conformed with English phonology. Each pseudoword was read aloud one at a time; after the non-word was presented the participant repeated what he/she heard. The total score, ranging from 0 to 30 is based on the total number of correctly repeated pseudowords.

The word span task is comprised of six sets of words, with each set containing three strings of words. The length of the word strings progressively increases across sets from two monosyllabic words in the first set to sequences of seven monosyllabic words in the sixth set. Each string is read aloud to the participant at a rate of one item per second. The participant is asked to repeat the words in the order they were presented. This task is discontinued when a child makes an error on all three items in a set. The total score, ranging from 0 to 81, is based on the total number of words repeated correctly.

Performance on both of the memory measures was recorded to facilitate subsequent scoring.

Procedure

This data set was originally collected by school psychology doctoral graduate students under the supervision of Dr. Susan Brady. Testing occurred over three time points beginning in fall 2003 when the sample of students were attending the first grade. Time 1 testing took place during October 2003. Time 2 testing was collected during May 2004 when the students were in the spring of first grade. Testing took place at Time 3 in May 2005 during the students' spring of second grade. Each of the measures of interest for this study, reading, vocabulary, pseudoword repetition, and word span, were collected at each time point.

CHAPTER 3

RESULTS

Analysis Plan

Data were analyzed in multiple ways to address the three aims of this project. First, preliminary analyses were conducted to gain a general understanding of the data from the group of participants who remained in the study (n = 54) and that from the group who dropped out (n = 22). Frequency and descriptive analyses were run for all measures at Time 1, including reading, vocabulary, and the two phonological memory (PM) measures (i.e., pseudoword repetition and word span). Then, a group differences analysis was operated to investigate the differences, if any, between the participants who dropped out of the study (n = 22) and those who remained (n = 54) at Time 1, the time wave that included the full group of participants who later dropped out at Times 2 or 3.

For the remainder of the analyses, only the sample of participants who participated throughout the entire project (n = 54) was examined. Descriptive analyses were performed to examine the change, if any, in mean scores on all measure across the three time points. Preliminary correlation analyses were run for all measures across the three time points (i.e., fall of first grade (Time 1), spring of first grade (Time 2), and spring of second grade (Time 3)). Next, the trajectories of each variable were graphed by the variables' means for the three time points. Following these visual graphs, a series of repeated analyses of variance (R-ANOVAs) were performed to determine whether the participants' performance on the measures significantly increased over time.

Following preliminary analyses, hierarchical regression analyses and multi-level modeling tests were performed to investigate the aims of this study. To address Aim 1, examining the Time 1 predictors of PM, and of reading performance at Time 2 and Time 3, a series of eight hierarchical regression analyses were conducted. The first four regression analyses were used to examine the initial predictors of PM and the latter four to investigate the contributing predictors to reading performance at Times 2 and 3. Next, Aim 2, investigating whether reading performance predicts the growth of PM, was studied using growth curve modeling. Finally, hierarchical regression analyses were operated to explore the shared variance between the PM measures (pseudoword repetition and word span) and investigate the best PM predictor of reading performance; these analyses addressed Aim 3.

Preliminary Analyses (Descriptive, Correlational, and Group Differences Analyses)

Comparing Groups: Analysis of Differences between Participants who Remained in the Study (n = 54) and those who Dropped Out (n = 22)

Descriptive analyses were conducted to explore the mean performances of the participants who remained in the study (n = 54) and those who dropped out (n = 22) on the four dependent measures at Time 1 (refer to Table 2 for descriptive results of the dependent variables at Time 1 for the participants who remained in the study versus those who dropped out).

Table 2
Summary of Descriptive Statistics for Variables at Time 1 for Participants who Remained (n = 54) versus those who Dropped Out of the Study (n = 22)

	Time 1			
	Participants who remained (n = 54)		Participants who dropped out (n = 22)	
Variable	M	SD	M	SD
Vocabulary	19.69	3.00	19.36	3.47
Reading	40.24	23.16	41.91	25.51
Word Span	33.59	8.95	35.91	7.19
Pseudo. Rep.[a]	14.61	5.50	13.18	5.29

Note. [a]Pseudo. Rep. refers to Pseudoword Repetition.

A one-way between-groups multivariate analysis of variance (MANOVA) was performed to investigate Time 1 group differences between the students who remained in the study (n = 54) and those who dropped out (n = 22). Five dependent variables from Time 1 were used: age, vocabulary, reading, word span, and pseudoword repetition. The independent variable was participant standing in the study (i.e., students who remained versus those who dropped out). There was a statistically non-significant result between participant standing, indicating that those who remained in the study did not differ significantly from those who dropped out of the study on the combined six dependent variables, F (5, 59) = 0.53, p = 0.75; Wilks' Lambda = 0.96; multivariate eta-squared = 0.04. A chi-square test was used to determine whether group status was based on gender. The chi-square test indicated no significant association between gender and group status, χ^2 (1, n = 54) = 0.02, p = 0.88, *phi* = 0.02.

For the participants who remained in the study (N = 54), descriptive analyses were run to analyze the mean scores for each variable across the three time points (refer to Table 3 for descriptive results of the participants who remained (N = 54) at Times 1, 2, and 3).

Table 3
Descriptive Statistics for Children who Remained in the Study at Times 1, 2, and 3 (N = 54)

		Time 1		Time 2		Time 3	
Variable	Maximum	M	SD	M	SD	M	SD
Vocabulary	44	19.69	3.00	21.33	3.15	23.83	2.91
Reading	219	40.24	23.16	91.33	20.44	125.26	19.10
Word Span	81	33.59	8.95	38.85	9.36	42.80	9.45
Pseudo Rep.[a]	30	14.61	5.50	15.54	5.92	18.41	5.00

[a]Pseudo Rep. refers to Pseudoword Repetition.

Correlations between the Dependent Variables for Participants who Remained in the Study (N = 54)

Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicolinearity, with no serious violations noted.

Correlational analyses were computed to determine relationships between the four variables (Reading, Vocabulary, Word Span, and Pseudoword Repetition) at Times 1, 2, and 3 for the participants who remained in the study. (See Table 4 for correlational analyses computed for the four dependent measures across the three time points (total of 12 variables) for these participants).

The correlational analyses indicated that each measure (Vocabulary, Reading, Word Span, and Pseudoword Repetition) strongly correlated with itself across the three time points. Each measure's correlations at the three time points were no less than 0.50, and the majority of the correlations were 0.60 and above. Specifically, strong significant relationships occurred between all the variables at different time points: Vocabulary at Time 1 and Time 2 ($r = 0.59$), Time 1 and Time 3 ($r = 0.60$), and Time 2 and Time 3 ($r = 0.75$); Reading at Time 1 and Time 2 ($r = 0.61$), and Time 2 and Time 3 ($r = 0.84$); Word Span at Time 1 and Time 3 ($r = 0.72$), and Pseudoword Repetition at Time 1 and Time 2 ($r = 0.80$), Time 1 and Time 3 ($r = 0.61$), as well as at Time 2 and Time 3 ($r = 0.73$).

Next, the relationships between Reading and Word Span were examined across the three time points. Correlations showed that Word Span at Time 1 moderately correlated with Reading at Time 1 ($r = 0.46$), but did not have a relationship with Reading at Time 2 or Time 3. Word Span at Times 2 and 3 significantly correlated with Reading at each time point; there was a small to moderate correlation between Word Span at Time 2 and Reading at Time 1 ($r = 0.33$), Time 2 ($r = 0.27$), and Time 3 ($r = 0.28$). Similarly, Word Span at Time 3 had a small to moderate relationship with Reading at Time 1 ($r = 0.39$), Time 2 ($r = 0.27$), and Time 3 ($r = 0.28$).

Pseudoword Repetition and Reading did not have many significant correlations. For instance, Pseudoword Repetition at Time 3 was the only time point when a relationship was present with Reading at Times 1 ($r = 0.26$), 2 ($r = 0.39$), and 3 ($r = 0.33$). In other words, Pseudoword Repetition at Time 1 and Time 2 did not significantly correspond with Reading at Times 1, 2, or 3.

There was a moderate to strong relationship between the two PM measures across the three waves of time. Respectively, Pseudoword Repetition at Time 1 significantly correlated with Word Span at Time 1 (r = 0.48), Time 2 (r = 0.33), and Time 3 (r = 0.41); Pseudoword Repetition at Time 2 significantly correlated with Word Span at Time 1 (r = 0.50), Time 2 (r = 0.48), and Time 3 (r = 0.51); and finally, Pseudoword Repetition at Time 3 had a moderate relationship with Word Span across each time. Specifically, Pseudoword Repetition at Time 3 significantly related to Word Span at Time 1 (r = 0.43), Time 2 (r = 0.48), and Time 3 (r = 0.46). These correlations suggest shared variance between PM measures.

The relationships between Vocabulary and the other variables are less central to this study, but still important to note. For Reading, performance at Time 1 had a small to moderate relationship with Vocabulary at Time 2 (r = 0.32) and Time 3 (r = 0.27). At Time 2, there was a moderate relationship with Vocabulary at Time 1 (r = 0.38), Time 2 (r = 0.38), and Time 3 (r = 0.36); and Reading at Time 3 also was found to be moderately associated with Vocabulary at Time 1 (r = 0.42), Time 2 (r = 0.33), and Time 3 (r = 0.42).

Both PM measures likewise were found to correspond with vocabulary levels. At Time 1, Word Span significantly correlated with Vocabulary at Times 1 through 3 (r = 0.33; r = 0.27; r = 0.38, respectively). At Time 2, Word Span significantly related to Reading at Time 1 and Time 3 (r = 0.30).

Table 4

Pearson Correlation Coefficients for the Dependent Measures at Time 1, Time 2, and Time 3 (N = 54)

Measures	1	2	3	4	5	6	7	8	9	10	11	12
1. Vocabulary 1	1											
2. Vocabulary 2	0.59**	1										
3. Vocabulary 3	0.60**	0.75**	1									
4. Reading 1	0.18	0.32*	0.27*	1								
5. Reading 2	0.38**	0.38**	0.36**	0.61**	1							
6. Reading 3	0.42**	0.33**	0.42**	0.50**	0.84**	1						
7. Word Span 1	0.33**	0.27*	0.38**	0.46**	0.22	0.21	1					
8. Word Span 2	0.30*	0.15	0.30*	0.33**	0.27*	0.28*	0.54**	1				
9. Word Span 3	0.29*	0.40**	0.41**	0.39**	0.27*	0.28*	0.72**	0.51**	1			
10. Pseudo. Rep.[a] 1	0.36**	0.15	0.35**	0.09	0.12	0.13	0.48**	0.33**	0.41**	1		
11. Pseudo. Rep.[a] 2	0.40**	0.26*	0.35**	0.14	0.22	0.22	0.50**	0.48**	0.51**	0.80**	1	
12. Pseudo. Rep.[a] 3	0.46**	0.26*	0.39**	0.26*	0.39**	0.33**	0.43**	0.48**	0.46**	0.61**	0.73**	1

Note. Pseudoword Repetition and Word Span are Phonological Memory (PM) measures.

*p < .05. **p < .01.

[a]Pseudo. Rep. refers to Pseudoword Repetition.

Word Span at Time 3 had a small to moderate relationship with Reading at all three times (r = 0.29, r = 0.40, r = 0.41, respectively).

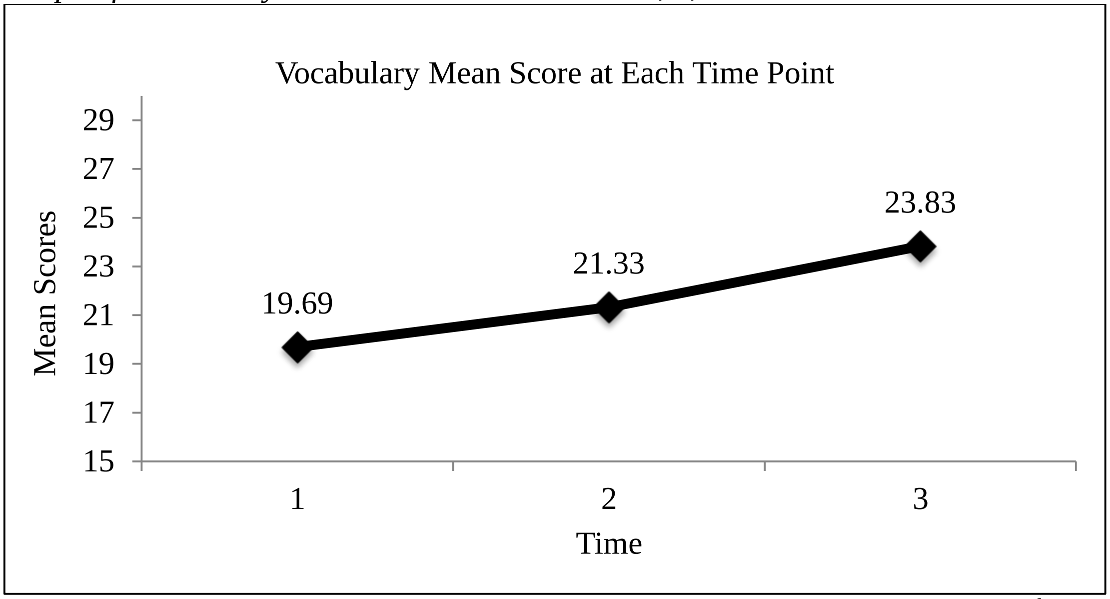
Performance on Pseudoword Repetition significantly related to Vocabulary at small to moderate levels. For Time 1, Pseudoword Repetition had a moderate relationship with Vocabulary at Times 1 (r = 0.36) and 3 (r = 0.35). At Time 2, Pseudoword Repetition significantly correlated with Vocabulary across each time point (Time 1: r = 0.40; Time 2: r = 0.26; Time 3: r = 0.35). Finally, Pseudoword Repetition at Time 3 had a small to moderate correlation with Vocabulary at Time 1 (r = 0.46), Time 2 (r = 0.26), and Time 3 (r = 0.39).

Repeated Analyses of Variance to Study Change in Dependent Variables over Time

Four one-way repeated measures analyses of variance (R-AVOVAs) were performed to study the change of vocabulary, reading, and both PM measures (i.e., word span and pseudoword repetition) across the three time points (fall of first grade, Time 1; spring of first grade, Time 2; spring of second grade, Time 3). Repeated ANOVAs were run to assess whether there were significant increases in each variable over time (refer to Table 5 for means, standard deviations, and repeated ANOVA results for each variable over time). Time was shown to have a significant effect on all variables.

First, a repeated ANOVA was conducted to compare the scores of vocabulary at Time 1, Time 2, and Time 3 (refer to Figure 1 for an illustration of the change in vocabulary performance over time). There was a significant effect for time, Wilks' Lambda = 0.25, F (2, 52) = 76.79, $p < 0.01$, $\omega^2 = 0.24$.

Figure 1
Graph of Vocabulary Mean Raw Scores at Times 1, 2, and 3



Note. Time 1: Fall of 1st grade, Time 2: Spring of 1st grade, Time 3: Spring of 2nd grade.

Three pairwise comparisons tests were used to make post hoc comparisons between conditions. The first follow-up comparisons test indicated that there was a significant difference between Time 1 vocabulary (M = 19.69, SD = 3.00) and Time 2 vocabulary (M = 21.33, SD = 3.15, $p < 0.01$). A second paired comparisons test indicated that there was a significant difference ($p < 0.01$) between the mean vocabulary during the Time 2 (M = 21.33, SD = 3.15) and Time 3 (M = 23.83, SD = 2.91). Finally, a third paired comparisons test showed that there was a significant difference ($p < 0.01$) between Time 1 (M = 19.69, SD = 3.00) and Time 3 (M = 23.83, SD = 2.91) vocabulary.

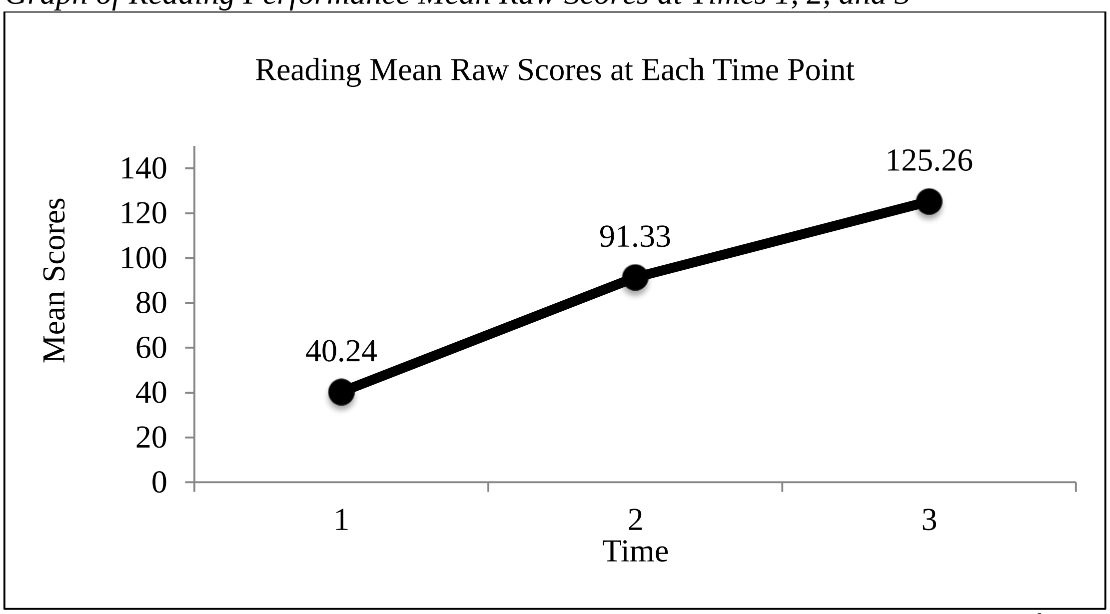
Second, reading performance scores were compared over time (refer to Figure 2 for an illustration of reading change over time). Time was significantly associated with increases in reading scores, Wilks' Lambda = 0.05, F (2, 52) = 469.24, $p < 0.01$,

$\omega^2 = 0.37$. The paired comparisons tests showed a significant difference ($p < 0.01$) between reading at Time 1 ($M = 40.24$, $SD = 23.16$) and Time 2 ($M = 91.33$, $SD = 20.44$), Time 2 and Time 3 ($M = 125.26$, $SD = 19.10$), and Time 1 and Time 3.

Third, word span scores were compared over time; there was a significant effect for time on word span, Wilks' Lambda = 0.35, F (2, 52) = 48.69, $p < 0.01$, $\omega^2 = 0.07$ (see Figure 3). Follow-up pairwise comparisons tests indicated a significant difference ($p < 0.01$) between word span mean scores at each time point: Time 1 ($M = 33.59$, $SD = 8.95$) and Time 2 ($M = 38.85$, $SD = 9.36$), Time 2 ($M = 38.85$, $SD = 9.36$) and Time 3 ($M = 42.80$, $SD = 9.45$), and Time 1 ($M = 33.59$, $SD = 8.95$) and Time 3 ($M = 42.80$, $SD = 9.45$).

Figure 2

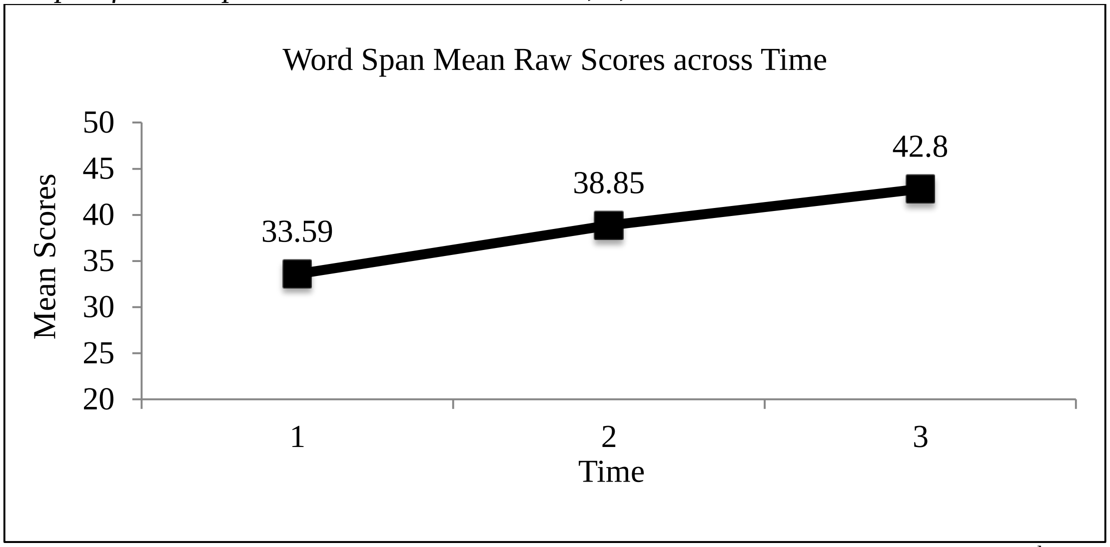
Graph of Reading Performance Mean Raw Scores at Times 1, 2, and 3



Note. Time 1: Fall of 1st grade, Time 2: Spring of 1st grade, Time 3: Spring of 2nd grade.

Figure 3

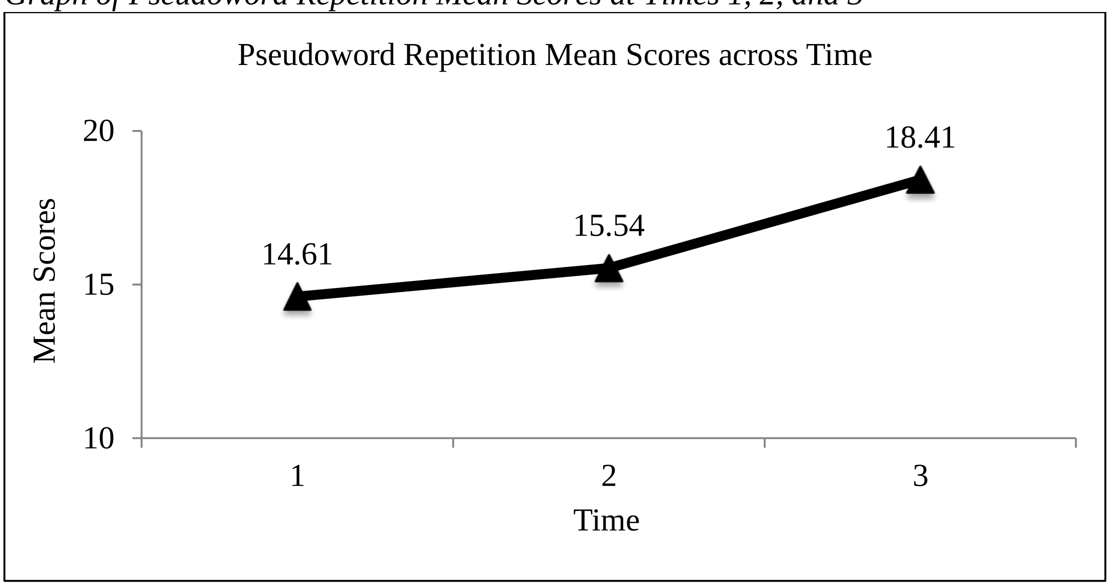
Graph of Word Span Mean Scores at Times 1, 2, and 3



Note. Time 1: Fall of 1st grade, Time 2: Spring of 1st grade, Time 3: Spring of 2nd grade.

Figure 4

Graph of Pseudoword Repetition Mean Scores at Times 1, 2, and 3



Note. Time 1: Fall of 1st grade, Time 2: Spring of 1st grade, Time 3: Spring of 2nd grade.

In addition, a repeated ANOVA was run to compare pseudoword repetition performance at Times 1 through 3 (see Figure 4 for the pseudoword repetition chart of change over time). Results indicated that time had a significant effect on this variable, Wilks' Lambda = 0.58, F (2, 52) = 18.86, $p < 0.01$, $\omega^2 = 0.04$. Follow-up pairwise comparison tests were run to compare each pair of time points for each measure to indicate whether the difference between the variables at different times was significant. Results indicated significant differences ($p < 0.01$) between Time 1 (M = 14.61, SD = 5.50) and Time 3 (M = 18.41, SD = 5.00), and Time 2 (M = 15.54, SD = 5.92) and Time 3 (M = 18.41, SD = 5.00). However, there was not a significant difference (p = 0.20) in pseudoword repetition performance from Time 1 (M = 14.61, SD = 5.50) to Time 2 (M = 15.54, SD = 5.92).

Table 5

Summary of Repeated ANOVA Results with Time as the Independent Variable for Each Dependent Variable (N = 54)

	Time 1		Time 2		Time 3		R-ANOVA Results		
Variable	M	SD	M	SD	M	SD	F (2, 52)	p	ω^2
Vocabulary	19.69	3.00	21.33	3.15	23.83	2.91	76.79	<.01**	.24
Reading	40.24	23.16	91.33	20.44	125.26	19.10	469.24	<.01**	.37
Word Span	33.59	8.95	38.85	9.36	42.80	9.45	48.69	<.01**	.07
Pseudo. Rep.[a]	14.61	5.50	15.54	5.92	18.41	5.00	18.86	<.01**	.04

*p < .05. **p < .01.

[a]Pseudo. Rep. refers to pseudoword repetition.

Aim 1, Regression Analyses: Examining Bi-Directional Relationships between Reading and Phonological Memory

In order to investigate the bi-directional relationships between reading performance and PM, eight hierarchical regression analyses were performed to assess the relationship between these variables in both directions at two different outcome times, Time 2 and Time 3, and with two measures of PM (see Table 6a for predictors of PM at Times 2 and 3, and Table 6b for predictors of reading at Times 2 and 3).

Each regression analysis was run twice with each measure of PM (i.e., pseudoword repetition and word span).

The first four regression analyses examined the Time 1 predictors of PM at Time 2 and Time 3 (see Table 6a for the aims of the first four regression analyses). The Time 1 predictors (independent variables) included PM (covariate), vocabulary, and reading. Two analyses were run to assess the Time 1 predictors of PM at Time 2 and two analyses were used to investigate the Time 1 predictors of PM at Time 3. Next, four regression analyses were run to investigate the Time 1 predictors of reading at Times 2 and 3 (see Table 6b for the aims of the final four regression analyses). Time 1 predictors included reading (i.e., the covariate), vocabulary, and PM. Two analyses assessed the Time 1 predictors of reading at Time 2 while two analyses were performed to examine the predictors of reading at Time 3.

Table 6a
Aim 1: Examining the Predictors of Phonological Memory (PM) at Times 2 and 3 using Hierarchical Regression Analyses

Aim	Regression Analyses	Time 1 Predictors	Outcome Variables
Predictors of Phonological Memory	1	1) Pseudoword repetition 2) Vocabulary 3) Reading	Time 2 Pseudoword Repetition
	2	1) Pseudoword repetition 2) Vocabulary 3) Reading	Time 3 Pseudoword Repetition
	3	1) Word Span 2) Vocabulary 3) Reading	Time 2 Word Span
	4	1) Word Span 2) Vocabulary 3) Reading	Time 3 Word Span

Hierarchical Regression Analyses 1 through 4: Time 1 Predictors of Phonological Memory

Hierarchical Regression 1 to Assess Time 1 Predictors of Phonological Memory (Pseudoword Repetition) at Time 2

Table 6b

Aim 1: Examining the Predictors of Reading at Times 2 and 3 using Hierarchical Regression Analyses

Aim	Regression Analyses	Time 1 Predictors	Outcome Variables
Predictors of Reading	5	1) Reading 2) Vocabulary 3) Pseudoword repetition	Time 2 Reading
	6	1) Reading 2) Vocabulary 3) Pseudoword repetition	Time 3 Reading
	7	1) Reading 2) Vocabulary 3) Word span	Time 2 Reading
	8	1) Reading 2) Vocabulary 3) Word span	Time 3 Reading

The first hierarchical regression analysis was run to examine the contributions of Time 1 predictors in Time 2 PM variance (see Table 7 for the results). PM was represented by the pseudoword repetition measure. The Time 1 predictors and order of entry consisted of the following: 1) Pseudoword repetition, the covariate, 2) vocabulary, and 3) reading. The outcome variable was pseudoword repetition at Time 2. Results indicated that pseudoword repetition exerted a large effect, explaining 64% of the variance in pseudoword repetition at Time 2. Vocabulary was entered second and did not account for any additional variance. Lastly, reading was entered and did not account for any additional variance in pseudoword repetition at Time 2 beyond that of pseudoword repetition at Time 1. The overall model explained 65% of variance in pseudoword repetition at Time 2, F (3, 50) = 32.37, $p < 0.01$. It is important to note that pseudoword repetition at Time 1 had a strong, significant relationship with itself at Time 2 (r = 0.80, $p < 0.01$). On the other hand, reading at Time 1 did not correlate with pseudoword repetition at Time 2, the outcome variable (r = 0.14, $p = 0.15$).

Table 7

Hierarchical Regression Analysis 1: Time 1 Predictors of Pseudoword Repetition Performance at Time 2

Step	Variable Added	R change	*p*	Final ß
1	Pseudoword Repetition	.64	<.01**	.76
2	Vocabulary	.01	.15	.12
3	Reading	.00	.55	.05

*$p < .05$. **$p < .01$.

Hierarchical Regression 2 to Assess Time 1 Predictors of Phonological Memory (Pseudoword Repetition) at Time 3

The second regression analysis was run to measure the amount of variance attributed by Time 1 predictors to PM at Time 3 (see Table 8 for the results from the second hierarchical regression analysis). Time 1 predictors included: 1) Pseudoword repetition, the covariate, 2) vocabulary, and 3) reading. Time 3 PM, measured by pseudoword repetition, was the outcome variable. The results showed that pseudoword repetition at Time 1 predicted 38% of the variance in pseudoword repetition at Time 3.

Table 8
Hierarchical Regression Analysis 2: Time 1 Predictors of Pseudoword Repetition Performance at Time 3

Step	Variable Added	R change	*p*	Final ß
1	Pseudoword Repetition	.38	<.01**	.51
2	Vocabulary	.07	.02*	.25
3	Reading	.03	.13	.16

**p* < .05. ***p* < .01.

In addition, vocabulary predicted an additional 7% of unique variance in the outcome variable, after controlling for pseudoword repetition at Time 1, R squared change = 0.07, F change (1, 51) = 6.06, $p = 0.02$. Reading, entered last, did not contribute any additional variance in Time 3 PM. The overall analysis described 48% of the variance on PM at Time 3, F (3, 50) = 14.68, $p < 0.01$.

Hierarchical Regression 3 to Assess Time 1 Predictors of Phonological Memory (Word Span) at Time 2

Next, the third and fourth regression analyses consisted of the same goal, but used word span as the PM measure. The third regression analysis was used to ascertain the amount of variance each Time 1 predictor contributed to PM at Time 2 (see Table 9 for the results from the third regression analysis). Predictor variables were entered in the following order: 1) Word span, the covariate, 2) vocabulary, and 3) reading. The outcome variable was PM, measured by word span, at Time 2. In this model, word span was the only Time 1 variable that contributed to the outcome, explaining 30% of the variance. Vocabulary and reading did not account for significant variance beyond that of word span. As a whole, this model explained 33% of the variance in PM at Time 2, F (3, 50) = 7.70, $p < 0.01$.

Table 9

Hierarchical Regression Analysis 3: Time 1 Predictors of Word Span Performance at Time 2

Step	Variable Added	R change	*p*	Final ß
1	Word Span	.30	<.01**	.46
2	Vocabulary	.02	.30	.13
3	Reading	.01	.50	.09

**p* < .05. ***p* < .01.

Hierarchical Regression 4 to Assess Time 1 Predictors of Phonological Memory (Word Span) at Time 3

Table 10

Hierarchical Regression Analysis 4: Time 1 Predictors of Word Span Performance at Time 3

Step	Variable Added	R change	*p*	Final ß
1	Word Span	.52	<.01**	.67
2	Vocabulary	.00	.55	.06
3	Reading	.00	.53	.07

**p* < .05. ***p* < .01.

The fourth regression model was run to assess the amount of variance each Time 1 predictor (i.e., word span, vocabulary, and reading, entered in this order) explained in PM at Time 3, with word span as the PM measure (see Table 10 for the results from the fourth regression analysis). Similar to the third hierarchical regression analysis, word span at Time 1 was the only predictor of PM at Time 3.

Specifically, Time 1 word span accounted for 52% of the final variance in word span at Time 3, which explained the overall contribution in this analysis, $F\ (3, 50) = 18.79$, $p < 0.01$.

Hierarchical Regression Analyses 5 through 8: Time 1 Predictors of Reading Performance

The following four regression analyses were used to determine the contributions of Time 1 predictors to reading at Times 2 and 3. Two analyses were run for each outcome variable (i.e., reading at Time 2 and reading at Time 3) in order to analyze the contribution of PM measured by pseudoword repetition and word span.

Table 11
Hierarchical Regression Analysis 5: Time 1 Predictors of Reading Performance at Time 2 with Pseudoword Repetition as the Phonological Memory Measure

Step	Variable Added	R change	*p*	Final ß
1	Reading	.38	<.01**	.56
2	Vocabulary	.07	.01**	.29
3	Pseudoword Repetition	.00	.77	-.03

$*p < .05$. $**p < .01$.

Hierarchical Regression 5 to Assess Time 1 Predictors of Reading Performance at Time 2 with Pseudoword Repetition as the Phonological Memory Measure

The fifth regression analysis was used to assess the ability of Time 1 PM (measured by pseudoword repetition) to predict reading performance at Time 2, after controlling for two additional Time 1 predictor variables, reading (covariate) and vocabulary (see Table 11 for results from the fifth hierarchical regression analysis). Preliminary correlation analyses displayed a non-significant relationship between Time 1 pseudoword repetition and Time 2 reading ($r = 0.12$, $p = 0.19$), which was the predictor variable of interest. On the other hand, reading explained 38% of the final outcome and vocabulary contributed 7% of unique variance after controlling for reading, R squared change = 0.07, F change $(1, 51) = 6.85$, $p = 0.01$. As a whole, this model explained 45% of the variance in reading performance at Time 2, F (3, 50) = 13.72, $p < 0.01$.

Hierarchical Regression 6 to Assess Time 1 Predictors of Reading Performance at Time 3 with Pseudoword Repetition as the Phonological Memory Measure

The sixth hierarchical regression analysis included the same independent predictor variables: 1) Reading, 2) vocabulary, 3) pseudoword repetition (see Table 12 for the results of the sixth hierarchical regression analysis). This analysis was run to evaluate the predictors of reading at Time 3, with specific interest in the contribution of the final predictor entered, PM. Before the regression analysis was conducted, a preliminary correlation analysis indicated a non-significant correlation between pseudoword repetition at Time 1 and reading at Time 3 (r = 0.13, $p = 0.17$). This regression analysis showed that the covariate, Time 1 reading, contributed a significant 25% of variance in reading performance at Time 3. Vocabulary accounted for 11% of the outcome variance beyond that of the covariate, R squared change = 0.11, F change (1, 51) = 9.09, $p < 0.01$. The total variance explained by the model as a whole was 36%, F (3, 50) = 9.51, $p < 0.01$.

Table 12
Hierarchical Regression Analysis 6: Time 1 Predictors of Reading Performance at Time 3 with Pseudoword Repetition as the Phonological Memory Measure

Step	Variable Added	R change	*p*	Final ß
1	Reading	.25	<.01**	.44
2	Vocabulary	.11	<.01**	.36
3	Pseudoword Repetition	.00	.78	-.03

**p* < .05. ***p* < .01.

Hierarchical Regression 7 to Assess Time 1 Predictors of Reading Performance at Time 2 with Word Span as the Phonological Memory Measure

The final two regression analyses were conducted to assess the contribution of variance explained by the Time 1 predictors (reading, vocabulary, and PM, entered into the hierarchical regression analyses in this order) in reading at Time 2, the seventh regression analysis (see Table 13 for results of the seventh hierarchical regression analysis) and Time 3, the eighth regression model (see Table 14 for the results of the eighth hierarchical regression analysis). These models differed from the previous two analyses presented (regression five and six) in that word span represented PM for regressions seven and eight. Preliminary correlation results from the seventh hierarchical regression model indicated a non-significant relationship between the main predictor variable of interest, word span at Time 1, and the outcome variable, reading at Time 2 ($r = 0.22$, $p = 0.06$). Thus, results from this regression analysis are quite similar to the results from the fifth regression, as pseudoword repetition and word span both did not correlate significantly with reading at Time 2. The results from this regression analysis showed that Time 1 reading contributed to 38% of the variance in reading at Time 2. In addition, vocabulary at Time 1 explained 7% unique variance in Time 2 reading, R squared change = 0.07, F change $(1, 51) = 6.85$, $p = 0.01$. The overall analysis explained 48% of the variance in reading performance at Time 2, $F(3, 50) = 15.13$, $p < 0.01$.

Table 13
Hierarchical Regression Analysis 7: Time 1 Predictors of Reading Performance at Time 2 with Word Span Performance as the Phonological Memory Measure

Step	Variable Added	R change	*p*	Final ß
1	Reading	.38	<.01**	.64
2	Vocabulary	.07	.01**	.32
3	Word Span	.03	.13	-.19

*$p < .05$. **$p < .01$.

Hierarchical Regression 8 to Assess Time 1 Predictors of Reading Performance at Time 3 with Word Span as the Phonological Memory Measure

The eighth hierarchical regression analysis consisted of the same Time 1 predictor variables, entered in the same order, as in the seventh hierarchical regression. The outcome variable was reading at Time 3. Preliminary correlations showed a non-significant relationship between Time 1 PM, measured by word span, and Time 3 reading (r = 0.21, $p = 0.06$). The results are therefore similar to the results from the sixth regression analysis because both PM measures did not correlate significantly with reading at Time 3. The regression analysis indicated that Time 1 reading explained 25% of Time 3 reading, and Time 1 vocabulary predicted 11% of the variance in Time 3 reading, R squared change = 0.11, F change (1, 51) = 6.09, $p <$ 0.01. As a whole, this model explained 38% of the variance in reading performance at Time 3, F (3, 50) = 10.09, $p < 0.01$.

Table 14
Hierarchical Regression Analysis 8: Time 1 Predictors of Reading Performance at Time 3 with Word Span Performance as the Phonological Memory Measure

Step	Variable Added	R change	*p*	Final ß
1	Reading	.25	<.01**	.49
2	Vocabulary	.11	<.01**	.38
3	Word Span	.02	.28	-.14

**p* < .05. ***p* < .01.

In sum, eight hierarchical regression analyses were run to assess the contributions of Time 1 predictor variables to PM at Time 2 (i.e., the first and third regression analyses) and Time 3 (i.e., the second and fourth regression analyses), and reading performance at Time 2 (i.e., the fifth and seventh regression analyses) and Time 3 (i.e., the sixth and eighth regression analyses). The outcome's covariate (i.e., the outcome variable at Time 1) was entered first to control for that variable. The first four regression analyses were used to investigate the early predictors of later PM, with Time 1 reading being the main predictor of interest. These four hierarchical regression analyses, however, indicated that reading did not contribute to the variance in later PM ability beyond that of the PM covariate. In model 1, it was expected that Time 1 reading would not relate to or contribute significant variance in Time 2 pseudoword repetition because these variables had a non-significant relationship indicated by preliminary correlation analysis. The latter four regression analyses were aimed at examining the key early predictors of later reading performance. For these analyses, results indicated that early PM did not explain any variance in later reading performance beyond what was accounted for by early reading and vocabulary variables. Preliminary correlational analyses revealed a non-significant relationship between each Time 1 PM measure and Time 2 and Time 3 reading. Thus, regression analyses five through eight were run for the purposes of this dissertation project with no expectation of finding valuable results.

Aim 2, Growth Curve Modeling: Investigating the Effects of Reading on Phonological Memory Growth

Growth curve modeling (GCM) was used to assess the effects of reading on PM growth, including both pseudoword repetition and word span (refer to Table 15 for the aim of Model 3, to analyze the effect of reading on PM). In order to assess whether reading had an effect on PM, three models were run, each building on the previous model. Each model was run using MIXED in SPSS.21. Model 1, the unconditional means (UM) model analyzed the initial status of each PM measure separately. This model assessed whether there was variation between participants in the initial status (i.e., intercept) for PM. Model 2, the unconditional growth (UG) model was run to investigate the rate of growth for PM across time and to ascertain if there was PM slope (i.e., growth) variation between individuals. Finally, Model 3, the conditional growth (CG) model, was run to analyze the effects of reading on PM growth (Heck, Thomas, & Tabata, 2014).

Two levels were included, Level 1 and Level 2. Level 1 referred to the intra-individual variation among the repeated measures (i.e., repeated measures). The Level 2 portion included the inter-individual variation (i.e., individuals). Thus, the repeated measures (Level 1) were nested within the individuals (Level 2) (Hayes, 2006).

In order to run GCM in SPSS.21, the data were reorganized from a person-period data set (one row per person; i.e., horizontal form) to a person-level data set (i.e., vertical or long form). Time-varying variables, including reading, pseudoword repetition, and word span, were rearranged by one row per wave of measurement (i.e., one row per time point) (Heck, Thomas, & Tabata, 2014). Time was coded as 0, 0.07, 0.19 to represent the time waves 1, 2, and 3 in months.

Table 15

Aim 2: Investigating whether Reading Affects the Growth of Phonological Memory (PM) using Growth Curve Modeling

Aim	Growth Curve Model 3	Predictor Variable	Outcome Variable
1. Effect of Reading on Pseudoword Repetition Growth	1	Reading	Pseudoword Repetition
2. Effect of Reading on Word Span Growth	2	Reading	Word Span

Model 1. Unconditional Means (UM) Model with No Predictors

The unconditional means (UM) model was run first as a baseline for the unconditional growth (UG) model. Specifically, the UM model was an intercept-only model used to investigate variation among individuals at the initial status (i.e., intercept) for PM, the outcome variable, without regard to time (Heck, Thomas, & Tabata, 2014). This model contained three parameters, including the fixed effect that described the average PM ability at the initial point (intercept), the Level 2 (between-individual) random variance, and the Level 1 (within-individual) residual variance. Two models were run, one for each PM measure (refer to Table 16 for results from the UM model for pseudoword repetition and word span).

Table 16
Summary of Unconditional Means (UM) Models for Pseudoword Repetition and Word Span

	UM Model for Pseudoword Repetition			UM Model for Word Span		
Parameter	Estimate	SE	*p* value	Estimate	SE	*p* value
Fixed Intercept	16.19	0.67	< 0.01	38.41	1.07	< 0.01
Random Intercept	20.26	4.77	< 0.01	43.67	12.36	< 0.01
Random Error	12.35	1.68	< 0.01	55.78	7.59	< 0.01

First, one UM model was run with the dependent variable pseudoword repetition. The fixed effects result indicated that the intercept estimate was significantly different from zero ($\beta = 16.19$, $SE = 0.67$, $p < 0.01$). In addition, there was variation around the intercept between individuals, as evidenced by the covariance intercept estimate of 20.27 (Wald Z = 4.25, $p < 0.01$). The intraclass correlation coefficient (ICC; the amount of total outcome variation that is related to interindividual differences) was 62.13% [(20.26)/(20.26+12.35) = 0.6213]. Thus, 62.13% of the variation in pseudoword repetition was due to student differences around the intercept. According to Shek and Ma (2011), multilevel modeling (MLM) is generally preferred if the ICC value is at or above 0.25.

The UM model was repeated with word span as the dependent PM variable. Results from the MIXED analysis showed that the fixed effects intercept for word span was significantly different from zero ($\beta = 38.41$, $SE = 1.07$, $p < 0.01$). Significant variation was established around the intercept (Wald Z = 3.53, $p < 0.01$). This indicated that participants' initial status varied significantly. The ICC value of 0.44 [(43.67)/(43.67+55.78) = 0.4391] indicates that 43.91% of the overall intercept variation for word span was attributed to interindividual differences (Shek & Ma, 2011).

Model 2. Unconditional Growth (UG) Model with Time

Two unconditional growth (UG) models were run to investigate the growth curves of the PM variables by taking time into effect. The UG model examined whether the time-related slopes (change/growth) for pseudoword repetition and word span varied across individuals. It also studied the individual changes over time and whether individual's rates of change varied from the population's true slope (refer to Table 17 for UG results).

The results from the UG model for pseudoword repetition showed significant values for both the fixed effects intercept ($\beta = 14.42$, $SE = 0.78$, $p < 0.01$) and slope (β

= 0.20, *SE* = 0.03, $p < 0.01$) parameters. The mean estimated intercept was 14.42 and the growth rate was 0.20. Thus, individual performance on pseudoword repetition increased at a rate of 0.20 across time. The random error term associated with the intercept was significant (Wald Z = 4.38, $p < 0.01$), indicating that variation occurred at the intercept between individuals. The slope's random error term was also significant (Wald Z = 1.95, $p = 0.05$), meaning that there was a significant amount of variation in the slope among individuals. The correlation between the intercept and the slope parameters was negative (β = -0.44; Wald Z = -1.96, $p = 0.05$). This suggests that individuals with higher PM abilities, measured by pseudoword repetition, had slower growth and those who had lower initial PM scores had faster growth.

Table 17
Summary of Unconditional Growth (UG) Models for Pseudoword Repetition and Word Span

	UG Model for Pseudoword Repetition			UG Model for Word Span		
Parameter	Estimate	SE	*p* value	Estimate	SE	*p* value
Fixed Intercept	14.42	0.77	< 0.01	34.36	1.16	< 0.01
Fixed Slope	0.20	0.03	< 0.01	0.47	0.06	< 0.01
Random Intercept	27.92	6.38	< 0.01	45.95	14.73	< 0.01
Random Slope	0.03	0.01	0.05	0.00	0.00	--
Intercept+Slope	-0.44	0.22	0.05	0.18	0.56	0.75
Random Error	6.22	1.20	< 0.01	35.65	4.85	< 0.01

The UG model was run once more to assess the growth in word span over time. This model did not converge. Thus, results are to be interpreted with caution and may not be valid. Estimates of the fixed effects intercept and growth parameters showed significant results indicating that the intercept ($\beta = 34.36$, $SE = 1.16$, $p < 0.01$) was greater than zero, and there was a positive rate of change ($\beta = 0.47$, $SE = 0.06$, $p < 0.01$). These results suggest that the mean initial status (Time 1) of word span was 34.36 with a positive rate of 0.47 per time wave. The random error term for the intercept estimate of 45.95 was significant (Wald Z = 3.12, $p < 0.01$), indicating variance between participants at the initial status point. However, the random error associated with the growth parameter was so small ($\beta < 0.01$) that it was unable to converge and thus was not modeled.

Model 3. Conditional Growth (CG) Model with Reading Performance

The conditional growth model incorporated the time-varying, mean-centered reading predictor. This model tested the effect of reading performance on the growth trajectory of PM ability within and between students. Moreover, this analysis provided information about whether reading performance was a predictor of the PM intercept and growth parameters. It should be noted that the CG model is only supposed to be run when the previous model, the UG model, identifies a significant growth trajectory (Hayes, 2006). In addition, preliminary correlational analyses have indicated a non-significant relationship between reading and PM at different time points. This model was run solely for the purposes of this dissertation project despite foreseeing non-significant results with the reading predictor added. The CG models did not converge for pseudoword repetition or word span due to a lack of variance surrounding the slope. Thus, the result estimates are not valid and should be interpreted with caution.

The first CG model was run to examine the reading performance effect on the growth trajectory of PM. Similar to the first two models, the intercept fixed effect was significant ($\beta = 14.37$, $SE = 0.96$, $p < 0.01$). In addition, the linear growth parameter was significant ($\beta = 0.20$, $SE = 0.08$, $p < 0.05$). The reading effect estimate was small ($\beta < .01$) and not significant. The covariance parameters, including the intercept and slope variance associated with reading performance, were not significant. Reading was not found to significantly affect the growth of pseudoword repetition.

Lastly, the CG model was run to investigate the effects of reading performance on word span growth. Just as it was determined in models 1 and 2, the word span initial status differed significantly from 0 ($\beta = 28.63$, $SE = 2.00$, $p < 0.01$). However, the slope and reading estimates were not significant. In addition, the covariance parameters were analyzed to investigate whether variance occurred between participants on the word span task due to a reading effect. Yet, these results were unable to converge as a result of model 2 not converging.

Aim 3, Exploratory analyses: Examining Phonological Memory Measures

Hierarchical regression analyses were conducted to explore the level of shared variance between the two PM measures, as well as evaluate which PM measure was a better predictor of reading performance (see Tables 18a and 18b for the aims of the exploratory analyses).

Hierarchical Regression Analyses to Examine the Shared Variance between the Phonological Memory Measures: Pseudoword Repetition and Word Span

Four hierarchical regression analyses were run to examine whether word span and pseudoword repetition shared variance. Two sets of regression analyses were conducted, the first set to address shared variance between word span at Time 1 and pseudoword repetition at Time 3, and the second set examined the shared variance between pseudoword repetition at Time 1 and word span at Time 3. Each regression was run in the reverse order. In the first model, word span at Time 1 was entered first, followed by Time 1 pseudoword repetition. The outcome variable was pseudoword repetition at Time 3 (see Table 19). The results showed that Time 1 word span contributed 18% of the variance in Time 3 pseudoword repetition, when not controlling for the covariate.

Table 18a
Aim 3: Exploring the Shared Variance between Phonological Memory (PM) Measures

Regression Analyses	Time 1 Predictor Variables	Time 3 Outcome Variable
1	1) Word Span 2) Pseudoword Repetition	Pseudoword Repetition
2	1) Pseudoword Repetition 2) Word Span	
3	1) Pseudoword Repetition 2) Word Span	Word Span
4	1) Word Span 2) Pseudoword Repetition	

Time 1 pseudoword repetition contributed an additional 22% of the variance beyond that of word span at Time 1. The overall model explained 40% of variance, F (2, 51) = 16.98, $p < 0.01$.

Table 18b

Aim 3: Exploring the Shared Variance between Phonological Memory (PM) Measures and the Best Predictor of Reading Performance

Regression Analyses	Time 1 Predictor Variables	Time 3 Outcome Variable
1	1) Reading 2) Pseudoword Repetition 3) Word Span	Reading
2	1) Reading 2) Word Span 3) Pseudoword Repetition	

For the second model, the predictors were entered in the reverse order (i.e., pseudoword repetition entered first followed by word span). In this model, Time 1 word span was not found to contribute any unique variance in the outcome, Time 3 pseudoword repetition, beyond what pseudoword repetition at Time 1 contributed to the outcome, specifically, 38% of variance.

Table 19

Summary of Hierarchical Regression Results for Examining the Shared Variance between Time 1 Word Span and Time 3 Pseudoword Repetition

Step	Variable Added	R change	*p*	Final ß
1	Word Span	.18	<.01**	.17
2	Pseudoword Repetition	.22	<.01**	.53
1	Pseudoword Repetition	.38	<.01**	.53
2	Word Span	.02	.17	.17

*$p < .05$. **$p < .01$.

The overall model explained 40% of the variance, $F\ (2, 51) = 16.98$, $p < 0.01$. These two models indicate the presence of shared variance between the PM measures. Specifically, word span was initially found to contribute variance in pseudoword repetition at Time 3 (ß = 0.17, $p < 0.01$), when it was entered alone. Yet, that variance contribution did not occur when Time 1 pseudoword repetition was the first predictor entered into the model, indicating that word span and pseudoword repetition share variance rather than word span holding unique variance in pseudoword repetition.

Table 20
Summary of Hierarchical Regression Results for Examining the Shared Variance between Time 1 Pseudoword Repetition and Time 3 Word Span

Step	Variable Added	R change	*p*	Final ß
1	Pseudoword Repetition	.17	<.01**	.08
2	Word Span	.36	<.01**	.69
1	Word Span	.52	<.01**	.69
2	Pseudoword Repetition	.01	.48	.08

$^*p < .05$. $^{**}p < .01$.

Next, models three and four were run to investigate the shared variance between pseudoword repetition at Time 1 and word span at Time 3 (refer to Table 20 for hierarchical results regarding the shared variance between pseudoword repetition at Time 1 and word span at Time 3). In the third model, Time 1 pseudoword repetition was entered first and Time 1 word span was entered second. On its own, pseudoword repetition contributed a significant 17% of the variance in word span at Time 3. Time 1 word span explained an additional 36% of the variance in the outcome, Time 3 word span. This overall model explained 53% of the variance, F (2, 51) = 28.50, $p < 0.01$. Next, in the fourth model, the predictors were reversed. Time 1 word span was entered first and accounted for 52% of the variance, although pseudoword repetition at Time 1 did not contribute any unique variance in the outcome variable beyond what was explained by Time 1 word span. This model explained an overall variance of 53%, F (2, 51) = 28.50, $p < 0.01$. Shared variance is again shown in these models between word span and pseudoword repetition. When entered first, pseudoword repetition contributed significant variance (ß = 0.08, $p < 0.01$) in later word span performance, but it did not explain variance in the outcome when it was placed in the model second. It is evidenced by the ß values that Time 1 word span holds more weight (ß = 0.17, $p < 0.01$) in Time 3 pseudoword repetition than does Time 1 pseudoword repetition in Time 3 word span (ß = 0.08, $p < 0.01$).

Hierarchical Regression Analyses to Investigate the Best Phonological Memory (PM) Predictor of Reading Performance

The goal of the next analyses was to investigate the best PM predictor of reading performance based on the results from two hierarchical regression analyses. Preliminary correlational analyses indicated a non-significant relationship between Time 3 reading and both PM measures, word span at Time 1 ($r = 0.21$, $p > 0.05$) and pseudoword repetition at Time 1 ($r = 0.13$, $p > 0.05$). For the purposes of this project, the regression analyses were run despite the lack of relationship between the independent variables and the dependent variable.

The Time 1 PM measures participated as the predictor variables and Time 3 reading was the outcome variable. In addition, Time 1 reading was placed in each model first to control for its contribution in the outcome variance. Two models were run; for the first model, pseudoword repetition was entered into step 2, following Time 1 reading, and word span was entered into step 3, the order of PM measures was reversed for the second model.

In the first model, reading at Time 1 was entered into step 1 and exerted a large effect, explaining 25% of the variance in reading at Time 3 (F (1, 52) = 17.20, $p < .01$. Neither word span nor pseudoword repetition accounted for any additional variance, which was expected due to the lack of correlation between these variables and reading at Time 3. The overall model explained 26% of variance in reading at Time 3, F (3,50) = 5.91, $p < .01$ (see Table 21 for hierarchical regression results).

When the entry of the PM variables was reversed, the model again explained 26% of the variance in reading at Time 3. In step 1, Time 1 reading was entered into the model and accounted for 25% of the variance, F (1, 52) = 17.20, $p < .01$. In the second step, pseudoword repetition at Time 1 was entered and did not explain any of the variance beyond that of reading at Time 1. Similarly, in step 3, Time 1 word span was entered and did not explain additional variance in the outcome variable. The overall model explained 26% of variance in Time 3 reading, F (3,50) = 5.91, $p < .01$ (see Table 21 for results).

Table 21
Summary of Hierarchical Regression Results for Phonological Memory Predictors of Reading Performance at Time 3

Step	Variable Added	R change	*p*	Final ß
1	Reading	.25	<.01**	.53
2	Word Span	.01	.85	-.10
3	Pseudoword Repetition	.01	.36	.13
1	Reading	.25	<.01**	.53
2	Pseudoword Repetition	.01	.48	.13
3	Word Span	.01	.54	-.10

*$p < .05$. **$p < .01$.

CHAPTER 4

DISCUSSION

The present longitudinal study was one of few to investigate the bi-directional relationship between early reading development and phonological memory (PM) ability. The current study also examined the role of reading performance on PM growth. Further, this study explored the relationship between PM measures, to understand whether shared variance exists between pseudoword repetition and word span, and whether one of these two PM measures is a better predictor of reading achievement. Specifically, two hypotheses were proposed. First, a bi-directional relationship between PM and reading would be present, with a stronger pull in the direction of early reading performance predicting later PM ability, beyond what could be explained by the Time 1 PM covariate (i.e., autoregressive effect) or vocabulary knowledge. Second, reading performance would be a significant contributor to PM growth and would affect the change in PM ability over time. In addition, the two PM measures, pseudoword repetition and word span, were closely examined to explore their shared variance. A secondary dataset was used for this study containing a sample of 54, English-speaking students attending one public elementary school in the Northeast region of the United States. The participants were tested three times: the fall of first grade (i.e., Time 1), the spring of first grade (i.e., Time 2), and the spring of second grade (i.e., Time 3). At each time point, students were administered assessments that evaluated their reading ability (i.e., the ability to read real words aloud, pseudowords aloud, and comprehend a passage), vocabulary knowledge (i.e., expressive vocabulary), and phonological memory (i.e., two orally presented measures, the pseudoword repetition measure and the word span measure).

Summary of the Findings

Aim 1 Findings: Determining the Nature of the Relationship between Phonological Memory (PM) and Reading

The bi-directional relationship between PM and reading was examined with a series of eight hierarchical regression analyses. The first four regression analyses investigated the contributions of early reading (i.e., Time 1) to later PM ability (i.e., Times 2 and 3). For these analyses, Time 1 reading was the primary predictor variable, and PM at Time 2 and Time 3 functioned as the outcome variables. The final four regression analyses analyzed the relationship in reverse, the role of early PM ability (i.e., Time 1) on later reading performance (i.e., Times 2 and 3). Among the latter four models, Time 1 PM, measured by either pseudoword repetition or word span, served as the main predictor of interest, and reading performances at Time 2 and 3 were the outcome variables. For each direction of the relationship under investigation, regression analyses were run separately for each PM measure, pseudoword repetition and word span, and for the different outcome time points (i.e., Time 2 and Time 3). The covariate (i.e., Time 1 PM or reading, depending on the outcome variable of interest) and vocabulary variables were controlled for by being entered first and second, respectively, into each model.

Aim 1.A: Early Reading as a Predictor of Later Phonological Memory (PM)

First, the relationships between early reading and later PM, at Times 2 and 3, were investigated. It was hypothesized that early reading would predict later PM, given the hypothesis that reading is causally related to PM (Nation & Hulme, 2011). Preliminary correlational analyses showed significant, small to moderate relationships between Time 1 reading and Times 2 and 3 PM, except between Time 1 reading and pseudoword repetition at Time 2 ($p = 0.14$, non-significant).

However, different from the results reported in Nation and Hulme's (2011) paper, in this study a non-significant relationship between early reading and later PM was found on every occasion. Three explanations for these discrepant findings can be considered and may be attributed to methodological differences between studies. First, the sample size of 54 participants in this study does not compare to the sample of 242 students who participated in Nation and Hulme's (2011) project. Based on a post-hoc power analysis, the present study met a medium effect estimate with a post-hoc power of 0.80 for a sample of 54 participants. Nation and Hulme (2011), on the other hand, reported large effect estimates, indicating less conservative effect-size estimates than what the present study reported. As such, their results may have been significant due to the large sample size alone, and perhaps not due to a true effect (Tabachnick & Fidell, 2007; van Voorhis & Morgan, 2007). Second, to determine whether Time 1 reading contributed to performance in PM at Time 2, Nation and Hulme (2011) used structural equation modeling (SEM) with three latent variables, including reading (i.e., sight word and oral reading fluency), oral language (i.e., expressive and receptive vocabulary), and phonological memory (i.e., two pseudoword repetition measures). The present study, on the other hand, conducted four hierarchical regression analyses to estimate this relationship, with independent variables, namely a composite score for reading, one measure of vocabulary, and two measures of PM that were treated as separate. SEM has been consistently documented to be a more powerful design for detecting significant results than first-generation regression analysis (Iacobucci, Saldanha, & Deng, 2007). Third, other significant information lending to variation between studies includes cultural and educational differences between the samples of participants. Nation and Hulme's (2011) participants were native speakers of British English, attending their first (i.e., Time 1) and second (i.e., Time 2) primary years of school in England, whereas this study included a sample of American English-speaking participants attending their second and third years of primary education (i.e., first and second grades). While the orthographies are the same, and the participant mean ages at Time 1 of both studies was approximately six-years old, the participants in the former experiment were first tested during their first year of school, whereas those in this study were in their second year of school, the first grade. Although necessary to address that the prediction analyses did not show similar results to the findings from Nation and Hulme's (2011) study, it is pertinent that the present study demonstrated a positive relationship between early reading and later PM, presented in the correlational analyses, as noted earlier. This project in conjunction with Nation and Hulme's (2011) study, are some of the few studies that have examined the relationship between early reading acquisition and later PM.

Other findings from the four regression analyses include the strong, positive prediction of Time 1 PM, the autoregressive effect, in later PM. Thus, little remaining variance was available for other variables (i.e., vocabulary and reading). This was evident in the first, third, and fourth regression analyses showing that Time 1 PM explained 64%, 30%, and 52% of the variance in later PM, when the models as a whole explained 65%, 33%, and 52% of variance in later PM, respectively. Nation and Hulme (2011), too, found the PM covariate to be strong in relation to later PM, but their results still pointed to early reading as a predictor of PM.

On one occasion, the second regression model, Time 1 vocabulary was found to contribute an additional 7% of variance in Time 3 PM beyond what was explained by the covariate. This provides evidence to support the positive association between PM and vocabulary, which is documented (e.g., Gathercole & Baddeley, 1989; 1990; Gathercole et al., 1992; Gathercole et al., 1999; Michas & Henry, 1994). Specifically, Gathercole, Willis, Emslie, and Baddeley (1992) found that vocabulary knowledge at ages five and six predicted PM at ages six and eight, respectively. The authors concluded that by the age of five-years old, vocabulary knowledge becomes a clear predictor of subsequent vocabulary development. On the other hand, as children age PM becomes less of a predictor of learning new words (Gathercole et al., 1992).

Aim 1.B: Early Phonological Memory (PM) as a Predictor of Later Reading

Additionally, the relationship in reverse was studied. That is, four hierarchical regression analyses were performed to analyze the role of early PM in later reading. Overall, the regression analyses revealed non-significant relationships between these variables. Thus, early PM, measured by both pseudoword repetition and word span at Time 1, was not found to significantly contribute variance in reading at Times 2 or 3, on any occasion, similar to results reported by Nation and Hulme (2011). These results did not come as a surprise since preliminary correlational analyses displayed non-significant results between early PM and later reading. However, the findings differed from those presented in the study by Gathercole and Baddeley (1993b). One plausible explanation is the discrepancy between the participants' mean age, and reading status, at the first wave of testing across studies. Gathercole and Baddeley (1993b) initially tested PM abilities among a sample of pre-readers who had a mean age of four-years old. In contrast, the present study included students who were six-years old during the first time point. Further, the participants from the present study already were reading by the time of the initial testing, and had experienced one full year of school (i.e., kindergarten); the participants from Gathercole and Baddeley's (1993b) study had not yet attended their first year of school.

Based on what is known about PM as a predictor of reading, early PM is suggested to be fundamental to later reading when it is tested prior to learning to read or during initial reading acquisition (Gathercole & Baddeley, 1993a). This is because, once reading is acquired, new variables, such as phonological awareness and reading itself, are found to supplant the role of early PM in explaining later reading performance (Al Otaiba & Fuchs, 2002; Scarborough, Neuman, & Dickinson, 2009; Stanovich, 1986). Though properties of PM are related to phonological awareness, other factors, namely letter knowledge and lexical information are additional key contributors to phonological awareness and play a crucial role in reading development (Alloway, 2006).

In conjunction with this discussion, results from the present study illustrated that Time 1 reading, the covariate, and vocabulary knowledge contributed significant variance in reading at Times 2 and 3. To be precise, early reading was found to explain between 25% to 38% of the variance in later reading. This is supported by the literature that demonstrates that early reading is the best predictor of later reading success (Cunningham & Stanovich, 1997; Scarborough et al., 2009). In addition, vocabulary was shown to account for an additional 7% to 11% of the variance in later reading above and beyond what the autoregressive effect of Time 1 reading. This further provides evidence of the shared variance between reading and vocabulary (Cunningham & Stanovich, 1997; Kamil, 2004; NICHHD, 2000; Senechal & LeFevre, 2000; Tannenbaum, Torgesen & Wagner, 2006; Verhoeven, van Leeuwe & Vermeer, 2012).

Aim 2 Findings: The Role of Reading on Phonological Memory (PM) Growth

To assess the second hypothesis that reading would affect PM growth, growth curve modeling (GCM) analyses of multilevel modeling (MLM) were conducted. The purpose was to add additional information regarding the role of reading in PM development beyond what could be explained by hierarchical regression analyses run for the purposes of *Aim 1.A*. For GCMs, a series of three models were run, each adding to the previous model.

The unconditional means (UM) model, the first one run, served as the baseline model. This model did not contain any predictors, nor did it account for time. The purpose was to determine whether interindividual variation around the intercept, or initial status, was present. The findings revealed significant variation around the intercept for both PM measures. An intraclass coefficient (ICC; i.e., the amount of total outcome variation that is related to interindividual differences) of 0.62 was found for pseudoword repetition, indicating that about 62% of the variation around the intercept was due to participant variation on this task. The ICC for word span was 0.44, meaning that approximately 44% of the intercept variation was explained by interindividual differences. Thus, this model not only indicated the presence of interindividual variation around the initial status for each PM measure, but also that it was necessary to proceed by adding onto this model (i.e., the effect of time) because of its significant results.

The second model tested the growth in PM, both pseudoword repetition and word span, with time in effect. Results from the unconditional growth (UG) model for pseudoword repetition were represented, whereas this model did not converge for word span. For pseudoword repetition, the findings were similar to the preliminary repeated analysis of variance (R-ANOVA), in that there was positive change in performance over time. In particular, pseudoword repetition ability increased at an estimated rate of 0.20 per testing phase. In addition, there was significant interindividual variation around the slope and the variation in the slope was found to be negative. This implies that students with strong performance in pseudoword repetition had slower growth following the first testing point than those who demonstrated lower initial performance on this PM task. This may have occurred because students with poorer PM abilities had more room for growth, as well as more opportunity to catch up (e.g., Baddeley, 2003; see Brady (1991) for a review).

The UG model for word span did not converge for the random effects. However, the model was able to illustrate a significant slope of 0.47 per time point, indicating an increased rate of 0.47 for word span performance over the three time points. Other information, such as whether variation between individuals was present, was not explained in this model. Thus, the repeated ANOVA model that shows significant, positive change over time, is a better fit for this PM measure.

Growth in PM has been documented quite extensively. Similar to the results from the repeated ANOVAs, and the information provided from the GCMs, research supports that PM performance positively changes over time. Historically, studies have reported that PM nearly triples from childhood to adulthood (Dempster, 1981; Wagner et al., 1997). More recently, Alloway, Gathercole, and Pickering (2006) examined the growth of PM over time with a large sample of 709, four-year old students who were followed until the age of eleven. Their findings supported previous research; PM was found to demonstrate steady developmental improvement across time. Variation in PM performance was suggested to relate to intrapersonal factors, such as reading performance and language development (Alloway et al., 2006). Another study indicated that PM growth followed a positive, linear trajectory that continuously increased until students were about fourteen years of age (Gathercole et al., 2004). The authors reported that the PM growth levels off by the age of fifteen (Gathercole et al., 2004).

It was proposed that a third model, the conditional growth (CG) model, would be run in order to determine whether reading performance had an effect on PM growth. In conjunction with *Aim 1.A* of this study, the hypothesis was that reading acquisition would contribute to PM. Furthermore, reading performance was expected to affect the growth in PM development (Nation & Hulme, 2011). One goal of this dissertation project was to conduct more complex models in addition to traditional regression analyses. However, converging this model was problematic for both PM measures, despite increases in iterations, alterations among the covariance type (i.e., attempts were made with the unstructured covariance matrix and the variancecomponents structure), and general trouble shooting within the SPSS.21 multilevel modeling statistical package. Convergence errors may have been due to limited variation around the slopes or the small sample size (Heck, Thomas, & Tabata, 2013). As such, the previously presented four hierarchical regression analyses from *Aim 1.A* best explain the role of reading achievement on PM development. To summarize those findings, reading performance did not predict PM ability at later points, in contrast to the results presented in previous work (e.g., Nation & Hulme, 2011).

Aim 3 Findings: Exploring the Shared Variance between Pseudoword Repetition and Word Span, and Determining the Best Phonological Memory (PM) Predictor of Reading

Exploratory hierarchical regression analyses were performed to investigate both the shared variance between PM measures and to assess whether one PM measure was a better predictor of reading. In the area of shared variance exploration, preliminary correlational analyses, as well as four hierarchical regression results will be discussed. The results from an additional four exploratory hierarchical regression analyses will be explained for the topic regarding the better PM predictor of reading.

Shared variance between the two PM measures was evidenced by significant, positive, moderate to large correlations between the pseudoword repetition and word span measures across time. The weakest relationship, though still a moderate association, occurred between Time 1 pseudoword repetition and Time 2 word span ($r = 0.33$, $p < 0.01$). Time 1 word span and Time 2 pseudoword repetition ($r = 0.50$, $p < 0.01$), as well as Time 2 pseudoword repetition and Time 3 word span ($r = 0.51$, $p < 0.01$) held the strongest connections to each other. Thus, the shared variance ranged from small to large, but was generally moderate. To further address the question of shared variance, four hierarchical regression analyses were conducted to evaluate whether one PM measure at Time 1 predicted variance in the other PM measure at Time 3. Results pointed to much overlap between the PM measures. Specifically, Time 1 word span explained 18% of the overall 40% of variance in Time 3 pseudoword repetition, when it was entered into the model first. However, when this order was reversed, Time 1 word span did not contribute additional variance beyond the autoregressive effect of pseudoword repetition at Time 1. Likewise, Time 1 pseudoword repetition was found to explain 17% of Time 3 word span variance when it preceded the entry of word span, but it did not account for any variance in Time 3 word span when it followed the entry of the covariate. As a whole, the findings show that the PM measures contained shared variance as opposed to unique variance with one another. It must be noted that the autoregressive effect of the Time 1 covariate accounted for significant variance in the outcome variable. However, that only further validates the presence of shared variance between these PM measures. Historically, word span and pseudoword repetition measures have been best described as verbal short-term memory (STM) measures (Al Otaiba & Fuchs, 2002; Baddeley, 2003; Gathercole & Baddeley, 1993b; Melby- Lervåg, 2012; Metsala, 1999). They are considered simpler PM tasks that require temporary storage, as well as immediate verbal recall (Baddeley, 2003). Despite their assumed similarities, researchers did not confirm whether these simpler PM measures, indeed, shared variance. Furthermore, inconsistent findings have been reported about the relationship between PM and reading, with some questioning about how the PM measure plays into this equation.

For instance, Sprugevica and Hoien (2003) did not find that word span was a predictor of reading, whereas Gathercole and Baddeley (1993b) identified that pseudoword repetition explained variance in later reading. However, based on the results from the present study, it appears that these variables contain shared variance and that the variability between studies likely was due to several other inconsistent factors, such as the sample size, the age of the participants, and additional predictor variables included (i.e., whether one study included the autoregressive effect, phonological awareness, or intelligence, for example, may affect the results).

Finally, exploratory hierarchical regression analyses were run to examine whether one PM measure, word span or pseudoword repetition, was a more powerful predictor of later reading performance. As noted previously, the Time 1 PM predictors did not relate to the Time 3 reading variable, as shown by the non-significant correlations. As such, hierarchical regression analyses were unable to add additional information to this exploratory area of interest.

A cross-sectional, developmental study reported different findings. Specifically, Metsala (1999) found variation in word span and pseudoword repetition ability depending on the participant's level of phonological awareness. The study indicated that five-year old children performed better on a pseudoword repetition task than children who were one year younger. In addition, the four-year old children were more successful with correctly repeating words on a word span task than they were at repeating pseudowords (Metsala, 1999). Metsala (1999) suggested that differences on the pseudoword repetition task between age groups were related to advanced phonological awareness development in the older individuals due to learning to read.

Though our previous analyses indicate the presence of shared variance between the PM measures, it may be that pseudoword repetition requires phonological processing abilities in addition to vocabulary knowledge. Research shows that participants perform better when repeating wordlike pseudowords than non-wordlike pseudowords on the pseudoword repetition task (e.g., Gathercole et al., 1991; Metsala, 1999). Word span, on the other hand, may rely more on top-down, vocabulary knowledge. In any event, the goal of this aim was to explore the best PM predictor of reading. As discussed previously, these results may not have been found because of the small sample size or the timing of the first round of testing (i.e., when students were in the first grade and already reading). Additionally, it simply may be that the PM measures used to represent PM in the present study were the reason for the non-significant findings between early PM and later reading, because documented inconsistencies across studies results have been shown when simpler PM measures represent verbal memory (see Savage et al. (2007) for a review).

Discussion of Results

The results of this study give rise to five considerations regarding the role of early reading on later phonological memory (PM), and the role of early PM on later reading performance. First, it is suggested that the reading status (i.e., pre-reading or reading level) of the participants during the initial time point for testing PM may be crucial for determining significant results between PM as a predictor of reading achievement. Participants in this study had learned to read by the first phase of testing. These participants were first tested during the fall of first grade; the mean age at this time was just under six years, five months. Nation and Hulme (2011), similarly, tested a sample of participants who had learned to read; these students were just over six-years old during the first time of testing. They, too, found that early PM, tested at age six, a time when the participants had learned to read, did not predict later reading performance (Nation & Hulme, 2011). On the other hand, studies that illustrated a significant relationship between early PM and later reading included participants who were pre-readers. For instance, Gathercole and Baddeley (1993b), who found that early PM predicted later reading, examined this association with similar PM and reading measures to those used in the present study, yet the participants were first tested at the age of four-years old when they were pre-readers. More recently, Bull et al. (2008) conducted a similar project with a sample of four-year old, pre-readers, who were tested yearly until the age of seven. Like Gathercole and Baddeley's (1993b) findings, these authors reported that early PM captured variance in later reading performance. Most recently, Elwér (2014) investigated the contribution of PM ability, tested with pre-reading, pre-school children who were five-years old, in reading comprehension during second, fourth, eighth, and ninth grades; this paper also pointed to a connection between these variables. All of these studies included similar, simple PM measures, such as word span or pseudoword repetition, and generally similar reading measures. What varied was the participants' reading status and their age when the first phase of testing took place. Even research on adult illiterate and ex-illiterate participants from similar socioeconomic backgrounds has documented the significant effect of learning to read on PM development (e.g., Kosmidis et al., 2011; Reis & Castro-Caldas, 1997).

It may be that PM is most related to reading during the earlier years of a child or adult's educational development and prior to learning how to read. One explanation to support this argument is that PM is shown to be closely associated with phoneme awareness, a crucial variable in reading outcomes (Berninger, Abbott, Nagy, & Carlisle, 2010; Wagner et al., 1997). During pre-reading development, it is suggested that PM may influence the emergence of phonological awareness, particularly phoneme awareness, thus promoting the ease of learning to read (Berninger et al., 2010). However, once a child's phoneme awareness is developed in tandem with learning to read, PM may have a reduced influence on reading.

A second, alternative explanation is that simpler PM measures may not be the best predictors of reading. Specifically, Gathercole et al. (2006) found that PM, measured by simple PM tasks, such as digit span and word span, did not correlate with reading performance, but did significantly relate to verbal working memory (WM) tasks, whereas the verbal WM variable was the strongest predictor of reading. More consistent findings support a link between verbal WM and reading attainment because of the level of required manipulation, processing, and retention involved in verbal WM tasks than required in simpler PM tasks (e.g., Baddeley et al., 1998; see Demoulin & Kolinsky, 2015 for review).

Third, it is necessary to discuss the results from this study that indicate positive correlations between early reading and later PM. Although early reading was not found to predict later PM from the hierarchical regression analyses, the fact that an association was present is valuable to report. How reading development influences later PM skill is best explained by the lexical restructuring hypothesis proposed by

Metsala (1997) and Metsala and Walley (1998). Fowler (1991), one of the first to document this idea, hypothesized a shift in a child's phonological system from holistic phonological attributes (e.g., whole words or syllables) to segmental phonemic units. In the process of learning to read, it is suggested that the phonological system reorganizes shifting to more fine-grained phonological units. This systematic restructuring, through learning to read an alphabetic language, in turn, may promote growth in PM development (Metsala, 1997; Metsala & Walley, 1998).

In addition to PM being influenced by early reading, vocabulary knowledge also was found to predict later PM. This study provides evidence to suggest that these variables share variance and that early vocabulary knowledge promotes later PM development. The findings of Gathercole et al. (1992) support this theory; these authors documented that students' vocabulary knowledge at the age of six correlated with their PM ability two years later. These findings suggest that vocabulary development bolsters verbal memory.

An important implication concerns the causal role of PM in reading development. Considerable research has documented that PM is directly related to reading achievement, and that deficits in PM are seen in children with dyslexia (e.g., Brady, Shankwiler, & Mann, 1983; Catts, Adolf, Hogan, & Weismer, 2005; Snowling, Goulandris, Bowlby, & Howell, 1986). Wagner and Torgesen (1987) reported that these weaknesses are part of the phonological deficits that contribute to reading disabilities, such as dyslexia. Yet, the present study did not find that early PM related to later reading. However, it did indicate that early reading linked to later PM. This may provide evidence to suggest that PM is a consequence of reading development, rather than a cause.

A final point worth noting is the shared variance between word span and pseudoword repetition, the two PM measures utilized in this study. Several studies include one or both of these PM measures, yet no research to date has provided evidence to suggest the existence of shared or unique variance among them. In this study, two simpler PM measures were used to assess their correspondences with reading. Results from the present project showed that pseudoword repetition and word span share variance. This is important to document considering that PM measures frequently are used interchangeably.

Limitations and Future Directions

The strengths of this study will be acknowledged before delving into its limitations and the future directions. First, the present study contained a longitudinal dataset with three time points. In addition, this study included two PM measures that were compared for shared variance; a novel comparison in the field of reading research. Another strength of this study was the similar sample of demographics (i.e., participants attended the same, middle-class school); this helped control for variability in findings related to environmental factors.

Turning to the limitations of the study, a number of points will be made. First, this study contained a small sample of 54 participants. A post-hoc power analysis indicated that this sample size yielded a medium effect size estimate of $f^2 = 0.19$, with a post-hoc power of 0.80, but did not support a conservative small effect size of $f^2 = 0.02$, with a post-hoc power of 0.13. Nation and Hulme (2011), however, reported large effect size estimates in their study. This indicates that although the present study may be underpowered for a conservative small effect size estimate, it is similar, or more conservative, than previously published work on this topic. Originally, the sample contained 76 participants. However, 22 students dropped out by either the second or third testing time point. Group differences testing indicated that the participants who remained did not differ from those who dropped out. Yet, this drop-out rate of 16.72% is considered a limitation to the study because the number of participants who could be followed longitudinally became so small. Another limitation is that the participants were initially tested after having begun to read a year earlier. Because the purpose of the study was to examine the nature of the relationship between reading acquisition and PM, it would have been strongly preferable for the initial phase of testing to occur when the students were pre-readers. The third limitation includes the lack of ability to generalize the findings because participants attended only one school. Fourth, this longitudinal study took place over one and one-half year time, when participants were in their first and second grades of school. Thus, this short duration may not have been enough time to lend significant results for prediction tests.

Further research is needed to more thoroughly examine the relationship between early reading acquisition and later PM. Nation and Hulme (2011) reported one of the first studies that provided evidence in support of an association between these variables. However, more research is warranted to test this theory. Future research also is essential to test different PM measures, both simple PM (e.g., word span or pseudoword repetition) and complex verbal WM measures (e.g., backward digit span, sentence recall) and their contributions to reading, as well as the link between early reading and each of these measures. Additionally, it is important to consider in the future, conducting longitudinal studies beginning at a time when participants have not yet learned to read. This will generate a clearer understanding of the role of reading on PM, and vise versa. Lastly, because great variability across studies is present, researchers should attempt to provide more consistency between studies in future work.

In sum, the present study indicates that early PM does not predict later reading, early reading performance is associated with later PM, and word span and pseudoword repetition contain a moderate amount of shared variance. This study did not support Gathercole and Baddeley's (1993) findings, in that this study found a non-significant relationship between early PM and later reading. To a limited extent, the present work did, however, illustrate a link between early reading and later PM, similar to Nation and Hulme's (2011) study. These results point to the need for further research on these questions and to methodological factors that may improve the research on these topics.

BIBLIOGRAPHY

Al Otaiba, S., & Fuchs, D. (2002). Characteristics of Children Who Are Unresponsive to Early Literacy Intervention A Review of the Literature. *Remedial and Special Education*, *23*(5), 300-316.

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of experimental child psychology*, *106*(1), 20-29.

Alloway, T. P., Gathercole, S. E., Adams, A. M., Willis, C., Eaglen, R., & Lamont, E. (2005). Working memory and phonological awareness as predictors of progress towards early learning goals at school entry. *British Journal of Developmental Psychology*, *23*(3), 417-426.

Alloway, T. P. (2006). How does working memory work in the classroom?. *Educational Research and Reviews*, *1*(4), 134.

Alloway, T. P., Gathercole, S. E., & Pickering, S. J. (2006). Verbal and Visuospatial Short-Term and Working Memory in Children: Are They Separable?. *Child development*, *77*(6), 1698-1716.

Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature reviews neuroscience*, *4*(10), 829-839.

Baddeley, A. (2012). Working memory: theories, models, and controversies. *Annual review of psychology*, *63*, 1-29.

Baddeley, A., & Gathercole, S. (1992). Learning to read: The role of the phonological loop.

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological review*, *105*(1), 158.

Badian, N. A. (1998). A validation of the role of preschool phonological and orthographic skills in the prediction of reading. *Journal of Learning disabilities*, *31*(5), 472-481.

Berninger, V. W., Abbott, R. D., Nagy, W., & Carlisle, J. (2010). Growth in phonological, orthographic, and morphological awareness in grades 1 to 6.*Journal of psycholinguistic research*, *39*(2), 141-163.

Brady, S. A. (1991). The role of working memory in reading disability. *Phonological processes in literacy: A tribute to Isabelle Y. Liberman*, 129-151.

Brady, S., Poggie, E., & Rapala, M. M. (1989). Speech repetition abilities in children who differ in reading skill. *Language and Speech*, *32*(2), 109-122.

Brady, S., Shankweiler, D., & Mann, V. (1983). Speech perception and memory coding in relation to reading ability. *Journal of experimental child psychology*, *35*(2), 345-367.

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental neuropsychology*, *33*(3), 205-228.

Case, R., Kurland, D. M., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of experimental child psychology*, *33*(3), 386-404.

Catts, H. W., Adlof, S. M., Hogan, T. P., & Weismer, S. E. (2005). Are specific language impairment and dyslexia distinct disorders?. *Journal of Speech, Language, and Hearing Research*, *48*(6), 1378-1396.

Conti-Ramsden, G., & Durkin, K. (2007). Phonological short-term memory, language and literacy: developmental relationships in early adolescence in young people with SLI. *Journal of Child Psychology and Psychiatry*, *48*(2), 147-156.

Cunningham, A. E., & Stanovich, K. E. (1997). Early reading acquisition and its relation to reading experience and ability 10 years later. *Developmental psychology*, *33*(6), 934.

Demoulin, C., & Kolinsky, R. (2015). Does learning to read shape verbal working memory?. *Psychonomic bulletin & review*, 1-20.

Dempster, F. N. (1981). Memory span: Sources of individual and developmental differences. *Psychological Bulletin*, *89*(1), 63.

Donald, M. W. (1993). Precis of Origins of the modern mind: Three stages in the evolution of culture and cognition. *Behavioral and Brain Sciences*, *16*, 737–791. doi:10.1017/S0140525X00032647

Ellis, N. (1990). Reading, phonological skills and short-term memory: interactive tributaries of development. *Journal of Research in Reading*, *13*(2), 107–122. doi:10.1111/j.1467-9817.1990.tb00328.

Elwér, Å., Furnes, B., Gustafson, S., & Samuelsson, S. (2014). Pattern of Preschool Prediction of Reading Comprehension Impairment: A 10 Year Longitudinal Study.

Fowler, A. E. (1991). How early phonological development might set the stage for phoneme awareness. *Phonological processes in literacy: A tribute to Isabelle Y. Liberman*, *97*, 117.

Gathercole, S. E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory & Cognition*, *23*(1), 83-94.

Gathercole, S. E., Alloway, T. P., Willis, C., & Adams, A. M. (2006). Working memory in children with reading disabilities. *Journal of experimental child psychology*, *93*(3), 265-281.

Gathercole, S. E., & Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. *Journal of memory and language*, *28*(2), 200-213.

Gathercole, S. E., & Baddeley, A. D. (1990). The role of phonological memory in vocabulary acquisition: A study of young children learning new names. *British Journal of Psychology*, *81*(4), 439-454.

Gathercole, S. E., & Baddeley, A. D. (1993a). Essays in cognitive psychology. *Working memory and language. Hillsdale, NJ, England: Lawrence Erlbaum Associates*.

Gathercole, S. E., & Baddeley, A. D. (1993b). Phonological working memory: A critical building block for reading development and vocabulary acquisition?. *European Journal of Psychology of Education*, *8*(3), 259-272.

Gathercole SE, Pickering SJ, Ambridge B, Wearing H (2004). The structure of working memory from 4 to 15 years of age. Developmental Psychol. 40:177-190.

Gathercole, S. E., Willis, C., Emslie, H., & Baddeley, A. D. (1991). The influences of number of syllables and wordlikeness on children's repetition of nonwords. *Applied Psycholinguistics*, *12*(03), 349-367.

Gathercole, S. E., Willis, C. S., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental psychology*, *28*(5), 887.

Hayes, A. F. (2006). A primer on multilevel modeling. *Human Communication Research*, *32*(4), 385-410.

Heck, R. H., Thomas, S. L., & Tabata, L. N. (2013). *Multilevel and longitudinal modeling with IBM SPSS*. Routledge.

Heck, R. H., Thomas, S. L., & Tabata, L. N. (2014). Examining individual change with repeated measures data. *Multilevel and longitudinal modeling with IBM SPSS, 2nd edn. Routledge, New York*.

Iacobucci, D., Saldanha, N., & Deng, X. (2007). A meditation on mediation: Evidence that structural equations models perform better than regressions. *Journal of Consumer Psychology*, *17*(2), 139-153.

Kamil, M. L. (2004). Vocabulary and comprehension instruction: Summary and implications of the national reading panel findings. In P. McCardle, & V. Chhabra (Eds.), *The voice of evidence in reading research.* (pp. 213-234). Baltimore, MD, US: Paul H Brookes Publishing.

Kosmidis, M. H., Zafiri, M., & Politimou, N. (2011). Literacy versus formal schooling: influence on working memory. *Archives of clinical neuropsychology*, *26*(7), 575-582.

Mann, V. A., & Liberman, I. Y. (1984). Phonological Awareness and Verbal Short-Term Memory. *Journal of Learning Disabilities*, *17*(10).

Mather, N., & Woodcock, R. (2001). *Woodcock-Johnson III Tests of Achievement, Examiner's Manual.* Itasca, IL: The Riverside Publishing Company.

Melby-Lervåg, M. (2012). The relative predictive contribution and causal role of phoneme awareness, rhyme awareness, and verbal short-term memory in reading skills: A review. *Scandinavian Journal of Educational Research,56*(1), 101-118.

Metsala, J. L. (1997). Spoken word recognition in reading disabled children. *Journal of Educational Psychology, 89*(1), 159.

Metsala, J. L. (1999). Young children's phonological awareness and nonword repetition as a function of vocabulary development. *Journal of Educational Psychology*, *91*(1), 3.

Metsala, J. L., & Walley, A. C. (1998). Spoken vocabulary growth and the segmental restructuring of lexical representations: Precursors to phonemic awareness and early reading ability.

Michas, I. C., & Henry, L. A. (1994). The link between phonological memory and vocabulary acquisition. *British Journal of Developmental Psychology*,*12*(2), 147-163.

Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding?. *Journal of experimental child psychology*, *64*(2), 199-231.

Morais, J., Bertelson, P., Cary, L., & Alegria, J. (1986). Literacy training and speech segmentation. *Cognition*, *24*, 45–64. doi:10.1016/0010-0277(86)90004-1

Morais, J., Cary, L., Alegria, J., & Bertelson, P. (1979). Does awareness of speech as a sequence of phones arise spontaneously? *Cognition*, *7*(4), 323–331. doi:10.1016/0010-0277(79)90020.

Nation, K., & Hulme, C. (2011). Learning to read changes children's phonological skills: Evidence from a latent variable longitudinal study of reading and nonword repetition. *Developmental science*, *14*(4), 649-659.

National Institute of Child Health and Human Development. (2000). *Report of the National Reading Panel. Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction* (NIHPublication No. 00-4769).

Perfetti, C. A. (1985). *Reading Ability*. New York, NY, US : Oxford University Press.

Piquard-Kipffer, A., & Sprenger-Charolles, L. (2013). Early predictors of future reading skills: A follow-up of French-speaking children from the beginning of kindergarten to the end of the second grade (age 5 to 8). *L'année Psychologique*, *113*, 491–521. doi: 10.4074/S0003503313014012.

Preßler, A. L., Könen, T., Hasselhorn, M., & Krajewski, K. (2014). Cognitive preconditions of early reading and spelling: a latent-variable approach with longitudinal data. *Reading and Writing*, *27*(2), 383-406.

Puolakanaho, A., Ahonen, T., Aro, M., Eklund, K., Leppänen, P. H., Poikkeus, A. M., ... & Lyytinen, H. (2008). Developmental links of very early phonological and language skills to second grade reading outcomes: Strong to accuracy but only minor to fluency. *Journal of Learning Disabilities*.

Reis, A., & Castro-Caldas, A. (1997). Illiteracy: A cause for biased cognitive development. *Journal of the International Neuropsychological Society*, *3*(05), 444-450.

Savage, R., Lavers, N., & Pillay, V. (2007). Working memory and reading difficulties: What we know and what we don't know about the relationship. *Educational Psychology Review*, *19*(2), 185-221.

Scarborough, H. S., Neuman, S., & Dickinson, D. (2009). Connecting early language and literacy to later reading (dis) abilities: Evidence, theory, and practice. *Approaching difficulties in literacy development: Assessment, pedagogy, and programmes*, 23-39.

Seigneuric, A., & Ehrlich, M. F. (2005). Contribution of working memory capacity to children's reading comprehension: A longitudinal investigation. *Reading and writing*, *18*(7-9), 617-656.

Senechal, M., & LeFevre, J. (2002). Parental involvement in the development of children's reading skill: A five-year longitudinal study. *Child Development*, *73*(2), 445-460.

Shek, D. T., & Ma, C. (2011). Longitudinal data analyses using linear mixed models in SPSS: concepts, procedures and illustrations. *The Scientific World Journal*, *11*, 42-76.

Siegel, L. S., & Ryan, E. B. (1989). The development of working memory in normally achieving and subtypes of learning disabled children. *Child development*, 973-980.

Snowling, M., Goulandris, N., Bowlby, M., & Howell, P. (1986). Segmentation and speech perception in relation to reading skill: A developmental analysis. *Journal of Experimental Child Psychology, 41*(3), 489-507.

Soltani, A., & Roslan, S. (2013). Contributions of phonological awareness, phonological short-term memory, and rapid automated naming, toward decoding ability in students with mild intellectual disability. *Research in developmental disabilities*, *34*(3), 1090-1099.

Sprugevica, I., & HØien, T. (2003). Early phonological skills as a predictor of reading acquisition: A follow-up study from kindergarten to the middle of grade 2. *Scandinavian Journal of Psychology*, *44*(2), 119-124.

Stanovich, K. E. (1982). Individual Differences in the Cognitive Processes of Reading: II. Text-Level Processes. *Journal of Learning Disabilities*, *15*(9).

Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading research quarterly*, 360-407.

Stone, B., & Brady, S. (1995). Evidence for phonological processing deficits in less-skilled readers. *Annals of Dyslexia*, *45*(1), 51-78.

Swanson, H. L., & Howell, M. (2001). Working memory, short-term memory, and speech rate as predictors of children's reading performance at different ages. *Journal of Educational Psychology*, *93*(4), 720.

Tabachnick, B. G. & Fidell, L. S. (2007). *Using multivariate statistics* (5^{th} ed.) Allyn & Bacon/Pearson Education, Boston, MA.

Tannenbaum, K. R., Torgesen, J. K. & Wagner, R. K. (2006) The relationships between word knowledge and reading comprehension in third-grade children. *Scientific Studies of Reading, 10*(4), 381-398.

VanVoorhis, C. R. W., & Morgan, B. L. (2007). Understanding power and rules of thumb for determining sample sizes. *Tutorials in Quantitative Methods for Psychology*, *3*(2), 43-50.

Verheuven, L., van Leeuwe, J., & Vermeer, A. (2011). Vocabulary growth and reading development across the elementary school years. *Scientific Studies of Reading, 15(1)*, 8-25

Wagner, D.A. (1974). The development of short-term and incidental memory: A cross- cultural study. *Child Development,45*. 389-396. doi: 10.2307/1127960.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological bulletin*, *101*(2), 192.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). Development of reading-related phonological processing abilities: New evidence of bidirectional causality from a latent variable longitudinal study. *Developmental psychology*, *30*(1), 73.

Wagner, R. K., Torgesen, J. K., Rashotte, C. A., Hecht, S. A., Barker, T. A., Burgess, S. R., ... & Garon, T. (1997). Changing relations between phonological processing abilities and word-level reading as children develop from beginning to skilled readers: a 5-year longitudinal study. *Developmental psychology*, *33*(3), 468.

Woodcock, R. W. (1998). *Woodcock Reading Mastery Tests, Revised, Examiner's Manual*. American Guidance Service.