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Working Memory and Attention as Predictors of Processing Speed in Elementary School Students: A Developmental Study

Monih Alshehri
Andrews University, monih@andrews.edu

ABSTRACT

WORKING MEMORY AND ATTENTION AS PREDICTORS OF PROCESSING SPEED IN ELEMENTARY SCHOOL STUDENTS: A DEVELOPMENTAL STUDY

by

Monih Alshehri

Chairs: Nadia Nosworthy and Tevni Grajales

ABSTRACT OF GRADUATE RESEARCH

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Title: WORKING MEMORY AND ATTENTION AS PREDICTORS OF PROCESSING SPEED IN ELEMENTARY SCHOOL STUDENTS: A DEVELOPMENTAL STUDY

Name of researcher: Monih Alshehri

Name and degree of faculty chairs: Nadia Nosworthy, PhD and Tevni Grajales, PhD

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Problem

Many studies suggest that Processing Speed (PS), Attention, and Working Memory (WM) are major cognitive functions that collaborate to achieve a coherent cognitive system. The aim of the current study was to improve the conception of how these cognitive functions interrelate. The study addressed two main questions: the first, whether PS can be predicted by WM (visual, verbal, and the central executive) and attention of elementary students in first and fifth grade; the second, whether there are gender differences in the rate of change in WM and PS from first to fifth grade.

Method

The participants were taken from a longitudinal study (*n* = 145, 71 boys) by Li and Geary (2017). In the study, students' WM was assessed by the Working Memory Test Battery for Children, PS was assessed by Rapid Automatic Naming, and attention was assessed by Strength and Weaknesses of ADHD—Symptoms and Normal Behavior (SWAN). The current study used canonical correlations and MANOVAs to answer the research questions.

Results

Overall correlations between the processing speed in fifth grade and working memory in first grade and attention was statistically significant (Wilks' *Lambda* = .78, $F_{(8, 278)}$ = 4.61, $p < .001$, Rc2 = .17). Attention was a significant predictor (*Beta* = -.19, p = .024) of processing speed of number in fifth grade. The central executive in first grade (*Beta* = -.36, p =.001) was also a significant predictor of the processing speed of number in fifth grade. Correlations between processing speed in fifth grade and working memory in fifth grade and attention was statistically significant (Wilks' *Lambda* = .80, $F_{(8, 278)}$ = 4.11, $p < .001$, Rc2 = .19). Visual working memory in fifth grade (*Beta* = -.21, p = .017) was the only significant predictor for processing speed of number in fifth grade. In terms of gender differences in the rate of change in working memory and processing speed from first to fifth grade the multivariate effect of gender was not statistically significant in which working memory (Wilks' *Lambda* = 0.98, $F_{(3, 141)}$ = .54 p = .65) and processing speed (Wilks' *Lambda* = 0.98, $\mathrm{F}_{(2, 1412)}$ = 1.29 p = .65)

Conclusions

The central executive and attention in fifth grade were the best predictors of processing speed performance in fifth grade. However, in fifth grade the role of these cognitive functions in predicting processing speed shifted in which only visual working memory was the best predictor.

Andrews University

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A Dissertation

Presented in Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

by

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APPROVAL BY THE COMMITTEE:

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Co-chair: Nadia Nosworthy

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Co-chair: Tevni Grajales

____
Member: D'Jaris Coles-White

____
External: Lionel Matthews

____
Dean, College of Education and
International Services
Alayne Thorpe

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Date approved

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In The Name of Allah, The Beneficent, The Merciful

I gratefully thank Allah who provided me with skills and patience through this journey. It is through Him that this project was completed. I would like to dedicate this accomplishment to my family for their love, prayers, encouragement, and caring, specially my father who inspired me in pursuing a doctorate degree. I wish he were here with me enjoying this success which was his dream as well. I am blessed to have my beloved husband, Mohammed, who has supported me during the last five years. I am extremely appreciative to have him along and for all that he has been to me.

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CHAPTER 1

INTRODUCTION

General Introduction

Cognitive abilities are interrelated inasmuch as one function is likely to affect the efficiency of another. All cognitive processes are harmonized to achieve a unified and goal-directed action. In cognitive development research, one goal is to determine cognitive functions that change over time and if that change is different from one cognitive ability to another. Cognition refers to the processes of the mind demonstrated in abilities like attention, memory, reasoning, spatial processing, problem-solving, language, and perception. The human cognitive function research emphasizes nature-and-nurture factors and its impact on learning and methods of thinking during the early years of life.

The interaction between development and cognition can be best explained by the roles of biology, experience, and environment. Hence, some of the developmental cognitive theories are driven by the biological domain, while others come from the social or experimental domain. The roles of biology, experience, and environment can be better understood via theories of cognitive function like fluid intelligence and crystallized intelligence as well as the difference between them. Both theories demonstrate the development and interaction between intellectual ability and fundamental cognitive functions such as attention and memory (Cattell, 1971; Horn & Cattell, 1966). Fluid intelligence is recognized as a biological ability in which the individual theoretically reasons through novel situations. Knowledge and skills that an individual develops by experience, education, and acculturation is crystallized intelligence (Tourva, Spanoudis, & Demetriou, 2016).

Tourva et al. (2016) investigated the association between general fluid intelligence and crystallized intelligence by examining the relationships among three cognitive functions—processing speed (PS), attention, and working memory (WM)—as well as the effect of age on each one. WM was the only predictor of general fluid intelligence and crystallized intelligence when controlling for both PS and attention. However, age significantly affected these three cognitive functions (attention, PS, WM), which is supported by other developmental studies (Brocki & Bohlin, 2004; Coyle, Pillow, Snyder, & Kochunov, 2011; Demetriou et al., 2013; Fry & Hale, 2000; Kail, 2007; McAuley & White, 2011).

One of the essential cognitive functions that affect academic skills and other cognitive functions is PS (Floyd, McGrew, & Evan, 2008; Naples, Katz, & Grigorenko, 2012; Vukivic & Siegel, 2010). In 1883, Galton was one of the first to study how PS related to other cognitive functions through measuring reaction time, various sensory, and motor variables relative to indicators of achievement or intellectual ability. Many studies claimed that PS explains the association between the capacity of WM and fluid intelligence and is an essential characteristic of intellectual capacity (Sheppard & Vernon, 2008).

According to mental speed theory, PS is considered a vital basis of higher cognitive functions like creativity and intelligence, which affect academic and job performance in daily life. The main goal of the current study was to understand cognitive function in elementary school students by examining whether PS abilities can be predicted by WM components (visual, verbal, the central executive), and attention. In addition, changes in WM and PS were compared between boys and girls from first to fifth grades, which provides a comprehensive construct of student cognitive function in first and fifth grades.

Statement of the Problem

According to many studies, PS and WM improve with age (Coyle et al., 2011; Demetriou et al., 2013; Fry & Hale, 2000; Kail, 2007; McAuley & White, 2011). McAuley (2008) provided a comprehensive understanding of the improvement and interaction among three cognitive functions – PS, inhibition, and WM – in a group of participants ages 6 - 24. Her study revealed that these cognitive functions are separate abilities which improved at different rates; however, they are interrelated in which PS directly affected inhibition and WM. In addition, inhibition partly mediates the effect of PS on WM. These connections were relatively sustained over the age range which may indicate that they are established during early childhood. In order to understand how these cognitive functions are related to each other, we need to define them first.

According to Jensen (2004), PS is the ability to efficiently perform an accelerated task to process any material, while WM involves holding and manipulating those materials, which can be either visual or verbal input, and at the same time blocking any additional information, which is basically an inhibition process. Inhibition includes two steps when operating with information (McAuley, 2008). The first step is during the input, in which only relevant information is attended to while irrelevant information is ignored. The second step is during the output — choosing the appropriate responses and blocking inappropriate responses (Jensen, 2004; McAuley, 2008).

The literature provides supporting evidence for the relationship among cognitive functions. Most studies have examined the developmental change in cognitive functions over the life span through the different stages of childhood, adolescence, and adulthood. However, the purpose of the current study was to examine the cognitive functions including PS, visuospatial WM, verbal WM, the central executive, and attention only during the elementary grades by identifying how these cognitive functions in first and fifth grades differently predict PS in fifth grade.

The cognitive development and relationship between cognitive functions like PS and WM (visual, verbal, and the central executive) can be illustrated through the developmental cascade model theory designed by Fry and Hale (2000). The intention of this model is to describe the effects of differences related to age in both PS and WM on differences related to age in fluid reasoning (see Figure 1). Various studies provided evidence of the Cascade Model among both children and adult populations (De Riabaupierre & Lecerf, 2006; Nettelbeck & Burns,2010). Improvement of PS and WM functions during childhood and adolescence can indicate the growth in the ability of solving arithmetic word problems accurately (Kail & Hall, 2001). Kail (2007) designed another model to test Fry and Hale’s (2000) cascade model through longitudinal evidence. Kale’s model links improvement in PS to higher WM capacity, and the role of WM in improving better inductive reasoning. The model provides a series of connections in which WM has direct effects in the developmental change of inductive reasoning directly, while indirectly affecting PS.

The variance in PS among individuals has been suggested to be dependent on the

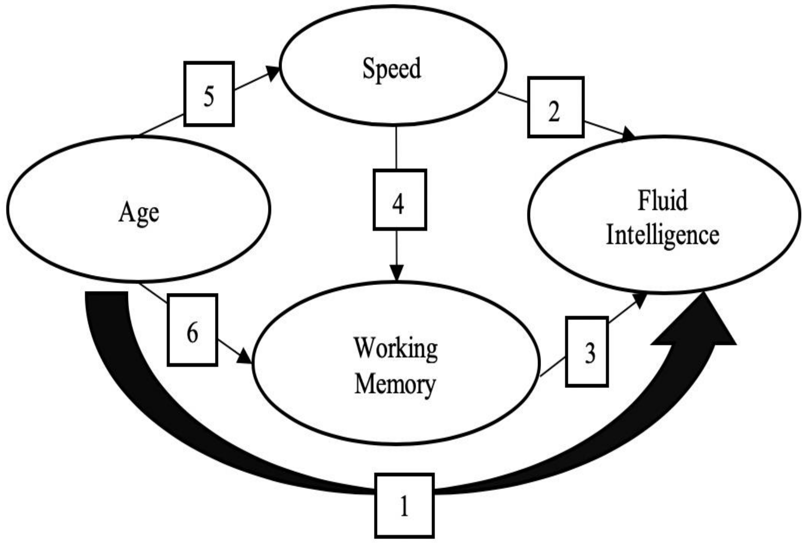

Figure 1. Developmental cascade model indicating the six possible causal links (Fry and Hale, 2000).

variation on the structured organization of the white matter pathways in the brain. Organization of the white matter pathways enforces and facilitates the communication and coordination between cortical nodes of the networks in the brain (Turken et al., 2008). Jensen (2006) suggested that a reduction in cognitive functions during adulthood and old age is linked to changes in brain structure that have been changing across childhood and lead to improved cognitive functions. Through childhood and adolescence PS improves and becomes faster, but then slows during adulthood (Nettelbeck & Burns, 2010). Kail (2007) also introduced the idea that during childhood PS improves quickly, but asymptotes during adolescence by about fourteen years old. Similarly, Salthouse (1996) provided supporting evidence that on average, during adulthood from age twenty to age eighty, PS shrinks, in an approximately linear manner.

According to Jensen (2006), an interpretation of the improvement in PS is a result of brain structures maturing. The structure of the brain achieves ideal capacities by early adulthood. Simultaneously, WM and all other cognitive functions improve and peak at their greatest level by early adulthood, then decline gradually during adulthood. According to Baddeley and Hitch (2000), a higher WM span is the result of rapid PS for two reasons. First, WM has only a limited time to process information. The second reason is the resource-related phenomena. Research has suggested that the limited cognitive resources used by the WM system are also shared by PS (Gavens & Barrouillet, 2004; Magimairaj & Montgomery, 2012). The hypothesis of shared resources is supported via an experiment that showed increases in WM load resulted in slower PS, while increased demands on PS caused a reduction in WM capacity (Gavens & Barrouillet, 2004).

The relationship among major cognitive functions like PS, attention, and WM is a fundamental aspect of intelligence (Burns, Nettelbeck, & McPherson, 2009; Deary, 2012; Fink & Neubauer, 2005; Schweizer, 2005; Schweizer & Moosbrugger, 2004; Tillman, Bohlin, Sorensen, & Lundervold, 2009). Many studies have suggested that PS, attention, and WM are major cognitive function pillars of intelligence. Various studies have stressed the contribution of attention which controls processing in intellectual abilities (Burns et al., 2009; Schweizer & Moosbrugger, 2004; Tillman et al., 2009).

Tourva et al. (2016) and Schweizer (2005) suggested that adults showed various forms of attention such as interference, inhibition, sustained attention, alertness, and attentional switching, which are connected to fluid intelligence. This correlation indicates that among other sources, attention is a cognitive source. However, Schweizer and

Moosbrugger (2004) suggested that these categories of attention are different from and dependent on each other. Thus, they each show a difference in relation to intelligence.

Another area of investigation is gender differences in cognitive functions such as PS and WM components. Longman, Saklofske, and Fung (2007) examined gender differences on composite and index results of the Wechsler Adult Intelligence Scale (WAIS) in two groups: one from the U.S. and the other from Canada. Males exhibited a slightly higher IQ (3–4 points) in the American group, while females exhibited a greater PS index score. In the Canadian group, the only gender difference was in the PS index, with females having slightly higher scores. According to Camarata and Woodcock (2006), there is a general opinion that general intellectual abilities are not different between males and females, but differences can occur within various cognitive abilities that contribute to general intelligence.

Purpose of the Study

The main purpose of this study was to understand cognitive function in elementary students. The present study examined whether WM components (visual, verbal, the central executive), and attention behavior in first and fifth grades can predict PS ability in fifth grade. This study also intended to determine whether changes in PS and WM from first to fifth grades differ between boys and girls.

The current study provides a better understanding of how attention, WM, and PS relate to each other and whether boys and girls are different in the rate of change in WM and PS. Understanding normal brain development of these cognitive functions provides educators and psychologists with knowledge of how to approach each grade level and gender by designing the right method of teaching, assisting, or even interventions for those who have deficits in one or more of these cognitive functions.

Importance and Significance

During the last three decades, human intelligence studies have emphasized the importance of identifying and analyzing cognitive components. Out of this analysis, vital cognitive components were identified in research: PS, WM capacity, and attention (Burns et al., 2009; Schweizer, 2005; Schweizer & Moosbrugger, 2004; Tillman et al., 2009). The developmental change of these cognitive functions and others has been extensively mapped over the last century. However, many questions are still open regarding how each of these cognitive functions are distinctly associated with different stages in the student's life. Most of the studies are interested in comparing how early children differ from adolescents or adults in these cognitive functions. However, the current study investigated how these cognitive functions relate to each other in early childhood students (first grade) compared to middle childhood students (fifth grade). Elementary school is extremely important for student's development and learning. Development at this stage influences cognitive, social, emotional, language, and physical development, which affects school preformance at higher levels. Futhermore, by ages 6-7 years old children have achieved 90% of their adult brain size (Duncan, Ziol-Guest& Kalil, 2010; Luby et al., 2013).

In addition, according to Hawke (2008), variation in cognitive functions has been connected to gender differences; various biological and environmental assumptions have been suggested as reasons for different cognitive rates between males' and females' genetic differences in brain functioning. However, there has been relatively little data revealing cognitive gender differences, specifically over developmental time. Moreover, few recent studies have investigated the developmental change in these cognitive abilities. The current study is the first to investigate the development of PS and WM components in the concrete operational stage by comparing first-grade to fifth-grade assessments in PS and WM. The current study examines the longitudinal change in these cognitive functions, unlike virtually most of the developmental studies that have been cross-sectional.

One of the cognitive functions, that has a major influence on other cognitive skills and academic performance, is PS (Floyd et al., 2008; Naples et al., 2012; Vukivic & Siegel, 2010). Various disabilities have been associated with poor PS (Floyd et al., 2008). Although this cognitive function is important, there is lack of agreement in the literature concerning the development of PS and how it can be predicted by other cognitive functions like WM components and attention in both elementary age boys and girls. The current study aims to fill this gap in the literature by investigating the relationship between predictor variables (WM and attention) and PS in a sample of students in first and fifth grade.

Limitations

1. A key limitation of the current study is the lack of previous studies that include the same cognitive functions when investgating PS. Most of the prior studies examined these cognitive functions separately.

2. Since the current study used secondary data taken from Li and Geary (2017), the study is restricted to the sample taken from their study. Also, the researcher did not have

control over what types of instruments were used to assess students' performance and time or environment when measuring students' performance.

Delimitations

While this study concentrates on PS, WM components (visual, verbal, central executive), and attention behavior, the following delimitations will be in effect:

1. The study investigates only elementary students who were assessed in attention, WM, and PS during first grade and later in fifth grade.

2. The study is interested in only elementary students who are not enrolled in any special program in school.

3. Other components of executive functions which are not included in the study include inhibition, cognitive flexibility, and problem-solving.

4. The study relies on preexisting longitudinal data that only examined the elementary cognitive abilities that have been suggested in the literature review as an essential ability of fluid intelligence.

5. Variation of the age of both first- and fifth-grade elementary students may influence the students' performance. Students at the same grade level might be at different ages which can affect the maturation of these cognitive functions.

Conceptual/Theoretical Framework

The current study integrated both the Cattell-Horn-Carroll (CHC) model of cognitive functions and Baddeley and Hitch's (2000) WM model to illustrate the relationship between PS, visual WM, verbal WM, central executive, and attention. The CHC model (see Figure 2) displays a wide-ranging taxonomy of entire human cognitive functions that are currently known (McGrew & Wendling, 2010). It integrates both Cattell-Horn's fluid and crystallized intelligence theory (McAuley, 2008) and Carroll's three-stratum theory (Schneider & McGrew, 2012). The CHC theory gains a lot of attention in the research literature. Numerous empirical studies support this theory such as developmental, neurocognitive, and outcome criterion of measurement. The theory is also utilized widely in designing and interpreting intellectual tests.

According to Schneider and McGrew (2012), Cattell built on Spearman's idea of general intelligence (g). Cattell suggested that general intelligence can be divided into Fluid Intelligence (Gf) and Crystallized Intelligence (Gc). Cattell and Horn then added Cognitive Speed (Gs) to their Gf-Gc model, which was considered one of five broad ability factors that they theorized to underlie g. PS remained a major part of the model as the theory.

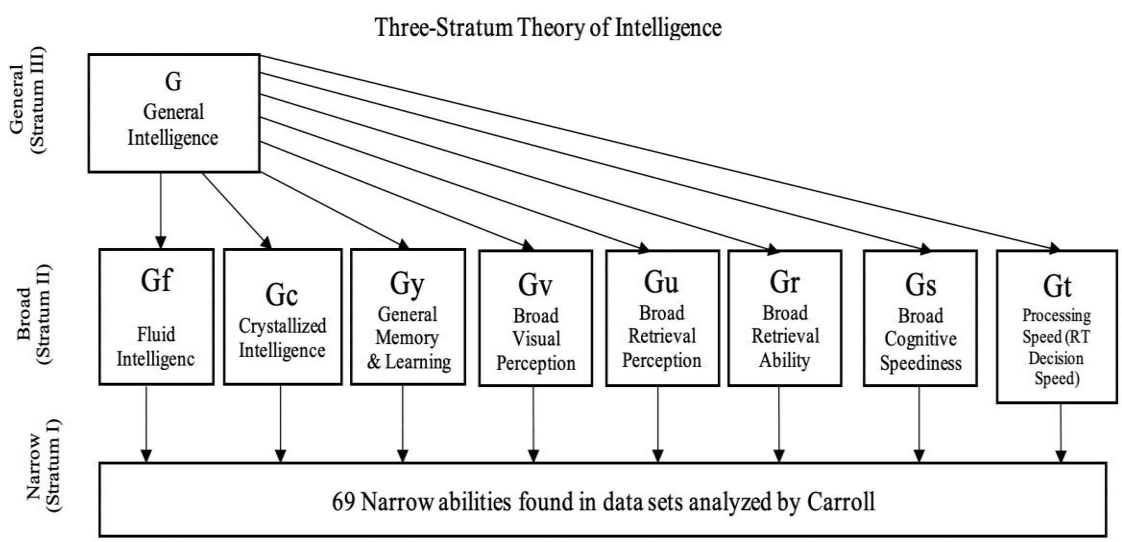

Figure 2. Cattell-Horn-Carroll (CHC) model of cognitive functions.

The model was then reorganized in the 1990s into tiers in which g was at the top in Stratum III (Schneider & McGrew, 2012). The next tier, Stratum II, included the wide-ranging abilities Gf, Gc, and Gs. The last tier, Stratum I, involved narrow abilities that factored together to create wide abilities. The Gs remains to be a wide Stratum II ability, and the narrow Stratum I abilities thought to underlie it was specified (see Figure 2). There were originally three narrow abilities for Gs: Perceptual Speed, Correct Decision Speed, and Writing/Printing Speed. The most current model of CHC included global intelligence, wide abilities, and narrow abilities. In the model, PS is a broad ability that factors into more specific abilities, including Perceptual Speed, Rate of Test Taking, Semantic Processing, Speed of Reasoning, Number and Math Fluency, and Reading and Writing Fluency (McGrew & Wendling, 2010; Schneider & McGrew, 2012).

Other theorists suggested that PS itself may not work in isolation but instead interrelates with the other cognitive functions such as WM (Miller, 2007). For example, a study examined how PS improved among multiple sclerosis (MS) and healthy individuals. The Visual Threshold Serial Addition Test (VT-SAT) was used to measure PS at varying WM loads (Lengenfelder et al., 2006). The study indicated that PS, not accuracy, was the main issue with the MS group. When WM load was low the MS group performed as well as the normal group, but needed more processing time; however, when the WM load was high, about 70% of the MS group performed as the normal group, but again needed more processing time. The study concluded that with high WM load there is an interference between PS and WM. During low WM loads no difference is observed in the level of WM performance in individuals either with or without multiple sclerosis. In addition, the study indicated that connection between the performance of PS and WM are naturally active which highlights the impact of other variables like disease-related factors and other cognitive functions on this connection between PS and WM (Lengenfelder et al., 2006).

The connection between PS and WM is best understood by Baddeley and Hitch's (1974) model of WM. They proposed a WM model that involves multiple components instead of a single, unified construct. In their model, Baddeley and Hitch suggested three parts of the WM—the central executive, phonological loop, and visuospatial sketchpad—as an alternative to the short-term memory in Atkinson and Shiffrin's (1968) "multi-store" memory model (Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005; Gavens & Barrouillet, 2004).

The current study focuses on WM components: the central executive, the phonological loop, and visual-spatial sketchpad. The central executive is basically a guiding system that controls the information coming in and out of its other systems, which are the phonological loop, and visual-spatial sketchpad. The phonological loop stores verbal content, while the visual-spatial sketchpad caters to visual-spatial data.

Baddeley (2012) defined the phonological loop as "a relatively modular system comprising a brief store together with a means of maintaining information by vocal or subvocal rehearsal" (p. 7). WM has a limited span. For instance, after a rehearsed number of repetitions, at some point, the first or second item will be forgotten. Word-length effect supports the function of articulation. Short-term memory span shrinks when word length increases. Recalling one syllable is easier than recalling five syllables.

Similar to verbal, visual WM is basically restricted to three or four items. Typically, we record visual details around us constantly, but most of them are unnecessary. Visual memory records objects, features like color, location, and shape, and dimension (Baddeley, 2000). The visual and spatial memory are different according to neuropsychological studies. According to Smith et al. (1995), the difference between visual and spatial coding relates to separate processing paths for the encoding of “what” and “where” information.

In terms of how academic achievement is linked to verbal and visual memory, studies have suggested that both visual-spatial and verbal illustrations are produced when solving, simple arithmetic problems (Imbo & LeFevre, 2010). Performance of single-digit calculations is associated with the phonological loop. Even though phonological load caused mediation on simple arithmetic problems, it did not produce more mediation than did the visual-spatial load on particular math operations such as multiplication (Raghubar, Barnes, & Hecht, 2010). According to Seitz and Shumann-Hengsteler (2000), small-size multiplication problems are not associated with the visual-spatial sketchpad in adult Germans. When the visual-spatial sketchpad was overloaded, performance in addition and subtraction was less adequate. However, multiplication needs the integrity of language-based representations of number since it is typically learned by rote verbal memorization (Dehaene, Piazza, Pinel, & Cohen, 2005).

Research Questions/Hypotheses

To what extent can students’ PS ability in fifth grade be predicted by their attentive behavior, and WM components (visual WM, verbal WM, and the central executive) in first and fifth grades? Do the changes in these cognitive functions differ between boys and girls?

Ho1: PS ability of number and letter in fifth grade can be predicted by attention, visual WM, verbal WM, and the central executive in first grade.

Ho2: PS ability of number and letter in fifth grade can be predicted by attention, visual WM, verbal WM, and the central executive in fifth grade.

Ho3: Change in WM components (visual WM, verbal WM, and the central executive) in first and fifth grades are significantly different among boys and girls.

Ho4: Change in PS (letter and number) in first and fifth grades are significantly different among boys and girls.

Definition of Terms

Attention: A cognitive process that leads to selective concentration on a particular object or material, and ignores other perceivable materials (Anderson, 2004).

Central Executive: A system that flexibly supervises and regulates cognitive processes. This system controls and coordinates the operation of the visuospatial sketchpad and phonological systems and relates them to long-term memory (LTM; Baddeley, 2012).

Cognitive Ability: refers to a broad range of skills involving the learning process, memory, attention, perception, language, intelligence, and reasoning (McQueen, 2017). However, for the purpose of the current study cognitive ability will be defined as the following specific functions: visual WM, verbal WM, central executive, and attention.

Processing Speed: The ability to rapidly, accurately, and smoothly complete a simple cognitive or academic task (Floyd et al., 2008).

Verbal Working Memory: According to Baddeley (2012), the phonological loop controls verbal WM and has two characteristics. The first is a phonological store, which conserves words in oral form for one to two seconds. The second is the process of articulating control. This articulation utilizes rehearsal and holds verbal materials from the phonological store.

Visual Working Memory: The study will adopt Baddeley's (2012) definition for Visuospatial Sketchpad (VSS). VSS is also utilized as a navigation system that stores and processes visual or spatial materials.

CHAPTER 2

LITERATURE REVIEW

Human cognitive abilities control all activities undertaken through storage, integration processes, and activation of new information or problems (McAuley & White, 2011). These activities may be either voluntary or involuntary. Whatever the case, it is the function of the brain to coordinate stimuli from the environment and coordinate the required action. Students at the elementary level undergo a variety of activities, which might be new to them. At this stage, their memories and synaptic activity are actively multiplying to accommodate the new aspects brought in the field of learning. This literature review is an in-depth discussion of the connection between PS and verbal WM, visual WM, the central executive, attention, and the difference in the cognitive functions between male and female elementary students.

Cognitive abilities are interrelated so that one function is likely to affect the efficiency of the others. All cognitive processes are harmonized to achieve a unified and goal-directed action. In elementary students, such processes are pivotal in establishing the foundation of the learning process (Baddeley, 2017). Researchers have been questioning whether cognitive function changes in individuals over time and whether this change is different from one cognitive ability to another (Demetriou et al., 2013; Demetriou et al., 2014; Fry & Hale, 2000; Kail, 2007; Tourva et al., 2016).

Investigating human intelligence cognitive foundations reveals a number of cognitive functions that strongly predict psychometric test scores such as PS, attention control, and WM (Deary, 2012; Deary, Spinath, & Bates, 2006; Fink & Neubauer, 2005; Tillman et al., 2009; Tourva et al., 2016). These three cognitive functions are essential cognitive correlates of human intelligence; they are considered to be major cognitive pillars of intelligence (Burns et al., 2009; Deary, 2012; Fink & Neubauer, 2005; Schweizer, 2005).

Processing Speed

PS is the overall time a person takes to correctly respond to a cognitive task. Bors and Forrin (1995) defined PS as the rate taken for perceiving, attending, and integrating stimuli through the cerebral cortex with the aim of performing a task or making a required response. According to DeLuca (2008), PS is the duration of time required to perform a certain cognitive task or the number of works that can be read during a limited period of time. Since the 1800s, PS has been considered an important cognitive process. However, until now there has been no universally accepted definition of PS in the field of psychology (Jensen, 2004).

According to Lichtenberger and Kaufman (2012), PS cannot predict how quickly students are likely to learn a new skill but is a decent predictor of how skilled they can become after mastering the new skill. In other words, if two students are equally good at learning a new skill, they still might be different in how rapidly and accurately they can perform the skill. Jensen (2004) stated that PS is the ability to efficiently process information, that efficiency is typically deduced from performance on accelerated tasks. PS function can be defined as processing information rapidly. This function is highly correlated to the ability to complete higher-order cognitive tasks, which is the main issue that causes deficits in complex cognitive measures in aging populations (Lichtenberger & Kaufman, 2012).

It has been suggested that PS can be divided into five models: two conceptual models (a unitary model and a complexity model), and three methodological models (a stimulus material model, an output modality model, and a timing modality model; Barth, Catts, & Anthony, 2008; Kail, 2000; Tucker-Drob & Salthouse, 2008). The unitary model suggests that PS develops in a constant manner across the lifespan (Kail, 2007). When analyzing PS among other latent variables of cognitive function, factor analyses identified a single latent variable of PS, which provides evidence for the unitary model (Gerst, 2017).

However, evidence has supported that the PS complexity model can be examined as separate factors, specifically in childhood. For example, the dedifferentiation theory proposes that in adults, the cognition re-integrates the differentiated factors present in late childhood/early adolescence. Another finding regarding the differentiation within construct structure in childhood can be examined in executive function (EF), which appears to be represented by a single, identifiable factor in early childhood, and this may later differentiate into separate but related processes in adolescence and adulthood (Anderson et al., 2001; Anderson, 2004; Gerst, 2017; Lee, Bull, & Ho, 2014; Miyake et al., 2000).

The methodological models are another construct of PS. Methodological models divide PS according to tasks like input material, either verbal or visual, output format, either oral or manual, and by timing formats like latency, either time-dependent or timed performance. In the input material, the task stimuli are divided into two categories:

alphanumeric (letter and words), and non-alphanumeric (shapes and colors). In the output format, PS is measured by a motor speed task or a verbal-response speed task, which makes it relevant for any studied population. In the timing format, measurement of PS is based on the time needed for a basic cognitive function (i.e., RT) or the latency between a presentation of a stimulus and a correct response (Gerst, 2017).

Gerst (2017) examined the five models of PS in late elementary school stduents and identified which models can predict reading skills. Two factors strongly fit the data, the timing model and complexity model. According to Gerst, PS in children between 8 to 11 is a dual-level construct. These two constructs have separate occurrence between a simple and complex level of timed processing. For reading skills, the complex level of PS was a strong predictor.

Researchers have defined the features of PS to recognize the nature of age progress therein and how it relates to other cognitive processes. In early and middle childhood, there is a significant improvement in PS, but during late childhood and early adolescence, the improvement slows and becomes nearly invisible in mid and late adolescence as PS reaches asymptotic values (De Alwis, 2011). Evidence of the global PS during the lifespan was observed in various task types among typically developing as well as atypically developing individuals (Peter, Matsushita, & Raskind, 2011).

PS function can be defined as the ability needed to regulate the speed of certain information at the level an individual needs to complete basic cognitive functions such as identifying objects or simple determination. Some scholars applied this definition of PS by excluding motor speed of the response (Fry & Hale, 2000). Recent multi-task experiments of PS suggest that it should be considered an independent variable of the task. According to De Alwis (2011), PS is a key characteristic of intellectual capacity that involves taking in new ideas, transforming and synthesizing thoughts around those ideas, and retrieving information about how we communicate those ideas.

PS is not only a major characteristic of intellectual abilities, but also an indicator for specific clinical groups. Several disorders are associated with a deficit in PS, such as learning disabilities, brain injuries, ADHD, emotional and behavioral disorders, and the autism spectrum (Phillips, 2015). PS has also been connected to some form of less common disorders and disabilities, like children with Phenylketonuria (PKU), Fetal Alcohol Syndrome (FAS), or Multiple Sclerosis (MS).

Studies like McEachern (2017) propose that verbal intelligence cannot be adequately predicted by the connection between PS, WM, and academic achievement in reading while quantitative intelligence can be predicted by PS, WM, and mathematics achievement. In addition, the study found that neither verbal nor quantitative aptitudes correlate to PS. According to McEachern, students' PS does not indicate impaired aptitude in reading or mathematics, but math and reading achievement. In addition, several disorders are associated with slow PS. Willcutt, Sonuga-Barke, Nigg, and Sergeant (2008) also stated that even though slowed PS is a sensitive function, it cannot be considered as a specific characteristic of a varied range of common disorders in childhood.

Processing Speed and Brain Structure

Studies of PS improvement throughout childhood have proposed that brain development might be directly connected to the improvement of PS. The maturation of myelin increases the speed of neural transmission. The myelination has been suggested as the neurobiological mechanism that is fundamental to improving PS in children (Turken et al., 2008). Paus, Collins, Evans, Pike, and Zijdenbos (2001) also proposed that the development of PS may be mediated by white matter maturation. As white matter matures, axons become progressively more myelinated.

According to Turken et al. (2008) the relationship between cognitive PS and the structure of white matter pathways in typical and brain-injured groups is positively correlated in young adults. In this study, convergent imaging was used to measure white matter and the Digit–Symbol subtest from WAIS-III was used to assess PS. In addition, the study indicated that short-term storage and PS significantly predicted functions in the fractional anisotropy in left parietal and temporal lobes, bilaterally and in the left middle frontal gyrus, bilateral parietal lobes, and bilateral temporal lobes.

Deficits in PS are linked to a reduction in white matter integrity. The solidity of white matter is fundamental to the link between the spread of cortical regions that trigger cognition, which is connected to the proficiency of cognitive ability and information processing in older age. White matter solidity relates to reaction time (Bucur et al., 2008; Deary et al., 2006; Kennedy & Raz, 2009; Madden et al., 2008). Furthermore, Waiter, Deary, Staff, Murray, Fox, Starr, and Whalley (2009) provided support through functional magnetic resonance imaging (fMRI) that the preservation of neural networks benefits processing information, which might be linked to successful cognitive aging.

The injury in white matter and its effect on PS was investigated using voxel-based lesion-symptom mapping (VLSM). The analysis indicated a relationship between PS impairment and damage in left parietal white matter, along with cortical lesions in supramarginal and angular gyri. Turken et al. (2008) stated that PS is significantly connected with the structure of white matter areas that are connected to parietal and temporal cortices and the left middle frontal gyrus. The brain's white matter pathways help in integrating operational processes that occurred in different areas of the brain. White matter pathways arrange information across brain networks particularly the long-range transmission, and support processes completed by individual areas in the brain. Theoretical analyses of the patterns of brain connection indicated that the structure of interaction fostered by the white matter fiber systems cause different patterns of cortical activity (Kotter & Sommer, 2000; Turken et al., 2008).

Walhovd et al. (2005) investigated the association between intelligence and PS which was measured by the latency of the electro-physiological ERP and component P3a. Both a combination of these measurements as well as individual measurements were used to predict higher mental functioning. Both intellectual performance and PS showed a relationship with cortical volume. There was no relationship between cortical volume and PS independent of age, but PS and the complementary cortical volume predicted the performance of intelligence.

Processing Speed Development

Many studies have examined the global developmental change in PS (Fry & Hale, 2000; Miller, Bradford & Maricle, 2011). Kail (2007) suggests that PS highly improves in early and middle childhood, then in late childhood and early adolescence, it continues to improve, but less rapidly. In mid-to-late adolescence, PS reaches asymptotic values. During infancy, change in PS is nonlinear between two and twelve months of age (Fry & Hale, 2000; Kail et al., 2013; Miller, 2013).

According to McArdle, Ferrer-Caja, Hamagami, and Woodcock (2002), changes in PS in childhood and adolescence are also nonlinear. In childhood, PS improves fast and starts to slow down at early adolescence, eventually reaching mature levels in mid-adolescence (Kail, 2007). A longitudinal model was used to identify the best function of developmental change in PS. After analysis, the data showed that the weakest fitting model was the linear function, which means that PS across childhood and adolescence does not increase linearly. This demonstrated that PS improved at different rates throughout childhood and adolescence (Kail & Miller, 2006).

PS could consistently change within a domain of processes but differ across such domains. For instance, the development of perceptual processing speed can occur at a stable rate that is different from the rate of processing speed of cognitive development (Kail, 2007). In their study, Kail and Miller (2006) found that PS for both language and nonlanguage domains improved between ages nine and fourteen. However, children who are nine years old are faster in language domains than in nonlanguage domains, but they showed more improvement in the nonlanguage domains. The PS of language tasks was faster than the PS of nonlanguage tasks at nine years old compared to fourteen. In both domains, PS was moderately constant between nine and fourteen years. Jenkins, Myerson, Joerding, and Hale (2000) also supported the idea of language tasks in older adults being relatively faster than in visual-spatial tasks.

A meta-analysis of 72 studies conducted by Kail (2007) supported the notion of a global development trend for PS. Fry and Hale (2000) found similar results. According to Kail, the PS of adulthood reflects linear improvement in childhood; however, this increase was a non-linear function (De Alwis, 2011). Gilbert (1894) was one of the first to investigate the development of speeded performance. He measured simple reaction times (RTs) to visual stimuli in participants who were six to seventeen years of age. The study revealed that average RT declined from 317 milliseconds (ms) in six-year-olds to 170 ms in seventeen-year-olds. The decrease of 147 ms in RT provides evidence that children need nearly twice as much time as adolescents to generate a response (McAuley, 2008).

Other studies have suggested that PS improvement is affected by culturally specific factors. Two known studies have examined cultural differences in PS. One study, by Kail et al. (2013), found that in first grade, students in the United States showed more rapid PS than Japanese and Chinese students. This was also true when comparing Chinese and United States students in fifth grade. However, different tasks used in grades one and five may explain the difference. The other study compared Chinese and Greek students who were eight to fourteen-years-old. Demetriou et al. (2005) found that Chinese children responded faster than Greek children, and that difference decreased with age. Analysis of data collected over long periods of time suggests that Chinese students in both Beijing and Hong Kong improved their PS faster than children in the United States. Korean students also showed rapid PS development. However, this finding was not consistent across measures or samples (Kail et al., 2013).

Working Memory

WM allows the ability to retain some pieces of information active in mind, but for a short period of time. This information can be used for additional processing. WM is, therefore, a storage and process system that is temporary but still critical for carrying out various daily tasks. In this regard, a person’s ability to retain information ensures that knowledge and skill become automatic, thus reducing the need to think about each step of a task. Many fields of study like psychology, education, cognitive science, and speech-language pathology have considered the construct of memory from different perspectives. Atkinson and Shiffrin (1968) proposed a memory model known as "the multi-store model." According to this model, human memory has three stores: a sensory register, short-term memory (STM), and long-term memory (LTM). However, Baddeley (2012) suggested a new model of short-term memory called WM.

As Figure 3 illustrates, WM is more than just a store holding limited amounts of information for short periods of time with relatively little processing. WM is a more complex process that requires not just a limited store, but also attention processes and coordination with long-term memory to complete tasks. WM is defined as the ability to store information temporarily while simultaneously performing tasks like completing a two-step mental math problem (Baddeley, 2012).

The central theme of study in researching learning impairment is the concept of WM and how it affects the mental capacity of a given individual's ability to learn. WM is defined as "a cognitive system through which information gathered from the perceptual organs and stored memories can be utilized to accomplish a variety of tasks" (Landry & Bartling, 2011, p. 79). Henry and Botting (2017) define it as "a set of cognitive functions involved in the temporary manipulation and storing of information during thinking, reasoning and remembering tasks" (p. 23). There is a consensus suggesting that the understanding of learning impairment automatically calls for the deconstruction of how human memory works, specifically because WM is the most immediate, versatile, and disposable form of memory (Baddeley, 2012). Memory is a crucial component of learning. This implies that any manifestation of learning disability, such as incoherent

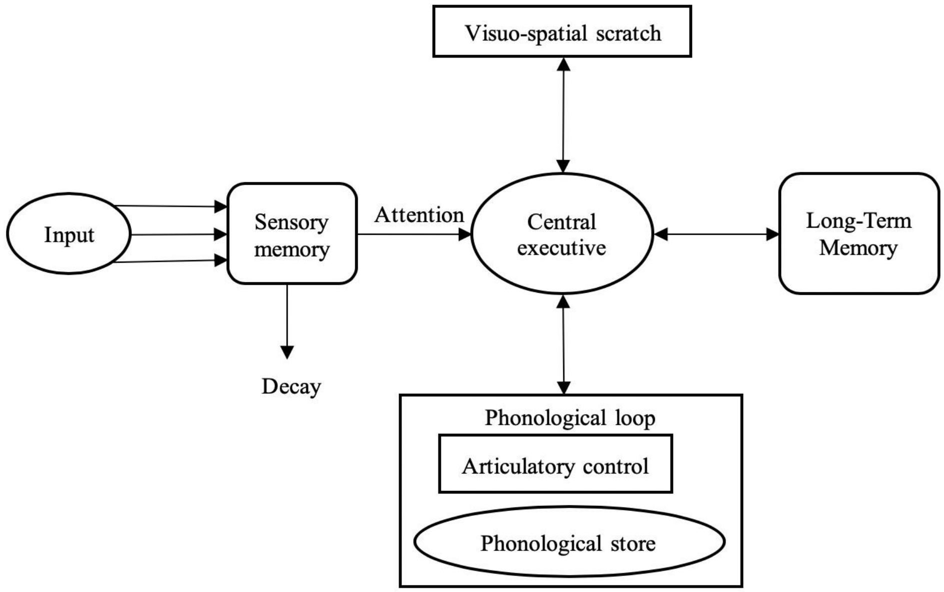

Figure 3. Working memory (Baddeley & Hitch, 1974).

phonological processing or syntactic deficits, is a consequence of deficiencies in WM.

When a person needs to shift between multiple information sources, this procedure requires WM processes (Shipstead, Harrison, & Engle, 2012) since it involves several cognitive processes, including goal maintenance and information retrieval (Cowan, 2010; Miyake et al., 2000; Unsworth & Engle, 2007). Baddeley proposed that WM is a multi-component model that involves three limited-capacity, inter-dependent systems: the central executive and two subsidiary slave systems—the phonological loop and visual-spatial sketch pad (Baddeley, 2000, 2012; Baddeley & Hitch, 1974; Logie, 1995).

Even though a myriad of models attempt to link WM to the process of learning in children, psychologists consider Baddeley's WM model as the more reliable, universally applicable, and most comprehensive WM model (Alt, 2011). Baddeley's WM model, hereafter referred to as the Baddeley model, posits that WM is an agglomeration of subsystems; each subsystem is endowed with abilities to manipulate only a specific category of information. It also asserts that each subsystem is limited in its capacity, works independently, and can draw upon the control module that Baddeley calls the central executive (CE).

Other subsystems of the Baddeley model include the visual-spatial sketchpad (VSS), the phonological loop (PL), and recently, the episodic buffer (Baddeley, 2012). Verbal memory helps in encoding, retention, and manipulation of verbal input used to achieve learning proficiency (Raghubar et al., 2008). Visual-spatial WM helps in shaping the formation of mental models, which enhances learning skills in elementary students. Older students also apply mental models to enhance complex problems like word problem solving (Glenberg et al., 2012; Holmes, Adams, & Hamilton, 2008; Raghubar et al., 2010).

However, both the VSS and PL subsystems are slave or passive subsystems with a lower carrying capacity than the CE and specific in their functionalities (Henry & Botting 2017; Ricker, Cowan, & Morey, 2010). For instance, while the VSS holds visual as well as spatial information needed for the functions executed by the CE, the PL holds phonetic information vital for CE functions (De Vasconcellos Hage, Nicolielo, & Guerreiro, 2014). Note that these subsystems are components of WM and therefore memory components themselves.

Using the term “subsystems” takes note of the relative fraction of WM that such subsystems represent and their functions, which is the retention of temporary memory. Therefore, the VSS is a visual-spatial short-term memory (VSSTM), while the PL is phonological short-term memory (PSTM). Baddeley (2012) introduced a third component: the episodic buffer (see Figure 4). The episodic buffer is considered a “backup” storage that connects long-term memory and the components of WM. The episodic buffer serves a peculiar sort of function necessary for the facilitation of coherence and a sense of perception. Apparently, WM requires synchronizing such “foreground” memory with “background” memory, the latter referred to as long-term memory (LTM) by researchers.

Visual-Spatial Working System

This part of WM describes the specific ways that different objects appear. Baddeley (2000) called the visuospatial sketchpad system the inner eye. This system encodes visual and spatial information processing and helps in preserving and manipulating visual and spatial information. The system also used the information required to navigate the environment and locate an item in space. The visuospatial sketchpad encodes information that is presented nonverbally (Fry & Hale, 2000). This information can be easily lost over time.

Baddeley and Hitch (1974) found that individuals can perform visual and verbal tasks simultaneously. Performing two visual tasks simultaneously is quite difficult because the tasks interfere with one another. This provides evidence that WM utilizes a different system for processing visual information than for verbal information. The verbal information interference may also occur when performing two verbal tasks simultaneously. This evidence supported the WM model that consists of separate systems: the phonological loop and the visuospatial sketchpad.

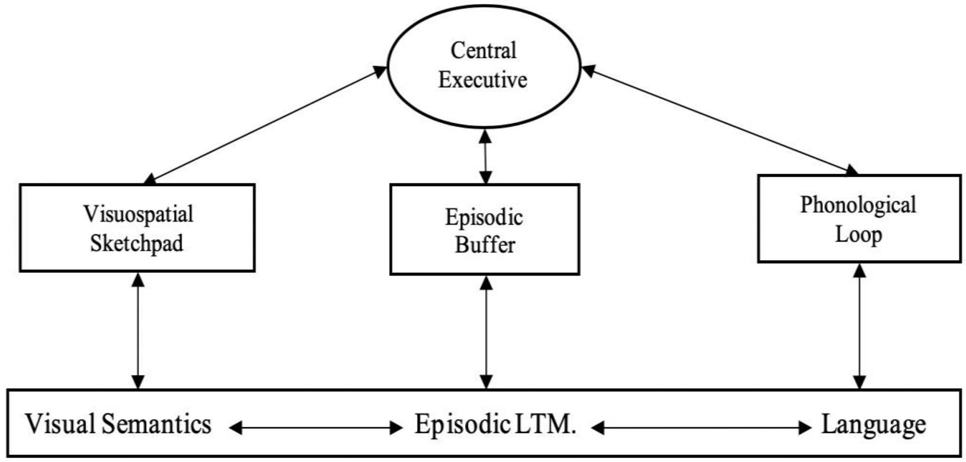

Figure 4. The Baddeley Model (Baddeley, 1986).

The impairments related to visual-spatial short-term memory (VSSTM) are manifested in an inability to keep a mental track of and report spatial and/or visual information (Ricker et al., 2010). Such individuals fail to notice a pattern previously shown to them or reproduce the same without the initial coherence. They have difficulty in learning the process. Studies that try to verify whether a given student experiences VSSTM impairment ask the test subjects to memorize a given pattern expressed in forms, shapes, and colors and identify their spatial positions.

The evidence tends to show that visual spatial short-term memory (VSSTM), and consequently VSSTM impairment, impact the academic performance of elementary students. According to Van der Ven, Van der Maas, Straatemeier, and Jansen (2013), visual-spatial WM is closely associated with math skills, an assertion that is supported by the findings of Van de Weijer-Bergsma, Kroesbergen, and Van Luit (2015). The results show that students in lower levels of elementary school are more inclined to use visual-spatial WM than those in higher classes, since the former have not developed the adequate mental capacity to solve division and multiplication problems, which are "augmented" additions and subtractions and thus require the use of verbal WM.

Phonological Loop System

According to Baddeley (2000) the phonological system serves as an inner ear that holds spoken and written information for one to two seconds at a time. The phonological loop system includes the phonological store and articulatory control process. Verbal information enters the store immediately, while written information must be transformed into an articulatory code before entering the phonological store. For example, written words convert to a "voice" we hear while we are reading. Meanwhile, the articulatory control process serves as an inner voice and is linked to speech production.

Verbal WM does not run into evidential hurdles as visual-spatial WM does, given that a majority of researchers in the academic/psychological field overlap, giving more priority to the former than to the latter. Nonetheless, the crucial entry point in trying to connect verbal WM deficiencies with math performance is by considering Alt's (2011) assertion: "when a child is exposed to a novel word, he or she must first encode that word into the phonological loop" (p. 176). Hesketh and Conti-Ramsden (2013) agree that the phonological loop, or rather the verbal WM, is a critical resource for enabling a child to master a new word and build upon the same to learn the fundamental principles of a given language, such as the syntactic and semantic rules that differentiate one language from another.

Central Executive System

According to Baddeley (1986), this system works as a supervisor to the phonological loop, visuospatial sketchpad, and episodic buffer. This system directs attention, determines priorities, and makes decisions (Baddeley & Hitch, 1974; Baddeley, 2000). The central executive is the main component of the model, but there is little information on its manner of functioning. The central executive both monitors and coordinates an individual's ability to process visual and verbal information, holding that information in visual and verbal WM systems, and connecting them to long-term memory (LTM; Baddeley, 2000).

The central executive system oversees attention processes, as opposed to being a store for memories. It then ensures that the WM system takes care of some stimuli and not others. The metaphor of a manager can be used to outline how the central executive works (Wass, Scerif, & Johnson, 2012). The manager often decides which issues need focus or should be cast aside. It also chooses various strategies to deal with challenges that might arise. However, just like any other employee in the company, the manager can only engage in a restricted number of activities simultaneously (Baddeley, 2012) and will collect data from numerous sources.

The central executive is a collective unit of memory that serves executive functions in the human body system. Executive functions basically point to a set of cognitive processes responsible for the control of behavior. The above phenomenon involves successful selection and monitoring of behavior to enhance the achievement of particular goals (Otto, Gershman, & Markman, 2013). The central executive serves all the cognitive processes such as cognitive inhibition, WM, attention control, and cognitive flexibility. From the above explanation, it can be deduced that the most pivotal unit of the entire memory is the central executive since all the cognitive aspects are redirected from it.

PS determines how all the executive functions are to be performed. For a highly effective PS, the central executive performs at a relatively efficient speed. However, the efficiency at which a task is performed depends on the ability of the brain to synchronize cognitive functions (Otto et al., 2013). For example, how efficient is it when an elementary student is listening to a teacher and at the same time, he/she is drawing cartoons in a notebook? Even if the PS is high, the central executive is characterized by many factors that enhance the performance of its duty. Often, it is tasked with more than one responsibility at a time. For example, a person can listen to music, read, and write at the same time.

The central executive of children at elementary age is not fully developed to carry out some specific functions. In this regard, the efficiency of executive functions changes gradually across the lifespan, from childhood to adulthood (Anderson, Vogel, & Awh, 2013). As much as PS matters to all cognitive abilities, it is not the sole factor to be considered when discussing the central executive functions. For example, psychiatric and neurological disorders adversely affect executive functions. Moreover, efficiency is much affected by Attention Deficit Hyperactivity Disorder.

In elementary students, the primary executive functions are WM and inhibitory control. They lay the foundation for the development of many complex cognitive functions in adulthood, such as decision making and problem-solving (Chen et al., 2013). Elementary students are likely to make many errors related to cognitive processes, not because they are disobedient, but rather because the cognitive system has not developed sufficiently to know how, where, and when to perform a specific function. In fact, such students are unaware of the implications of the cognitive actions they perform. Cognitive flexibility, coherent planning, placement of ideas, and goal setting are driven primarily by executive functions.

In the psychology of human growth and development, the central executive functions are the latest to mature (Chen et al., 2013). This is exemplified by the fact that even in the pre-adolescent stage, students manifest executive function spurts spontaneously. This implies a nonlinear development of cognitive abilities. In elementary students, educationists have observed that PS may be high but basically has no impact since the central executive is still growing (Deater-Deckard, 2014). In this light, many elementary learners are unable to direct their actions to the intended goal. They tend to perform poorly in the field of attention control, a factor responsible for absent-mindedness in class.

As a result of the ongoing behavioral inhibitory control that elementary students possess, most executive functions are ineffective because students apply them in a limited context. However, PS does not necessarily depend on the student's growth and maturity. It can only be more effective in conjunction with a functional central executive (Deater-Deckard, 2014).

Episodic Buffer

Baddeley (2000) modified the original WM model by adding a system he called the episodic buffer, which is responsible for communication between long-term memory and WM. This change is an alternative view of the model from isolated subsystems to the integrating information processes because the previous model failed to provide an explanation of the results of several experiments. For example, Baddeley observed that some intelligent patients who suffer from amnesia showed good short-term recall of stories but struggled with adding new information to their long-term memory. This provides "evidence of a temporary store that is capable of holding complex information, manipulating it and utilizing it over a time scale far beyond the assumed capacity of the slave systems of WM" (p. 419).

The episodic buffer often takes on the role of a backup store that interconnects with different components making up WM and long-term memory. The episodic buffer acts as the third part of the WM system and integrates the information that is heard and seen with a distinct sense of time (Baddeley, 2012). In this way, the episodic buffer ensures that activities or tasks take place in a smooth sequence, like a plot for a movie or story. This explains why an individual's memories often occur as a series of coordinated events instead of specific segments (Diamond, 2013). This segment of the WM system retrieves system memories through a process of conscious awareness. It allows people to use some units of information already stored in their minds to come up with new ideas (Baddeley, 2012).

Working Memory and Brain Structure

Many brain-imaging studies suggest that certain areas in the brain, mostly the pre-frontal lobe, become very active when holding information in the WM. The dorsolateral prefrontal cortex seems to be a factor in mediating WM (Curtis & D'Esposito, 2006). This region of the brain is recognized to be responsible for the difference in higher-order cognitive function. Other areas in the brain such as cortico-striatal-thalamic-cortical

(CSTC) loops, neurophysiology, and genetic material interact to impact WM (Fournier, 2014).

Based on the type of stimulus, different regions of the brain relate to WM. However, those areas activated with various stimulus are also cohesions. Basically, during WM and delay periods of performance the same regions of the brain that store sensory information are responsible for sensory processing. The frontal regions of the brain involving the middle frontal gyrus, inferior frontal gyrus, and caudal part of the superior frontal sulcus are connected to the frontal-eye field (Rottschy, Langner, Dogan, Reetz, Laird, Schulz, & Eickhoff, 2012). Visual WM is strongly associated with the intraparietal cortex and caudal superior frontal gyrus, which is significantly triggered during visuospatial WM performance (Rottschy et al., 2012).

Brain imaging indicated different neuroanatomical bases for both subsystems of WM. The left hemisphere, which is connected to language production includes Wernicke's region and Broca's region which appear to be triggered by the phonological loop. The occipital cortex, which is generally associated with visual processing, is linked to visual/spatial memory. The coordinating role of the central processor is confirmed by the fact that certain regions of the brain are activated only during memorizing tasks that are difficult (Rottschy et al., 2012).

Areas like the hippocampus and nearby cortical areas of the temporal lobe are activated with the transfer of information from short-term to long-term memory. Durable memories are formed when WM is involved in the ventromedial area of the temporal lobe collecting information that is also processed by other areas of the brain. In addition, the ventromedial area of the temporal lobe gets the information that has been already processed by other cortical areas like the visual or somatosensory areas (Robertson, 2002). Studies have associated WM with the prefrontal cortex (PFC; Curtis & D'Esposito, 2006; Fournier, 2014). Electrophysiology research has indicated neural correlations between WM and prefrontal cortex in monkeys (Constantinidis & Klingberg, 2016).

Working Memory Development

Numerous studies have found that WM constructs improve with age (Cowan, 2010; Gilchrist, Cowan, & Naveh-Benjamin, 2009) and changes to this capacity occur across the lifespan (Cowan, 2010). From the first year of life, children show evidence of WM capacity (Reznick, Morrow, Goldman, & Snyder, 2004). According to Gathercole and Baddeley (2014), preschool children can hold about two items in memory. This capacity then increases gradually between five and eleven years of age due to neurological development that facilitates both memory and language. While children grow, they learn how to use strategies such as rehearsal and grouping information into meaningful categories (Cowan, 2010).

Developmental changes influence WM, which significantly affect the most common cognitive functions. Visual WM seems to be more sensitive to age than verbal WM (Brown, Brockmole, Gow, & Deary, 2012). When comparing performances of young adults and people aged 60 to 70 years old in verbal and visual PS and verbal and visual WM, older adults show slower processing for visual than verbal information. In addition, their memory for letters is better than memory for location. When learning new information older adults also have difficulty learning visuospatial information compared to verbal information (Jenkins et al., 2000).

Attention

Since the 1800s, William James recognized the complexity of the attention construct. According to Goldstein, Naglieri, Princiotta, and Otereo (2011) many definitions and theories of attention have been developed, such as the one stated by Titchener (1924), who described attention as a "pattern of consciousness arranged into focus and margin, foreground and background, and center and periphery" (p. 253). These various definitions reflect the complexity and multimodal nature of the attention construct, which likely contributes to the difficulty in establishing a universally accepted definition for attention (Fournier, 2014).

Studies have suggested aspects or subdomains of attention, such as selective or focused attention, sustained attention, shifting attention, divided attention, and attentional capacity (Baron, 2004; Miller, 2013). The ability to concentrate on certain tasks and ignore other stimuli is defined as selective or focused attention. Sustained attention is the ability to focus on a task for lengthy periods of time. Shifting attention over various tasks smoothly and using cognitive flexibility is defined as alternating attention. Divided attention is defined as the ability to reply to several tasks at the same time. Attentional ability encompasses cognitive loads in which the subdomains of attention reflect how an individual can successfully manage a certain number of stimuli (Fournier, 2014).

Attention is a complex construct in which a person first focuses on certain stimuli in order to process information. Attending to both auditory and visual stimuli is essential to organize intellect and complete tasks of daily living like schoolwork (Miller, 2013). Higher-order cognitive processing such as language, memory, and visuospatial skills fundamentally rely on attention. Factorial analysis studies use assessment for attention and have provided several models. Attention can be divided into aspects or subdomains of attention including selective or focused attention, sustained attention, shifting attention, divided attention, and attentional capacity (Baron, 2004; Miller, 2013).

A comprehensive review of the neuropsychology of attention provides categories of attention including attentional orientation, selective attention, divided attention, and sustained attention (Miller et al., 2011). All four types are hypothesized to have spatial attention as subcategories. These categories help to regulate attentional tasks according to their demands, but that raises a question about how individual differences in attentional tasks align with these alternative classifications. When investigating the relationship between gains and declines in other cognitive abilities, eight factors were included in an Exploratory Factor Analysis (EFA) solution; three of them were attentional factors: search, concentration, and attentional flexibility (Fournier, 2014).

Schweizer (2005) suggested that attention was an essential indicator of the relationship between perceptual processes and higher cognitive functions. They found that attentive processes are responsible for 70% of the common variance of perceptual processes with cognitive ability. According to Moosbrugger, Goldhammer, Schweeizer (2006), differences in attention measures among individuals might be because of perceptual attention and executive attention variables. Schweizer and Moosbrugger (2004) indicated that all types of attention previously mentioned exhibited a large degree of overlap that correlated with intelligence. They proposed that attention is a cognitive foundation of intelligence. Nevertheless, they indicated that attentional measurements are like some other measurements of cognitive functions, particularly PS.

Attention and Brain Structure

The nature of attention is complex. Thus, multiple regions in the brain have been proposed to involve different subdomains of attention (Goldstein et al., 2011). Attention is connected to various activations of brain structure. In addition, different distant brain regions are activated by each attention process. In 1990, Posner and Petersen first suggested an attention framework. According to these researchers, attention is divided into three networks that are functionally and anatomically separate: alerting network, orienting network, and executive attention (Suades-González et al., 2017).

Petersen and Posner (2012) re-examined their original model of the human brain's attention system which they originally suggested in 1990. In their study, they evaluated interactions between the three networks and identified variations to individual differences in network efficiency. The three networks defined in the attentional system involved an alerting network, orienting network, and executive attention. The alerting network allows the ability to produce and maintain caution during changed states that occur in the activation's aspects. The brain stem arousal system together with the right hemisphere, cause alerting in states of constant caution. Petersen and Posner recently identified a strong connection between neuromodulator norepinephrine (NE) and the alerting system.

Also, in both the locus coeruleus and source of NE, a combination of activities occurred during a warning signal. Through the NE pathway, the most important nodes in the frontal cortex and parietal regions are associated with only dorsal visual pathways, not the ventral visual pathways (Petersen & Posner, 2012). Recently, extensive brain imaging studies provide evidence of a relationship between the alerting system and a largely common right-hemisphere and thalamic set of areas. However, other imaging research indicated the involvement of the left-hemisphere.

The orienting process includes shifting attention between endogenous or exogenous references, which involves activation of parietal sites and frontal eye fields. The orienting network occurs in the parietal cortex. Corbetta and Shulman (2002) indicated that orienting to external stimuli is related to two brain systems. Additionally, dorsal systems such as the frontal eye fields (FEFs) and intraparietal sulcus utilized fast approach to control attention. Switching attention involves the temporoparietal junction (TPJ) and ventral frontal cortex. Cholinergic systems have an essential effect in orienting that emerges in the basal forebrain (Petersen & Posner, 2012). However, this effect involves the superior parietal lobe instead of the basal forebrain.

Executive attention is responsible for targeting detection. According to Petersen and Posner (2012), several areas in the brain involving the executive network includes midline frontal and the anterior cingulate cortex. Selection involves orienting and executive attention networks. Studies have been conducted to detect signals linked to top-down task control, suggesting two separate executive control networks. These signals may involve an instruction of tasks which occurs at the beginning of a task.

Neuroimaging studies have found that all characteristics of attention—activation, selection, and control—are associated with brain circuits with comparatively independent anatomy and neurophysiology (Rueda, Pozuelos, & Cómbita, 2015). Several studies with patients who suffered from frontal and parietal lobe injury, particularly in the right hemisphere, compared to brain image studies of normal people, have indicated the connection of these regions in the endogenous maintenance of the alert state in the absence of warning signals.

Attention Development

Cross-sectional studies have suggested that from early infancy, both exogenous alertness and orienting to external cues begin to develop. Later, at the end of the first year, there is voluntarily controlled attention. The three networks continue to improve, and the endogenous attention, reorienting of attention, and inhibitory control exhibit development during childhood. In addition, due to prefrontal cortex maturation, the executive attention, network develop more in adolescence (Rueda et al., 2015).

Different subdomains of attention—selective, sustained, shifting, divided, and attentional capacity—have been suggested in various models of attention. The differential development of these subdomains can be explained through a neurological level at various times throughout development. In infancy, the intentionally direct attention ability is advanced by an improvement in the capacity to control eye, hand, and body movements. Attentional control then becomes less connected to stimuli, and the infant can engage in basic directed or selective attention.

In contrast, infants show a low capacity for sustained attention. The nature of attention in preschool can be described as exploratory (Goldstein et al., 2011). Children at this age are better at direct and sustained attention, which lead to improved motor control, but select attention and focus remain restricted to the external environment. Thus, interesting stimuli in the environment are directed and sustained in attention. The orienting network of the Posner model remains unchanged between six years old and adulthood (Rueda et al., 2015).

The executive network in preschool also remains unchanged between seven years old and adulthood, which might be linked to the relative effortlessness of the tasks in which people have been asked to engage when examining these networks. Overall, preschool children respond to environmental stimuli in a more systematic way. Therefore, impulsive behaviors in response to environmental stimuli gradually decrease during middle childhood and transition to behaviors that are goal-directed and task-oriented. At the period of middle childhood, children who are developing typically operate selective and sustained attention sufficiently (Goldstein et al., 2011). Children at this age can select the stimuli needing attention and disregard unnecessary ones in the environment, based on their interest.

Attentional processes develop and expand through one's lifespan. In the first year, children show aspects of attentional processes that improve during childhood, while more subdomains of attention begin to emerge. The development and maturation of additional cognitive processes account for differences between attentional processes noted in children and adults. It is also important to note that the developmental trajectory of attention may be impacted by the social environments to which a child is exposed and his or her neurobiological makeup (Berger, Kofman, Livney, & Henik, 2007). Thus, this trajectory would be true for children who are average or typically developing.

Relationship Between Working Memory and Processing Speed

Both PS and WM collaborate to achieve a coherent system of function (Baddeley, 2012). As a cognitive ability, PS can be basically defined as the time it takes for a person to perform a mental activity or task. This means that it varies from person to person. In addition, it can also be described as the time taken by a person to understand and react to an external stimulus and other given information. It is the time needed to respond after receiving a specific stimulus. WM, sometimes called a short-term memory system, consolidates all the information together (Baddeley, 2000, 2012).

Understanding the function of both WM and PS provides an adequate clarification of how both cognitive abilities are related to each other. When PS works quickly and adequately, it allows WM to hold information and function at capacity. However, WM has limited capacity and can for a limited time store information. Thus, a student who struggles with slow PS will quickly fill his or her allotted storage. Improvement in WM enables students to process and represent more information units simultaneously. Accordingly, more complex concepts or relations can be established.

The literature has established that PS improvement is connected to WM improvement, which is sequentially connected to increases in higher levels of cognitive development (Demetriou et al., 2014). Faster processing facilitates various memory strategies such as chunking and imagery. These strategies enhance verbal or spatial information before recall (De Alwis, 2011). A study identifying predictors of visual WM performance indicated that PS, visuospatial executive, spatial WM, and older-age IQ were associated with visual working memory in older adults. Moreover, the performance of visual WM was significantly predicted by only PS and executive measure. However, verbal fluency and central executive were not correlated or predictive of visual WM performance. Processing speed effect in visual WM can be explained through the rate of rehearsal and speed of encoding, while the role of the executive can be explained through the resources associated with visuospatial material (Brown et al., 2012).

One of the common causes of the relationship between WM and PS is biological factors such as brain maturation and myelination (De Alwis, 2011). When processing information rapidly, more items are maintained in WM in a short period of time, which allow for extended WM span. More cerebral connections increase processing, which would improve the PS span. Interchangeably, if WM capacity is larger more items will be processed simultaneously, which causes faster PS. Until now, it is not clear whether PS is a cause or effect.

Fry and Hale (2000) developed a cascade model to identify the correlation between PS, WM, and reasoning. The model revealed that PS improvement is directly connected with improvement in WM related to age. Consequently, both age-related developments affected the improvement of fluid reasoning (Demetriou, 2013; Kail, 2007; Nettelbeck & Burns, 2010). In other words, WM mediated the effect of PS improvement correlated to age change and fluid reasoning. De Alwis (2011) stated that during both childhood and adulthood, the developmental cascade model was confirmed.

The accounts for the relationship between WM and PS can be explained in four hypothetical models including integrated storage and processing, separable capacities, number of operations, and WM as a PS mediator (Poll et al., 2013). The relationship between WM and PS can be explained as an integrated model in which both storage capacity and PS trigger common neural activation. The competition for resources occurs between storage and processing. When the task requires processing, WM storage is compromised and information will be lost; however, if the task required storage, processing is compromised and becomes slower.

Separable capacities are another model of the connection between WM and PS. Factor analysis of children's cognitive functions indicated that even though WM and PS were correlated, they were ideally identified as separate factors (Bayliss et al., 2005). The differences in PS among individuals, according to the separate capacities model, for example, predict variations in language abilities independent of WM tasks (Poll et al., 2013).

The number of operations is another model that may explain the correlation between PS and WM. Variances in the number of operations and the types of tasks which need to be accomplished may influence PS. Kail (2007) proposes that the time needed to complete a single cognitive operation is common across a range of tasks, but individuals differ in the required time. Like with the separable capacities model, PS and WM concede independent factors. However, in the number of operations models, the nature of the task is considered. Miller (2013) measured the response time of various complex tasks ranging in cognitive, language, and motor tasks. When a common proportion across tasks was applied, children with language difficulties needed more time to respond than children with typical language capabilities. Previous studies indicated that the nature of tasks affects the association between PS and the capacity of storage (Towse, Hitch, Horton, & Harvey, 2010).

WM as a mediator of PS is the last model suggested to explain the relationship between PS and memory. This model is based on the discovery that changes in WM capacity are influenced by the developmental change in PS (Fry & Hale, 2000). According to Kail (2007), WM explains fluid intelligence reasoning ability. Moreover, WM is a function that mediates the PS effect on cognitive functions. The difference between this mediation view and the integrated view is that processing and storage use a different resource. Alternatively, children’s PS and WM are sequentially connected. The developmental cascade is the best model for the relationship between PS and WM. PS improvement explains the improvement in WM capacity over time (Fry & Hale, 2000; Kail, 2007; McAuley & White, 2011).

Relationship Between Attention and Processing Speed

Attention is another important ability that might be related to processing speed. Attentive behavior connotes the tendency to show commitment and concentration to something. It is mostly realized through listening and looking. Both listening and looking are voluntary and intentional reflexes. A person is said to be attentive if they concentrate on the instructions being given. In other words, attentive behavior incorporates the aspects of conscious processes reflected from the subsequent behaviors.

Tourva et al. (2016) stated that attention and executive functions are closely connected to each other. Executive functions comprise several cognitive functions such as inhibition of prepotent responses, interference control, shifting, planning, etc. Executive functions generally involve all WM components and various types of attention. Moreover, some studies considered the attentional construct to be the executive component of WM. A few studies indicated that WM and various types of attention in childhood and adulthood have moderate to strong relationships (Burns et al., 2009; Miyake et al., 2000; Schweizer & Moosbrugger, 2004).

A study of neurocognitive processes attempted to determine whether variance in inattention differ between term-born and very preterm children. Verbal and visuospatial short-term memory and visuospatial WM were low in both groups. Among very preterm children, variance in inattention was explained by slower motor processing speed. The cognitive mechanisms related to inattention were mainly overlapping between the groups. Very preterm children showed unique connections between motor processing speed and inattention (Retzler et al., 2018).

Relationship Between Working Memory, Attentive Behavior, and Processing Speed

The relationship between attention and WM, as well as WM and PS have been studied several times. However, the relationship between all three of these neurocognitive constructs is rarely investigated (Fournier, 2014). Attention, PS, and WM have been hypothesized as fundamental in the facilitation and support of higher-order cognitive processes and functional skills (Conklin et al., 2008; DeLuca, 2008; Miller, 2013).

According to Fournier (2014), attention is a foundation to all other higher-order cognitive functions, while WM is essential for general cognition and academic functions; and PS is necessary for the efficient completion of advanced cognitive functions and functional or daily living skills. Therefore, the role of attention and PS has been highlighted in some models of WM that have been proposed (Cowan, 2010; Fry & Hale, 2000). Both PS and attentional constructs can mediate changes in WM related to age. However, lack of evidence supports the independent role of both the attention function capacity from PS function in episodic memory and WM related to age (Levitt, Fugelsang, & Crossley, 2006).

Changes in fluid reasoning are largely explained by a speed-related improvement in WM (Fournier, 2014; Nettelbeck & Burns, 2010). PS improvement helps to improve WM span. In addition, PS helps to maintain material through subvocal rehearsal in the verbal WM system, but the effect of PS on the visual-spatial system is still not clear (Cowan, 2010; Kail, 2007; Fry & Hale, 2000). In contrast, only WM significantly affects both general fluid and crystallized intelligence when observing the role of age, PS, attention, and WM in adolescents. All three cognitive functions—PS, attention, and WM—are directly affected by age in general and crystallized intelligence, but not in fluid intelligence. WM also mediates the indirect effect of age on general fluid intelligence and crystallized intelligence (Tourva et al., 2016).

McAuley (2008) developed a model for typically developing students which demonstrates the relationship between PS, inhibition, and WM. In this study, the four cognitive skills—PS, inhibition, WM storage, and WM updating—were separate, but interrelated functions. WM was affected by PS which was mediated by inhibition. The model was as follows: PS directly affected inhibition, WM storage, and WM updating. The effect of PS on WM is facilitated to a certain degree by inhibition. The relationship among these cognitive operations was relatively stable over 6 to 24 years old. Thus, McAuley concluded that the relationships between PS, inhibition, and WM were established during early childhood and development does not affect this interrelationship. However, those cognitive abilities involved in the study matured at different rates during development.

Another study, conducted by Magimairaj, Montgomery, Marinellie, and McCarthy (2009) with children ages six to twelve years old, wanted to identify the role of short-term memory storage, PS, and attentional allocation on WM. The study identified a significant correlation between short-term storage, PS and attention and WM performance when controlled by age. A unique discrepancy in WM performance was contributed by short-term memory and PS, but attentional control was not. WM performance was strongly predicted by short-term storage and PS (Kunimi & Kojima, 2014).

Magimairaj et al. (2009) found that PS, WM span, and long-term memory span increase with age. In addition, long-term memory span and PS have the same influence on WM. When comparing the effect size of both PS and memory span on WM, the study found that visual WM and auditory WM function differently and visual WM was less affected by memory span than auditory WM.

Attention, PS, and WM, which are vital cognitive functions related to intelligence (Burns et al., 2009; Deary, 2012; Fink & Neubauer, 2005; Schweizer, 2005; Schweizer, Moosbrugger, & Goldhammer, 2005; Tillman et al., 2009) are essential to intelligence. According to Schweizer and Moosbrugger (2004), attention and WM are correlated with each other. This study also revealed that attention and WM are adequate predictors of intelligence. Another study used confirmatory factor analysis and structural regression modeling to identify the cooperative effect and connection among attention, PS, and WM. According to Fournier (2014), no connection was found among attention, PS, and WM neurocognitive constructs, but WM and attention were significantly related. Attention and WM predicted a few basic cognitive processes including visuospatial, auditory, and executive processes.

Students who have WM deficits demonstrate difficulty meeting regular curriculum goals (Gathercole & Pickering, 2001). They also struggle to follow complex directions given in the classroom compared to students without WM deficits. Likewise, low PS is related to learning disabilities, specifically in reading (Dornbush & Pruitt, 2009; Miller, 2007). Thus, understanding the rates of WM capacity and cognitive processing in students is very helpful within the classroom setting.

The Difference in Cognitive Functions Between Boys and Girls

Even though the rate of change in cognitive function is quite important, few longitudinal studies have concentrated on gender differences in this rate of change. From the previous discussion, there has been a debate on which gender performs tasks faster and more efficiently (Clark, Sheffield, Wiebe, & Espy, 2013). Many researchers have concluded that girls perform tasks faster than boys do. This implies that girls have a higher PS compared to boys. When comparing cognitive abilities between males and females across the lifespan, boys in kindergarten, elementary, middle, and high school show lower PS, which is initially low in kindergarten but increases through high school (Camarata & Woodcock, 2006).

Studies on the function of the brain indicate gender differences in the level of cognitive function, which showed better memory function and speed in women, while men outperformed in spatial abilities and reasoning (Aartsen, Martin, & Zimprich, 2004). Some studies suggest that men are faster in tasks that require mental rotation (Clark et al., 2013). However, Jansen-Osmann and Heil (2007) identified little difference in the speed of mental functions between men and women when using other stimuli (i.e., characters, primary mental abilities (PMA) that included symbols, animal drawings, or cube figures).

Phenotypic and genetic analysis showed that the relationships among three measures of PS (rapid automatized naming of letters and numbers [RNLN]; Rapid automatized naming of colors and pictures [RNCP]; The Colorado perceptual speed test [COS]) and reading performance are different between women and men. Women show better performance in all three PS measures than men do. However, women and men did not differ in reading performance. The univariate genetic analyses indicated that females were higher than males in PS measurements; however, the results were not significant (Hawke, 2008).

The rationale for believing that boys and girls develop at different rates in cognitive functions is drawn from many factors, both genetic and environmental. The difference in task performance in boys and girls may be referred to as psychological sex differences (Clark et al., 2013). They can be attributed to cognitive, emotional, and motivational differences between the two genders. What is more astonishing, however, is the fact that boys tend to have higher intellectual quotients than girls do. According to Aartsen et al. (2004), the structure of the brain provides evidence for differences in levels of function between men and women. This can be explained through the greater atrophy in men compared to women as a result of aging. This indicates that cognitive functions in men are more affected by change than in women. The structure of the brain shows more decreases in fluid abilities in men.

A study examined differences between male and female adults in four cognitive functions—immediate recall, delay recall, non-verbal reasoning, and information PS—over six years. In the study, women were better at immediate recall and, more significantly, delay recall. The study also indicated that PS and non-verbal reasoning are not different in men and women. There was no significant difference in the rate of cognitive decline between men and women (Aartsen et al., 2004).

Camarata and Woodcock (2006) investigated the gender developmental change in cognitive PS from preschool through adulthood. Participants were included in the study using different, standardized, comprehensive cognitive functions. Three measurements were used. Out of 4,253 participants, 2,014 males, and 2,239 females were assessed by the Woodcock-Johnson III (WJ III), 2,014 males, and 2,239 females were assessed by the WJ-R, and 1,964 males, and 2,261 females were assessed by the WJ-77. In the three normative samples, females were significantly higher in PS. The adolescent subgroups showed the largest difference. Additionally, the males were significantly higher in comprehensive knowledge among all groups. The achievement tests also showed lower performance.

When investigating the difference in the PS of both genders, it is imperative to consider the type of task that they are to perform. Boys show high manipulative skills in mechanical works such as building, construction, and engineering courses, while girls exhibit a high-performance rate in less mechanical courses such as music, linguistics, and other humanities (Hedvall et al., 2013). Many psychologists believe that variance in the brain structure and sex hormones play a role in different functions between males and females, which manifest earlier in girls than in boys and are said to highly affect behavioral changes and some cognitive abilities.

CHAPTER 3

METHODOLOGY

This study aimed to investigate whether WM components (visual, verbal, the central executive) and attention can predict PS during elementary school grades. The study utilized a data analysis from Li and Geary (2017) that was designed to examine whether math achievement in early adolescence can be predicted by visuospatial WM in childhood. By using this longitudinal assessment, the current study tried to determine whether visual WM, verbal WM, the central executive, and attention in first and fifth grades can predict PS in fifth grade. This study was also interested in the difference between boys and girls, specifically the developmental change from first to fifth grades in PS, visual WM, verbal WM, and the central executive.

The area of cognitive development is very important, especially since PS can facilitate the development of many cognitive abilities (De Alwis, 2011). What makes longitudinal studies unique is the idea of providing information within an individual change. This method of study identifies both variation and covariation in different functions compared to change related to age. Longitudinal studies of cognitive development can be more efficient and practical which adds supporting information to our understanding (Hofer & Siliwinski, 2001). The current study offers an additional understanding of the relationship among WM components, PS, attention in both genders, and how they may change across elementary school.

Type of Research

A non-experimental quantitative research methodology was used in this study, specifically a correlational and comparative design. The current study used secondary data collected for a study by Li and Geary (2017). The current study aimed to understand how cognitive abilities changed in elementary students by examining how these cognitive abilities related to each other and compared changes in those abilities among boys and girls from first to fifth grades. Students' progress from first to fifth grades in cognitive abilities and how they are related to each other is the main concern of this study. A correlational study is concerned with assessing relationships between two or more phenomena. Correlational design can be used as explanatory or predictive (McMillan & Schumacher, 2014).

In the current study, the researcher used a predictive correlational design to examine the first and second hypotheses. This method of research allows the investigation of multiple correlations at the same time. The current study also used a comparative design to answer the third and fourth hypotheses. In comparative studies, the value of the dependent variables in two groups are compared to identify the difference between them by examining the relationship of one variable to another (McMillan & Schumacher, 2014).

Population and Sample

The target population for this study was elementary students in first and fifth grades. The students were taken from a previous longitudinal study by Li and Geary (2017). In their study, twelve elementary schools joined a longitudinal prospective study of math learning disability (MLD) in Missouri, U.S.A. Participants in the study consisted of 311 children. The students were assessed extensively on WM at both first and fifth-grade level. In first grade, a total of 254 students were assessed on WM and PS. In fifth grade, only 175 of these students were assessed again using the same measurements. Out of these 175 students, thirty were dropped due to missing data. Thus, the final sample was 145 students (71 boys, 104 girls). The mean intelligence of these first-grade students was average (M = 102, SD = 14) based on the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999).

Hypotheses

The current study asks, "To what extent can PS ability in fifth grade be predicted by attentive behavior, and WM components (visual, verbal, and the central executive) in the first and fifth grades? Do the changes in working memory and processing speed differ between boys and girls?"

Ha1: PS ability of number and letter in fifth grade can be predicted by attention, and visual WM, verbal WM, and central executive in first grade.

Ho1: There is no significant relationship between the predictor variables (attention, and visual WM, verbal WM, and the central executive in first grade) and dependent variables (PS ability of number and letter in fifth grade).

Ha2: PS ability of number and letter in fifth grade can be predicted by attention, and visual WM, verbal WM, and the central executive in fifth grade.

Ho2: There is no significant relationship between the predictor variables (attention, and visual WM, verbal WM, and the central executive in fifth grade) and dependent variables (PS ability of number and letter in fifth grade).

Ha3: Change in WM components (visual WM, verbal WM, and the central executive) in first and fifth grades are significantly different among boys and girls.

Ho3: There is no significant difference between boys and girls regarding the change in WM components (visual WM, verbal WM, and the central executive) in first and fifth grades.

Ha4: Change in PS (letter and number) in first and fifth grades is significantly different among boys and girls.

Ho4: There is no significant difference between boys and girls regarding the change in PS (letter and number) in first and fifth grades.

Definition of Variables

A table with all variables, including conceptual, instrument, and operational definitions is available in Appendix A.

Processing Speed of Number

In general, PS has many definitions. According to Floyd et al. (2008), PS is the ability to quickly, accurately, and fluently complete a simple cognitive or academic task. In the current study, the PS ability of number was measured by the Rapid Automatized Naming (RAN) task (Denckla & Rudel, 1976; Mazzocco & Myers, 2003). The RAN tasks consist of four types of items: objects, colors, letters, and numbers. These are used to assess the PS of the number in which the child has to encode and articulate numerals. First, the child needs to read the stimuli of five numerals correctly. Then a 5x10 matrix which includes frequencies of these numerals is presented to the child, and the child names the numerals as rapidly as they can without errors. Reaction time in seconds is measured by a stopwatch.

Processing Speed of Letter

In the current study, the PS of letter was measured by the Rapid Automatized Naming (RAN) task (Denckla & Rudel, 1976; Mazzocco & Myers, 2003). The child needs to read the stimuli of five lower-case letters (p, o, d, a, and s) correctly. A 5×10 matrix of incidences of these letters is presented to the child to name them as quickly as possible without error. The reaction time is measured using a stopwatch.

Visual Working Memory

The current study adopted Baddeley's (2012) definition for Visuospatial Sketchpad (VSS). The VSS is utilized as a navigation system that conserves and processes material in a visual or spatial form. In this study, the Working Memory Test Battery for Children (WMTB–C; Pickering & Gathercole, 2001) was used. The test consists of nine subtests that assess the central executive, phonological loop, and visuospatial sketchpad.

To measure visual WM, two subtests—Block Recall Span and Mazes Memory Tasks—were administered. The Block Recall is used to assess visuospatial information that is sequential. The Block Recall span is a board consisting of nine blocks presented to the child in random order. On one side of the blocks there is a number that only the experimenter can see from his side. First, the experimenter taps a block or several blocks in a certain sequence, then asks the child to repeat the same sequence. Concurrent visuospatial memory was assessed using the Mazes Memory Task. The experimenter presents a maze in a response booklet that can be solved in different ways, having more than one solution. The child is then shown a picture of the same maze but only one solution is drawn. The picture is removed, and the child must replicate the path shown in the picture in the response booklet. In each level, a wall is added to the mazes, making them larger.

Verbal Working Memory

According to Baddeley (2012), the phonological loop is responsible for verbal WM and has two characteristics: one is the phonological store, which conserves words in speech-based form for one to two seconds. The second is the process of articulating control, which is used to rehearse and hold verbal information from the phonological store. In the current study, the four-subtests—Recalling Span Tasks, Digit Recall, Word List Recall, and Nonword List Recall, which are taken from the Working Memory Test Battery for Children (WMTB–C; Pickering & Gathercole, 2001)—were used to assess precise phonology. The tasks include different content stimuli. In the test, the child must recall words spoken in the same sequence as the subtests. In the Word List Matching Task, the child is presented with a series of words starting with two words. Then, after presenting the same word in either the same or different order, the child identifies whether the list has the same order.

Central Executive

The central executive is a supervisory system that flexibly controls and regulates cognitive processes. This system monitors and coordinates the visuospatial sketchpad and phonological systems and relates them to long-term memory (LTM; Baddeley, 2012). In the current study, Listing Recall and Backward Digit Recall were subtests taken from the Working Memory Test Battery for Children (WMTB–C; Pickering & Gathercole, 2001) to assess the central executive function. These measurements require maintaining a set of items in mind while processing another set of items at the same time. In Listing Recall, the child is asked to identify the true and false sentence read aloud, then, out of those series of sentences, he or she must recall the last word of each sentence. In Counting Recall, the child is asked to count a set of dots on a card and, later, the child is required to remember the number dots at the end of a series of cards. Backward Digit Recall is a standard backward digit span in which the child reads a sequence of numbers and recalls the numbers in reverse order (Geary, Hoard, Byrd-Craven, & DeSoto, 2004).

Attention

Attention is a cognitive function that requires focus on particular information about subjects or objects, and disregards other information that has been perceived (Anderson, 2004). In this study, the Strengths and Weaknesses of ADHD–Symptoms and Normal Behavior (SWAN; Swanson et al., 2008) was used to assess attention. The nine items assessed the child's ability to focus on detail and avoidance of careless mistakes. Teachers rate the behavior of the children from grade two to grade four and compare their score with their peer group on a scale of 1 to 7 where 1 is the lowest score. Scores across grades were highly correlated, *rs* = .71 to.75 ($p < .0001$), and thus for children with multiple ratings, a composite was created using their mean scores ($\alpha = .88$; Geary et al., 2017).

Change of Processing Speed Ability of Number

In this study, the change in PS ability of number from first grade to fifth grade was calculated by subtracting the fifth-grade score from the first-grade score. A positive score indicates growth in the students' performance.

Change of Processing Speed Ability of Letter

In this study, the change in PS ability of letter from first grade to fifth grade was calculated by subtracting the fifth-grade score from the first-grade score. A positive score indicates growth in the students' performance.

Change in Visual Working Memory

The current study adopted Baddeley's (2012) definition for Visuospatial Sketchpad (VSS). VSS is also utilized as a navigation system that conserves and processes material in a visual or spatial form. In this study, the change in visual WM from first grade to fifth grade was calculated by subtracting the fifth-grade score from the first-grade score. A negative score indicates growth in the students' performance.

Change in Verbal Working Memory

According to Baddeley (2012), the phonological loop is responsible for verbal WM and has two fundamental features. First, the phonological store, which conserves words in speech-based form for one to two seconds. Second, the articulatory control process, which is used to rehearse and hold verbal information from the phonological store. In the current study, the change in verbal WM from first grade to fifth grade was calculated by subtracting the fifth-grade score from the first-grade score. A negative score indicates growth in the students' performance.

Change in the Central Executive System

The central executive system flexibly controls and regulates cognitive processes which may be referred to as a supervisory system. It is also responsible for directing attention to specific information about WM activity and linking it with long-term memory (Wongupparaj, Kumari, & Morris, 2015). In the current study, the change in central executive memory from first grade to fifth grade was calculated by subtracting the fifth-grade score from the first-grade score. A negative score indicates growth in the students' performance.

Gender

In the current study, the students were identified as boys or girls who were attending first and fifth grades.

Instruments

Working Memory

The Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001) was used. This standardized test assesses the three core components of WM. The central executive is measured using three subtests with α = .75, .68 for first and fifth grades, respectively; phonological memory span consists of four subtests with α = .78, .77 for first and fifth grades, respectively; and visuospatial memory span consists of two subtests with α = .55, .57 for first and fifth grades, respectively. Each subtest had six items in each span level, which ranged from one to six and one to nine. The child had to pass at least four items to move to the next level. At each level, one item is added to the total number of items the student needs to remember. For the purpose of research, the total number of correct items is more reliable in the analyses than span scores are (Geary et al., 2017).

Processing Speed

The Rapid Automatized Naming (RAN) letter and number tasks were used to assess PS (Denckla & Rudel, 1976; Mazzocco & Myers, 2003). The RAN does not measure all the known components of PS. However, the current study's interest is on the processing of words and multi-digit Arabic numerals which is the main educational ability related to encoding a serial range of visual stimuli (Wolf, Bowers, & Biddle, 2000). In the assessment, the child needs to read stimuli of five-letters or numerals correctly. Children then are required to rapidly name a 5×10 matrix of incidences of letters or numerals without making any mistake (Mazzocco & Myers, 2003). Reaction time is measured in seconds using a stopwatch. The correlation times of letter and number were high in each grade (rs = .74 to .81, $p < .0001$). The mean across-grade reaction for the collective letter and number naming reaction times were also highly correlated (rs = .88, $p < .0001$; Geary et al., 2017).

Attention

To measure student attentive behavior, the Strengths and Weaknesses of ADHD–Symptoms and Normal Behavior (SWAN; Swanson et al., 2008) was used. The attention's scores are typically distributed according to normal children in the classroom. The nine-items assessed the child's ability to focus on detail and avoidance of careless mistakes. Teachers rate the behavior of children from second to fourth grades, then, compare the child's score to other children of the same age. The scale ranges from 1 (far below average) to 7 (far above average). The correlation across grades was highly correlated,

rs = .71 to.75 ($p < .0001$), and thus a composite was created using their mean (α=.88) for children with multiple ratings (Geary et al., 2017).

Data Collection

Before conducting the study, the research proposal was approved by the dissertation committee and department. In order to receive the approval, the researcher completed an application for human subject's research by the Institutional Review Board (IRB) to protect the rights of participants in the research. Application number 18-016 has been evaluated and determined exempt from IRB review under regulation CFR 46.101(b)(2) (see Appendix B).

The current study used secondary data taken from Li and Geary (2017), which does not have any identifiable private information that can be used to readily link a subject to the study. The original data used a longitudinal assessment that investigated mathematical development from kindergarten to ninth grade from 2005 to 2013. In the current study, the researcher only interfaced with the cognitive abilities of elementary students in first and fifth grade. Therefore, the researcher removed data unrelated to the current study.

Data Analysis

To test the first and second hypotheses, canonical correlations statistical analysis was used. Basically, the canonical correlation determines overall relationships between two sets of variables, as well as the relationships between individual variables among the two sets. Canonical correlations can be used for many purposes such as simply looking for correlations between two sets of variables, attempting to confirm a theory, attempting to understand latent variables, and determining if one set of variables can predict the other (Meyers, Gamst, & Guarino, 2016). In the current study, canonical correlation analysis is used to determine if the first set of variables (attention, visual WM, verbal WM, and central executive in first and fifth grades) can predict the other set of variables (PS ability of number and letter in fifth grade).

The null hypothesis was tested by computing four different multivariate significance tests: Pillai's trace, Hotelling's trace, Wilks' Lambda, and Roys. If $p < .05$ was found to be statistically relevant, that means the overall model presented significant and shared variance among predictor and criterion variables (Meyers et al., 2016). The total amount of shared variance among predictor and criterion variables can be determined by Eigenvalues and canonical correlations (Rc2). The structure coefficients and function coefficients allow for a more accurate interpretation of the relationship between the variables and composite variables (Courville & Thompson, 2001; Sherry & Henson, 2005; Thompson, 1984). The structure coefficients indicate the zero-order correlation between the predictor and the composite variable to which it contributes (Courville & Thompson, 2001; Sherry & Henson, 2005).

To test the third and fourth hypotheses, Multivariate Analysis of Variance (MANOVA) was used. MANOVA identifies mean differences in the continuous dependent variables within an independent variable. The independent variable is a categorical variable that has more than two groups (Meyers et al., 2016). To help analyze these hypotheses, the null hypotheses need to be tested.

Multivariate is an extension of the ANOVA test which examines the significant difference in multiple continuous dependent variables and rolls them together into a linear composite variable. The $p < .05$ of the Wilks' *Lambda* test determines if there are significant differences between the levels of the independent variable on a composite of all the dependent variables. The *Eta Squared* value determines how much of the population can be described. Further analysis using the R-E-G-W-R post-hoc test needs to be done if one or more variables show statistical differences based on the levels of the independent variable.

CHAPTER 4

RESULTS

Introduction

This chapter provides the outcome of the data analysis for the current study. The main goal of this study was to understand how cognitive functions develop in elementary students by examining the relationships existing between a number of cognitive functions—PS, WM, and attention—and whether PS abilities can be predicted by WM components (visual memory, verbal memory, and the central executive), and attention. Besides examining the relationship between these cognitive functions, comparing changes in these functions among boys and girls from first to fifth grades provides a comprehensive construct of cognitive development in elementary students.

Data Screening

Before conducting data analysis, all variables were screened for possible violation of the statistical assumption, along with outliers and missing values, using SPSS Frequencies, Explore, and Plot. A total of 145 elementary students were screened for missing values on six initial continuous variables (visual WM, verbal WM, central executive, attention, PS of number, and PS of letter). Attention was the only variable that had missing values for 28 participants. Using linear interpolation, the 28 missing values were discovered and replaced.

Checking for outliers for all variables (visual WM, verbal WM, the central executive, attention, PS of number, PS of letter, change of PS of number, change of PS of letter, change in verbal WM, change in visual WM, and the change in the central executive) indicated that about 24 of the participants show either higher or lower values across the variables than the rest of the participants. The participants differed according to variables, except for a certain number of participants, such as participants #112 and #116, who exhibited higher scores on the first-grade PS of number and letter functions. Participant #116 also showed high scores in both variables (change of PS of number and change PS of letter).

In first grade, participant #64 had higher scores on the PS of letter and number. Participant #61 (in fifth grade) exhibited higher scores on PS of letter and number, but lower scores on the variables of change of PS of number and change of PS of letter. Participants #65 and #94, in first and fifth grades, respectively, had higher scores in verbal WM.

Those scores with higher or lower values might be due to the characteristics of the students, administration of the measurements, or even the environment at measurement. Thus, the outlier's value was maintained when analyzing the data. The next step after checking for missing values and outliers was to test whether variables were normally distributed. Skewness and histograms were used in order to identify if the data were normally distributed. Both tests indicated that the data was normally distributed within an acceptable range for skewness below +1.5 and above -1.5 (Tabachnick & Fidell, 2013).

Demographics and Backgrounds of Participants

This section describes the demographic characteristics of participants, which include gender, ethnicity, and age, of both periods of assessment for the students. Descriptive statistics were assessed to provide a better picture of the participants in the study (see Table 1). The sample included 145 elementary students of both genders (71 males, 74 females). The study involved several ethnicities: white—111, black—7, Asian—6, mixed—8, unknown—5. In first-grade, students' ages ranged between 80 to 99 months (*M* = 86.03, *SD* = 3.77), while in fifth-grade students, ages ranged between 126 to 141 months (*M* = 133.12, *SD* = 3.84).

Table 1

Descriptive Statistics

Variables		*M*	*SD*	*SK*	*N*
Processing Speed Letter	First grade	31.53	7.00	1.01	145
	Fifth grade	23.29	5.36	1.09	145
Processing Speed Number	First grade	33.76	7.10	.89	145
	Fifth grade	23.67	5.12	.78	145
Verbal Memory	First grade	76.07	13.48	-.09	145
	Fifth grade	90.76	13.85	.64	145
Visual Memory	First grade	28.71	6.72	-.37	145
	Fifth grade	45.88	8.99	-.33	145
Central Executive	First grade	34.11	9.14	.07	145
	Fifth grade	50.59	9.94	-.12	145
Age	First grade	86.03	3.77	.26	145
	Fifth grade	133.12	3.84	.22	145
Attention		4.89	1.14	-.21	145
Processing Speed Letter Change		8.25	6.67	.042	145
Processing Speed Number Change		10.08	5.48	.27	145
Verbal Memory Change		-14.67	9.87	-.37	145
Visual Memory Change		-17.17	7.56	-.09	145
Central Executive Change		-16.48	8.65	-.02	145

Variables Distribution

The current study involved 11 variables: PS of letter, PS of number, attention, verbal WM, visual WM, central executive, change in PS of letter, change in PS of number, change in verbal WM, change in visual WM, and change in central executive. Table 1 provides means, standard deviations, and skewness for all variables. Students' PS of letter scores in first grade ranged from 20.03 to 55.50 (range of 35.47, *M* = 31.53, *SD* = 7.0), while students' PS of number scores in first grade ranged from 20.58 to 56.37 (range of 35.79, *M* = 33.76, *SD* = 7.1). The means for verbal WM and visual WM in first grade were 76.07 and 28.71, respectively. These fell within their respective average ranges. The score in central executive for first-grade students varied from 12 to 59 (range of 47, *M* = 50.59, *SD* = 9.94).

The change in WM components (visual, verbal, and central executive) from first grade to fifth grade was calculated by subtracting fifth-grade scores in these variables from first-grade scores. The means of the students' changes in verbal WM and visual WM were -14.68 and -17.17, respectively. Their change in central executive ranged from 6 to -39 (range of 45, *M* = -16.48). The same procedure was done with PS components (letter and number). The means and standard deviation of the students' change in PS of letter were M = 8.25, SD = 6.67, while in PS of number, they were *M* = 10.08, *SD* = 5.48.

Correlation Among the Variables

The correlations among all variables utilized in the current study was computed. A Pearson's r analysis revealed a strong positive correlation that ranged between *r* = .5 and *r* = .8 among PS of letter and number in both first and fifth grades (see Table 2). PS of letter and change in PS of number in first grade also had a strong positive correlation with the change in PS of letter and change in PS of number ranging between $r = .7$ and $r = .8$. Visual WM and verbal WM in first and fifth grades had strong positive correlations ranging between $r = .5$ and $r = .6$, with the central executive in first and fifth grades.

Verbal WM, visual WM, and central executive had negative moderate correlations ranging between $r = -.3$ and $r = -.4$ with PS of letter and number in first and fifth grades. Verbal WM, visual WM, and central executive had negative weak correlations ranging between $r = -.2$ and $r = -.1$ with changes in PS of letter and number. PS of letter and number in first and fifth grades also had negative weak correlations ranging between $r = -.2$ and $r = -.1$ with changes in the verbal, visual, and central executive. Attention had strong positive correlations with the central executive in fifth grade. Attention had a positive moderate correlation ranging between $r = -.3$ and $r = -.4$ with verbal and visual WM in first and fifth grade.

Table 2

Correlation Among the Variables

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PS Letter 1	1															
PS Number1	.76	1														
Attention	-.41	-.38	1													
PS Letter 5	.44	.54	-.28	1												
PS Number 5	.45	.64	-.28	.78	1											
Verbal WM1	-.32	-.23	.30	-.22	-0.11	1										
Visual WM1	-.32	-.39	.38	-.19	-.23	.43	1									
CE1	-.41	-.42	.36	-.34	-.35	.57	.54	1								
Verbal WM 5	-.35	-.31	.28	-.26	-.18	.74	.32	.50	1							
Visual WM5	-.26	-.32	.32	-.36	-.32	.30	.57	.47	.31	1						
CE5	-.43	-.39	.46	-.34	-.29	.50	.42	.59	.51	.49	1					
Change PS Letter	.69	.37	-.20	-.34	-0.15	-0.16	-.18	-0.16	-0.16	0.02	-.18	1				
Change PS Number	.56	.70	-.23	-0.03	-0.10	-.20	-.29	-.21	-.23	-0.11	-.24	.62	1			
Change Verbal WM	0.05	0.12	0.02	0.07	0.11	.33	0.13	0.08	-.39	-0.02	-0.03	0.00	0.05	1		
Change Visual WM	0.03	0.03	-0.04	.26	.18	0.02	.21	-0.08	-0.09	-.68	-.20	-.18	-0.13	0.15	1	
Chang CE	0.05	0.01	-0.15	0.03	-0.04	0.03	0.08	.38	-0.06	-0.06	-.52	0.03	0.05	0.12	0.15	1

Hypotheses Testing

Four hypotheses were used to answer the main research questions that examined the development of cognitive functions in elementary students by examining whether PS function can be predicted by WM components (visual, verbal, and central executive) and attention. Then changes in these cognitive functions among boys and girls from first and fifth grades were also compared.

Hypothesis 1

Null Hypothesis 1

The first null hypothesis states that there is no significant relationship between the predictor variables (attention, visual WM, verbal WM, and central executive WM in first grade) and the dependent variables (PS ability of number and letter in fifth grade).

In order to test the first hypothesis, canonical correlations were conducted to explore the relationships between two sets of cognitive functions. The dependents variate was PS in fifth grade while the predictors variate was cognitive ability in first grade.

With 145 participants in the analysis, the overall correlation between the dependent variables and predicted variables was statistically significant, Wilks' *Lambda* = .78, $F_{(8, 278)} = 4.61$, $p < .001$, $Rc^2 = .17$, which meant the null hypothesis is rejected. The first function was statistically significant at $p < .00$. The eigenvalue for the first function was .21. Dimension reduction analysis indicated that only the first function was statistically significant, in which only 15% of the shared variance was explained between cognitive ability in first grade and PS in fifth grade (see Figure 5).

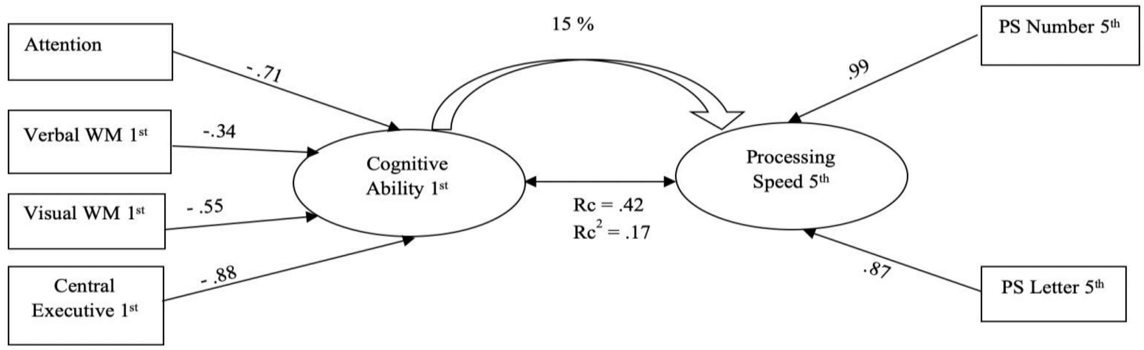

Figure 5. First hypothesis multivariate analysis.

The structure coefficients for the first function for the predictor and dependent variables are shown in Table 3. The first predictor function is associated with low levels of the central executive, visual WM, and verbal WM in first grade, as well as attention. The first dependent function is associated with high levels of PS of letter and PS of number.

At the univariate level, it appears that approximately 15% of the variance of the PS of letter in fifth grade was explained by the linear combination of independent variables (cognitive ability first grade), R^2 = .15, $F_{(4, 140)}$ = 5.9, $p < .001$, while the

Table 3

Structure Coefficients for Predictor Canonical Variates and the Dependent Variables

Variables		*Correlations Function*	*Standardized Function*
Dependent Variables			
	Processing Speed Letter Fifth Grade	.87	.26
	Processing Speed Number Fifth Grade	.99	.77
Predictor			
	Attention	-.71	-.49
	Verbal Memory First Grade	-.34	.31
	Visual Memory First Grade	-.55	-.04
	Central Executive First Grade	-.88	-.85

linear combination of independent variables explained about 17% of the variance of the PS of number in fifth grade, R^2 = .17, $F_{(4, 140)} = 7.1$, $p < .001$.

The regression analysis indicated that only attention (*Beta* = -.19, *p* = .027) and central executive in first grade (*Beta* = -.28, *p* = .008) were significant predictors of PS of letter in fifth grade. Analyses also indicated that visual WM (*p* = .61), and verbal WM (*p* = .81) in first grade were not good predictors of PS of letter in fifth grade (see Table 4).

Attention was a significant predictor (*Beta* = -.19, *p* = .024) of PS of number in fifth grade. Central executive in first grade (*Beta* = -.36, *p* =.001) was also a significant predictor of the PS of number in fifth grade. However, verbal WM in first grade (*Beta* = -.17, *p* = .075) was a marginal predictor of the PS of number in fifth grade. Table 4 shows that visual WM in first grade (*p* = .71) was not a strong predictor of the PS of number in fifth grade (see Figure 6).

Table 4

Processing Speed Relationship With Independent Variables in First Grade

Variables	Processing Speed of Letter				Processing Speed of Number			
	B	*Beta*	*SE*	*P*	*B*	*Beta*	*SE*	*P*
Attention	-.91	-.19	.41	.03	-.88	-.19	.38	.02
Verbal Memory First Grade	-.01	-,02	.04	.81	.07	.17	.04	.07
Visual Memory First Grade	.04	.05	.08	.61	-.03	-.04	.07	.71
Central Executive First Grade	-.16	-.28	.06	.01	-.20	-.36	.06	.001

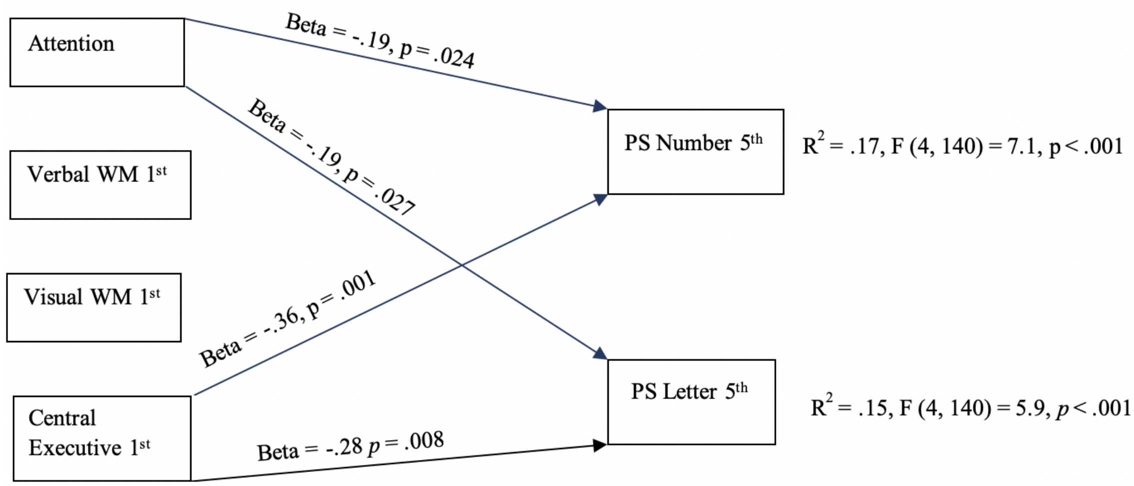

Figure 6. First hypothesis univariate analysis.

Hypothesis 2

Null Hypothesis 2

The second null hypothesis states that there is no significant relationship between the predictor variables (attention, and visual WM, verbal WM, and central executive in fifth grade) and the dependent variables (PS ability of number and letter in fifth grade). In order to test the second hypothesis, canonical correlations were conducted to explore the relationships between two sets of cognitive functions. The dependent variables are PS in fifth grade. The predictor variables is cognitive abilities in fifth grade.

The overall correlation between the dependent variables and predicted variables in fifth grade was statistically significant, Wilks' *Lambda* = .80, $F_{(8, 278)} = 4.11$, $p < .001$, $Rc^2 = .19$. Therefore, the null hypothesis was rejected. The first function was statistically significant at $p < .001$. The eigenvalue for the first function was .23. Dimension reduction analysis indicated that only the first function was statistically significant, in which only 16.5% of the shared variance was explained between cognitive ability in fifth grade and PS fifth grade (see Figure 7).

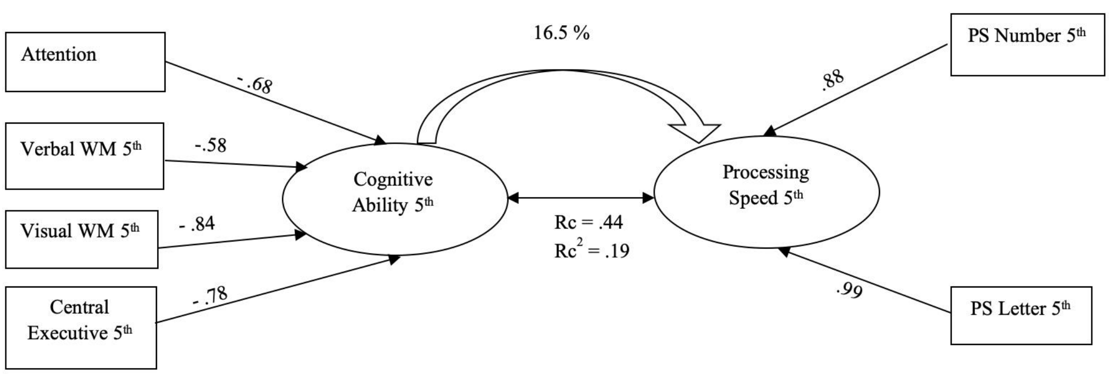

Figure 7. Second hypothesis multivariate analysis.

The structure coefficients for the first function for the predictor and dependent variables are shown in Table 5. The first predictor function is associated with low levels of the central executive, attention, and visual WM and verbal WM in fifth grade. The first dependent function is associated with high levels of PS of letter and PS of number.

At the univariate level, it appears that approximately 18.4% of the variance in PS of letter in fifth grade was explained by the linear combination of the independent variables (cognitive ability in fifth grade), $R^2 = .18$, $F_{(4, 140)} = 7.9$, $p < .001$, while about

Table 5

Structure Coefficients for Predictor Canonical Variates and the Dependent Variables

Variables		Correlations Function	Standardized Function
Dependent Variables			
	Processing Speed Letter Fifth Grade	.99	-.77
	Processing Speed Number Fifth Grade	.88	-.27
Predictor			
	Attention	-.68	-.33
	Verbal WM Fifth Grade	-.58	-.18
	Visual WM Fifth Grade	-.84	-.55
	Central Executive Fifth Grade	-.78	-.27

15% of the variance in PS of number in fifth grade was explained by the linear combination of the independent variables, $R^2 = .15$, $F_{(4, 140)} = 6.1$, $p < .001$.

The regression analysis indicated that visual WM in fifth grade was the only significant predictor of PS of letter in fifth grade (*Beta* = -.23, *p* = .010). Table 6 shows that attention, verbal WM, and central executive in fifth grade were not good predictors of PS of letter in fifth grade.

Visual WM in fifth grade (*Beta* = -.21, *p* = .017) was the only significant predictor for PS of number in fifth grade. However, attention (*Beta* = -.16, *p* = .06) was a marginal predictor of the PS of number in fifth grade. Table 6 shows that verbal WM in fifth grade, and central executive were not good predictors of the PS of number in fifth grade (see Figure 8).

Hypothesis 3

Null Hypothesis 3

The third null hypothesis states that there is no significant difference between

Table 6

Processing Speed Relationship With Independent Variables in Fifth Grade

Variables	Processing Speed of Letter				Processing Speed of Number			
	B	*Beta*	*SE*	*P*	*B*	*Beta*	*SE*	*P*
Attention	-.59	-.13	.40	.14	-.74	-.16	.4	.06
Verbal WM Fifth Grade	-.04	-.09	.03	.29	-.01	- .02	.03	.08
Visual WM Fifth Grade	-.14	-.23	.05	.01	-.12	-.22	.05	.02
Central Executive Fifth Grade	-.06	-.12	.06	.24	-.05	-.09	.05	.35

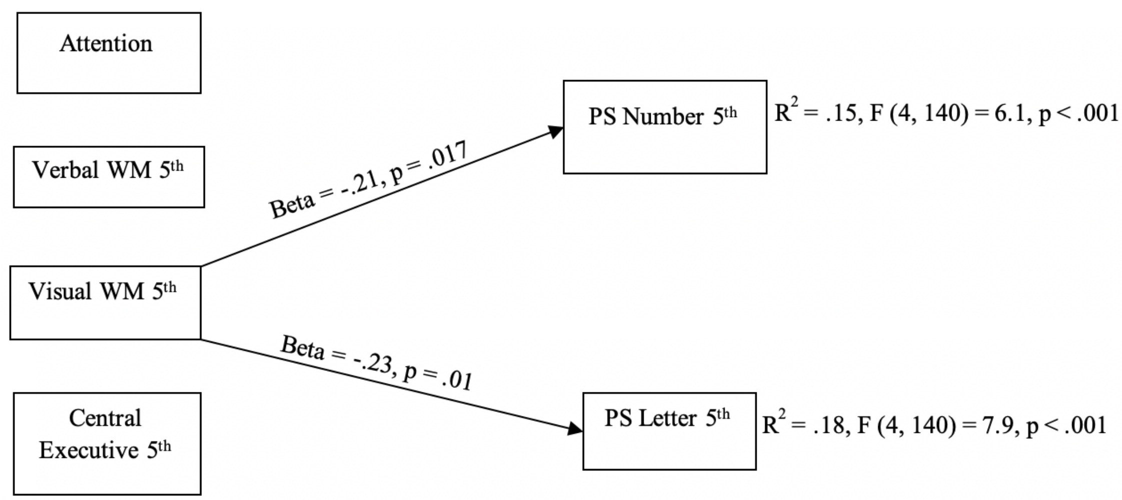

Figure 8. Second hypothesis univariate analysis.

boys and girls regarding the change in WM components (visual WM, verbal WM, and the central executive) in the first and fifth grades.

To test this hypothesis, Multivariate Analysis of Variance (MANOVA) was used. In this hypothesis, the independent variable was gender. The changes in visual WM, verbal WM, and central executive were dependent variables.

In order to use MANOVA, there are three main assumptions: normal distribution of the data, the linearity of the dependent variables, and homogeneity of variances-covariances. To determine whether the data is normally distributed, skewness was used which showed that the data was normally distributed but within an acceptable range of -1 and +1 (see Table 1). To determine whether the dependent variables were linear, Barlett's test of sphericity was conducted and was statistically significant (approximate *Chi-square* = 17.82, df = 5, $p < .003$), indicating that the correlations of the dependent variables were sufficient to support the MANOVA. The Box's test of the equality of the variance-covariance matrices was not significant (Box's $M = 2.13$, $F_{(6, 147462.74)} = .346$, $p = .912$) suggesting that the matrices were equal variances. Regarding WM components, results did not indicate a significant multivariate main effect for differences between boys and girls, Wilks' *Lambda* = 0.98, $F_{(3, 141)} = .54$, $p = .65$, thus the null hypothesis was retained. The test of between subject effect for WM can be seen in Table 7.

Table 7

Tests of Between-Subjects Effects of Working Memory

Variables	*df*	*MS*	*F*	*P*	*Eta²*
Change in Verbal WM	1	80.43	0.83	0.37	0.006
Change in Visual WM	1	19.76	0.34	0.56	0.002
Change in Central Executive	1	22.07	0.29	0.59	0.002

Hypothesis 4

Null Hypothesis 4

The fourth null hypothesis was that there is no significant difference between boys and girls regarding the change in PS of letter and PS of number from first to fifth grades.

In order to test this hypothesis, a Multivariate Analysis of Variance (MANOVA) was used. In this hypothesis, the independent variable was gender. The changes in PS of letter and PS of number were dependent variables.

MANOVA assumptions were examined again. The skewness indicated that the data was normally distributed within an acceptable range of -1 and +1 (see Table 1). Barlett's test of sphericity was statistically significant (approximate *Chi-square* = 74.90, $df = 2$, $p < .001$), indicating that the correlations of the dependent variables were sufficient to support the MANOVA. Box's test of the equality of the variance-covariance matrices was not significant (Box's $M = .28$, $F_{(3, 3895880.84)} = .096$, $p = .96$), suggesting that the matrices were equal variances. Regarding PS, results did not indicate a significant multivariate main effect for differences between boys and girls, Wilks' *Lambda* = 0.98, $F_{(2, 1412)} = 1.29$ $p = .65$, thus the null hypothesis was retained. The test of between subject effect for WM can be seen in Table 8.

Table 8

Tests of Between-Subjects Effects of Processing Speed

Variables	*df*	*MS*	*F*	*P*	*Eta*^{2}
Change in PS of letter	1	27.25	0.61	0.34	0.004
Change in PS of number	1	11.54	0.38	0.54	0.003

Summary of Results

In this study, PS (letter and number), WM components (verbal, visual, and central executive), and attention were examined in elementary school students according to four hypotheses. Two hypotheses investigated the relationships between the variables. Canonical correlations were conducted to determine if attention, verbal WM, and visual WM in first and fifth grades were good predictors of PS (letter and number) in fifth grade. The third and fourth hypotheses used MANOVA to investigate gender differences between boys and girls in how WM (verbal, visual, and central executive) and PS (letter and number) change from first to fifth grades.

Hypothesis 1 investigated the relationship between the predictor's variables (attention, verbal WM and visual WM in first grade) and dependent variables (PS of letter and PS of number in fifth grade). The results indicated a statistically significant canonical relationship between these two sets of variables, Rc = .42 (p =.001). Approximately 15% of the variance of the PS of letter in fifth grade was explained by cognitive ability in first grade, while cognitive ability in first grade explained about 17% of the variance of the PS of number in fifth grade. Analysis of these beta coefficients showed that only attention and central executive in first grade were significant predictors of PS of letter and number in fifth grade.

Hypothesis 2 investigated the relationship between the independent variables (attention, verbal WM and visual WM in fifth grade, and gender) and dependent variables (PS of letter in fifth grade, and PS of number in fifth grade). The results indicated a statistically significant canonical relationship between these two sets of variables, Rc = .45, (p = .001). Approximately 18.4% of the variance in PS of letter in fifth grade was explained by cognitive ability in fifth grade while about 15% of the variance in PS of number in fifth grade was explained by cognitive ability in fifth grade. Analysis of these beta coefficients showed that only visual WM in fifth grade was a significant predictor of PS of letter and number in fifth grade. However, attention was a marginal predictor of the PS of number in fifth grade.

Hypothesis 3 investigated if there was a difference between boys and girls regarding the change in visual WM, verbal WM, and central executive from first to fifth grades. The results indicated that the multivariate effect of gender was not statistically significant, Wilks' *Lambda* = 0.98, $F_{(2, 1412)}$ = 1.29, p = .65, which means there is no gender difference between boys and girls in the rate of change in WM.

Hypothesis 4 investigated if there was a difference between boys and girls regarding the change in PS of letter and PS of number from first to fifth grades. The results indicated that the multivariate effect of gender was not statistically significant, Wilks' *Lambda* = 0.98, $F_{(3, 141)}$ = .54, p = .65, which means there is no gender difference between boys and girls in the rate of change in WM.

CHAPTER 5

SUMMARY, FINDINGS, DISCUSSION, RECOMMENDATIONS, AND CONCLUSIONS

This chapter provides an overview of the current study, including a brief review of the study background, statement of the problem, the purpose of the study, research method, and significance of the study. It discusses the key findings from the research questions and hypotheses, assessments, and suggestions for future research. Implications for educational psychologists, counseling psychologists, teachers, and the education system, including curricula, are also presented.

Introduction

Cognitive abilities are interrelated so that one function is likely to affect the efficiency of another. All cognitive processes are harmonized to achieve the same directed action. In elementary students, such processes are pivotal in establishing the foundation of the learning process (Baddeley, 2017). One of the essential cognitive abilities that affects academic skills and other cognitive abilities is PS (Floyd et al., 2008; Naples et al., 2012; Vukivic & Siegel, 2010).

The correlations between PS, attention, and WM constitute a fundamental aspect of intelligence (Burns et al., 2009; Deary, 2012; Fink & Neubauer, 2005; Schweizer, 2005; Schweizer & Moosbrugger, 2004; Tillman et al., 2009). Moreover, PS, WM, and attention processes are the main functions of human intelligence (Fournier, 2014).

According to Ferguson and Bowey (2005), PS is a major factor underlying memory in children, particularly auditory span. Encoding and storage have a limited capacity, which causes the decay or displacement of early processing before later processing is completed. Losing information might occur during rehearsal or recall, but if a child can sufficiently rehearse or retrieve information, he or she will perform better than those with slower processing rates.

Many studies have considered the connection between attention and WM and WM and PS. However, the relationship between all these neurocognitive constructs (attention, PS, and WM) is rarely investigated (Fournier, 2014). Attention, PS, and WM have been hypothesized as fundamental in the facilitation and support of higher-order cognitive processes and functional skills (Miller, 2013; Schweizer & Moosbrugger, 2004). Several studies have indicated that WM and different types of attention in both adults and children have moderate to strong relationships (Burns et al., 2009; Miyake et al., 2000; Schweizer & Moosbrugger, 2004).

Statement of the Problem

The cognitive function of PS is being able to process the information accurately and rapidly. Executive function is a system that outlines various cognitive processes like attention, self-regulation, and goal setting. Both functions—PS and executive function—are connected to the prefrontal cortex along with the cognitive and behavioral functions during development such as episodic memory changes (Dias et al., 2018).

Research has suggested that the limited cognitive resources used by the WM system are also shared by PS (Gavens & Barrouillet, 2004; Magimairaj & Montgomery, 2012). The hypothesis of shared resources was supported via an experiment that showed that increases in WM loads resulted in slower speed of processing and increased demands on PS caused a decrease in WM capacity (Gavens & Barrouillet, 2004).

Studies have also indicated gender differences in cognitive functions. However, few longitudinal studies focused on gender differences in the rate of change. Many researchers have concluded that girls perform tasks faster than boys do. This implies that girls have a higher PS compared to boys. When comparing cognitive abilities between males and females across the lifespan, boys in kindergarten, elementary, middle, and high school show lower PS, which is initially small in kindergarten but increases through high school (Camarata & Woodcock, 2006). According to Aartsen et al. (2004), males showed weaker memory functioning than females did. However, females and males did not show differences in non-verbal and speed reasoning changes. The studies also did not indicate differences between males and females in cognitive function decline, despite the evidence of age-related differences in the brain structure of males.

According to many studies, PS and WM improve with age (e.g., Brocki & Bohlin, 2004; Coyle et al., 2011; Demetriou et al., 2013; Fry & Hale, 2000; Huizinga, Dolan, Molen, 2006; Jensen, 2006; Kail, 2007; McAuley & White, 2011). McAuley and White (2011) provided a comprehensive understanding of the development of PS, inhibition, and WM and how those abilities are interrelated with each other. According to McAuley (2008), these abilities are a separate function which showed different developed rates. Moreover, McAuley and White (2011) and McAuley (2008) indicated that these functions are interrelated to each other in which inhibition, WM storage, and WM updating were directly affected by PS. The relationship was sustained over an age range, which indicated those abilities are established in early childhood.

Purpose of the Study

The main purpose of the current study was to understand cognitive functions in elementary students. It examined whether WM components (visual, verbal, central executive), and attention behavior, in first and fifth grades can predict PS ability in fifth grade students. The study also aimed to identify whether there are gender differences in cognitive changes, more specifically PS and WM components (visual, verbal, and central executive) among elementary students from first to fifth grades.

The current study serves to improve the conception of gender differences in the rate of cognitive functions in WM and PS change from first to fifth grades. Understanding change in these cognitive abilities provides educators, psychologists, and teachers with knowledge of how to approach each grade level and gender by designing the right method of teaching, assistance, or even intervention for those who have deficits in one or more of these cognitive functions.

Hypotheses

The main research question for the current study was as follows: To what extent are students' PS ability related to attention behavior, and WM components (visual WM, verbal WM, and the central executive) in elementary students, and do changes in these cognitive functions differ between boys and girls?

Ho1: PS ability of number and letter in fifth grade can be predicted by attention, visual WM, verbal WM, and the central executive in first grade.

Ho2: PS ability of number and letter in fifth grade can be predicted by attention, visual WM, verbal WM, and the central executive in fifth grade.

Ho3: Change in WM components (visual WM, verbal WM, and the central executive) in first and fifth grades are significantly different between boys and girls.

Ho4: Change in PS (letter and number) in first and fifth grades are significantly different between boys and girls.

Research Design

The current study used non-experimental quantitative research. The main purpose of this study was to provide a comprehensive understanding of cognitive functions in elementary students by first identifying the relationship between PS, attention, and WM. The second purpose was to determine if boys and girls are different in the rate of change in WM and PS from first to fifth grades. Therefore, both a predictive correlational design and comparative designs were utilized. A canonical correlational method was used to examine the first and second hypotheses, while a comparative design was used to answer the third and fourth hypotheses.

The current study examined whether PS of number and PS of letter in fifth grade can be predicted by the following variables: attention, visual WM, verbal WM, and the central executive in first and fifth grades. Multivariate Analysis of Variance (MANOVA) was also used to determine gender differences in cognitive function change from first to fifth grades in the following variables: PS of letter, PS of number, verbal WM, visual WM, and the central executive.

The data for the current study were taken from a previous longitudinal study conducted by Li and Geary (2017). In the study, students were assessed extensively on WM in both first and fifth grades. The final sample included 145 students (71 boys, 74 girls). When screening the data, the mean intelligence of these first-grade students was average (M = 102, SD = 14) based on the WASI (Wechsler, 1999).

Students' WM was also assessed using the Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001), which includes the three core components of WM: the central executive consists of three subtests with α = .75, .68 for first and fifth grades, respectively; phonological memory span consists of four subtests with α = .78, .77 for first and fifth grades, respectively; and visuospatial memory span consists of two subtests with α = .55, .57 for first and fifth grades respectively (Geary et al., 2017).

PS was assessed by Rapid Automatized Naming task (RAN; Mazzocco & Myers, 2003). Reaction time (in seconds) was measured using a stopwatch. Reaction times for letter and number naming were highly correlated in each grade (r = .74 to .81, $p < .0001$). The mean across-grade reaction time for the collective letter and number naming reaction times was also highly correlated (r = .88, $p < .0001$; Geary et al., 2017).

To measure student attention behavior, the Strengths and Weaknesses of ADHD Symptoms and Normal Behavior (SWAN) by Swanson et al. (2008) was used. Scores across the grades were highly correlated, r = .71 to.75 ($p < .0001$), and thus for children with multiple ratings, a composite was created using their means (α = .88; Geary et al., 2017).

In the current study, the dependent variables were PS of letter and PS of number in fifth grade, and the independent variables were gender, attention, and visual WM, verbal WM, and central executive WM in first and fifth grades.

All variables were screened for possible violation of the statistical assumption, along with outliers and missing values using SPSS Frequencies, Explore, and Plot. A total of 145 elementary students were screened for missing values on six initial continuous variables (visual WM, verbal WM, central executive, attention, PS of number, and PS of letter). Attention was the only variable that had missing values in 28 cases. Using liner interpolation, the 28 missing values that were discovered were replaced.

The demographic characteristics of the participants included gender, ethnicity, and age of both periods of assessment for the students. Descriptive statistics were assessed to provide a better picture of participants in the study (see Table 1). The study included 145 elementary students of both genders, ($M = .49$, $SD = .50$). Boys were 49% of the sample, and girls were 51% of the sample. The study involved several ethnicities: 111 were White, 7 were Black, 6 were Asian, 8 were mixed, and 5 were of unknown race. In first-grade students, the age ranged between 80 to 99 months ($M = 86.03$, $SD = 3.77$), while in fifth-grade students, the age ranged between 126 to 141 months ($M = 133.12$, $SD = 3.84$).

Summary of Findings

The current study examined four hypotheses to answer the main research question, which is concerned with cognitive function development in elementary students. The first two hypotheses investigated whether PS function can be predicted by WM components (visual, verbal, and central executive), and attention. The third and fourth hypotheses compared changes in those abilities among boys and girls from first to fifth grades.

A canonical correlation was conducted to determine if attention, verbal WM, and visual WM in first and fifth grades are good predictors of PS (letter and number) in fifth grade. The third and fourth hypotheses used a MANOVA to investigate gender differences between boys and girls in how WM (verbal, visual, and central executive) and

PS (letter and number) change from first to fifth grades.

Hypothesis 1 investigated the relationship between the independent variables (attention, verbal WM and visual WM in first grade) and the dependent variables (PS of letter and PS of number in fifth grade). The results indicated a statistically significant canonical relationship between these two sets of variables, $Rc^2 = .17$, $p = .001$. Analysis of these beta coefficients showed that attention (*Beta* = -.19, *p* = .024), and the central executive (*Beta* = -.35, *p* = .001) in first grade were significant predictors of the PS of number in fifth grade while attention (*Beta* = -.19, *p* = .027), and the central executive (*Beta* = -.28, *p* = .008) in first grade were significant predictors of the PS of letter. The verbal WM in first grade was a marginal predictor of only PS of number in fifth grade.

Hypothesis 2 investigated the relationship between the independent variables (attention, verbal WM and visual WM in fifth grade) and dependent variables (PS of letter and PS of number in fifth grade). The results indicated a statistically significant canonical relationship between these two sets of variables, $Rc^2 = .16$, $p = .001$. Analysis of these beta coefficients showed that only visual WM in fifth grade was significantly predictive of PS of number and letter in fifth grade respectively (*Beta* = -.21, *p* = .017; *Beta* = -.23, *p* = .01). However, attention was a marginal predictor of PS of number in fifth grade.

Hypothesis 3 investigated if there was a difference between boys and girls regarding their changes in visual WM, verbal WM, and central executive from the first to fifth grades. There was no gender difference between boys and girls in the rate of change in WM components, Wilks' *Lambda* = 0.98, $F_{(2, 1412)} = 1.29$, $p = .65$.

Hypothesis 4 investigated if there was a difference between boys and girls regarding their changes in PS of letter and PS of number from the first to fifth grades. There was no gender difference between boys and girls in the rate of change in WM components, Wilks' *Lambda* = 0.98, $F_{(3, 141)} = .54$, $p = .65$.

Discussion of the Findings

The primary goal of this study was to use developmental data to examine how PS, WM components, and attention connect to each other and how the change in these cognitive functions is different between boys and girls in elementary school. Two methods were used to answer this question. One method was a canonical correlation that was conducted to determine if attention, verbal WM, and visual WM in first and fifth grades are good predictors of PS (letter and number) in fifth grade. The second was a MANOVA to investigate gender differences between boys and girls in how WM and PS change from first to fifth grades.

The first and second hypotheses were statistically significant, and five main findings emerged out of them. Attention is a significant predictor of PS of letter and number in fifth grade. Central executive in first grade is a significant predictor of PS of letter and number in fifth grade. Interestingly, verbal WM in first grade is a marginal predictor of the PS of number in fifth grade, but not for PS of letter. Visual WM in fifth grade was significantly predictive of PS of letter and number in fifth grade. However, attention was a marginal predictor of only PS of number in fifth grade.

In order to have a comprehensive view of the cognitive functions among elementary students, several variables, including attention, visual WM, verbal WM, the central executive, PS of number, and PS of letter were investigated in first and fifth grades. Gender differences were also examined. A MANOVA was used to test gender differences in cognitive change from first to fifth grades in visual WM, verbal WM, central executive, PS of letter, and PS of number.

The results showed that the multivariate effect of gender was not statistically significant in hypotheses three and four. In the following section, the findings for each hypothesis and a possible explanation for the correlation between these cognitive functions are discussed in detail.

The correlations among all variables involved in the current study were computed. A Pearson's *r* analysis revealed strong positive correlations that ranged between $r = .5$ and $r = .8$ among PS of letter and number in first and fifth grades (see Table 2). The correlation between attention and PS of number and letter in first grade were moderately negative, while the correlation between attention and PS in fifth grade was weakly negative. In addition, attention was moderately correlated with visual WM and verbal WM in both first and fifth grades. Attention was moderately correlated with the central executive in first and fifth grades.

The correlation between central executive and PS of number and letter in first grade was moderately negative, while the correlation between central executive in first grade and PS of number and letter in fifth grade was weakly negative. Also, the central executive in first grade was moderately correlated with visual WM and strongly correlated with verbal WM in first grade. Central executive in fifth grade was moderately correlated with visual WM and verbal WM in fifth grade.

H1: PS function of number and letter in fifth grade can be predicted by attention, and visual WM, verbal WM, and central executive in the first grade. The results demonstrated that the overall correlation between the dependent variables (PS of number and letter in fifth grade) and predicted variables (attention, visual WM, verbal WM, and central executive in first grade) was statistically significant (Wilks' *Lambda* = .78, $Rc^2 = .17$, about $F_{(8, 278)} = 4.61$, and $p < .001$).

The *Beta* coefficients revealed that attention was identified as a negative predictor of PS of letter and number in fifth grade. They also revealed that central executive in first grade was identified as a negative predictor of PS of letter and number in fifth grade. Interestingly, verbal WM in first grade was a marginal predictor of only PS of number, not letter, in fifth grade. The weak reliance on verbal WM in PS of number is parallel to the analysis of Geary et al. (2004), which found that students in second grade show a correlation between verbal WM and mathematical reasoning abilities, but not in third grade.

Even though Geary et al.'s (2004) study suggested a correlation between verbal WM and processing math information, it is still ambiguous why verbal WM in first grade predicts PS of number but not PS of letter in fifth grade. An explanation might be that students need to decode those numeric symbols into verbal representations by a phonological loop before processing them. Therefore, more research should consider which component of WM students rely on for different subjects and grade level.

These findings imply that PS in fifth grade can be affected by students' attention behavior in first grade. Being able to focus one's attention results in less effort needed to process information. Therefore, children's inattentive behavior may cause slow PS during performance. The findings of Weiler, Bernstein, Bellinger, and Waber (2000), and Shanahan et al. (2006) provide support for these assertions. They found that disorders characterized by attention deficits such as ADHD exhibit PS impairments. Individuals with ADHD show slower PS when performing nonlinguistic and matching tests, naming, and fluency tasks. According to Chhabildas (2003), genetic studies of twins provide evidence that PS is related to symptoms of ADHD.

A study by Retzler et al. (2019) compared the association of cognitive processes with inattentive behavior in children who are term-born and very pre-term (VP) children. Parental-rated inattention in children born VP was predicted by slower PS. In addition, the inattentive behavior was significantly predicted by visuospatial WM in both VP and term-born children after controlling for the difference that can be explained by short term memory.

One explanation of the connection between PS and attention is white matter maturation. Barnea-Goraly et al. (2005) investigated changes in anisotropy and white matter thickness with age in typically developing children and adolescents. The fractional anisotropy (FA) used to estimate the connection in the brain which was obtained through diffusion tensor imaging (DTI). The study found that the developmental changes in white matter anisotropy (FA values) were significant and widespread in typically developing children and adolescents between six and nineteen years old. The study demonstrates that brain regions showing a change in white matter anisotropy are significant for attention, motor process, cognitive function, and memory functions.

The current study’s findings also revealed that PS of letter and number might be affected by central executive in first grade. This suggests that students who score high in central executive function in first grade are more likely to process information faster in fifth grade. The connection with PS can be explained through the role of the central executive. This system is responsible for directing attention, determining priorities, and making decisions (Baddeley, 2000; Baddeley & Hitch, 1974). It is through the central executive that an individual's ability is monitored and coordinated to process visual and verbal information in their respective WM systems and connect them to previous knowledge (Baddeley, 2000, 2012).

According to Otto et al. (2013), PS determines how cognitive functions are to be performed. For highly effective PS, the central executive performs functions at a relatively efficient speed. However, the efficiency at which a task is performed depends on the ability of the brain to synchronize cognitive functions.

H2: PS of number and letter in fifth grade can be predicted by attention, and visual WM, verbal WM, and central executive in fifth grade. The correlation between the dependent variables (PS of number and letter in fifth grade) and predicted variables (attention, and visual WM, verbal WM, and central executive in fifth grade) were statistically significant (Wilks' *Lambda* = .80, $Rc^2 = .19$, about $F_{(8, 278)} = 4.11$, and $p < .001$).

The *Beta* coefficients revealed that visual WM in fifth grade was identified as a negative predictor of PS of letter and number in fifth grade. These findings imply that a student in fifth grade relies more on visual WM to process information faster. However, attention was a marginal predictor of the PS of number in fifth grade. Table 6 shows that verbal WM, and the central executive were not good predictors of PS in fifth grade.

Many studies have suggested that visuospatial WM is more sensitive to age compared to verbal WM, which can be observed among both children and adults (Brown et al., 2012; Jenkins et al., 2000; Johnson, Logie, & Brockmole, 2010; Kemps & Newson, 2006; Leonards, Ibanez, & Giannakopoulos, 2002). Both adults and children display more difficulty in the spatial domain, compared to the verbal domain, while performing a task (Jenkins et al., 2000). Moreover, at the end of childhood and the adult lifespan, age influences both PS and WM functions in which change in PS leads to change in WM (Kail, 2007; Kail & Miller, 2006; Kail et al., 2013).

Kail (2007) provided a longitudinal model that tested the connection between WM, PS, and reasoning. The linked improvement in PS and WM capacity is interrelated to better inductive reasoning. The model provides a series of connections in which WM has direct effects in developmental change of inductive reasoning directly while indirectly affecting PS. Kail's model provides support to the hypotheses of the current study of the role of WM components in PS. In contrast, according to Fry and Hale (2000), improvement in PS contributes to the improvement of WM function.

De Alwis (2011) suggested that a biological effect is one of the common factors that explain the relationship between WM and PS. For example, visual WM is strongly associated with the intraparietal cortex and caudal superior frontal gyrus and particularly, strongly activated in visuospatial WM (Rottschy et al., 2012). The performance of the fractional anisotropy in the left middle frontal gyrus, as well as the left parietal and temporal lobes, bilateral parietal lobes, and bilateral temporal lobes, were significantly predicted by PS (Turken et al., 2008).

Diamond (2013) stated that in short-time tasks, PS facilitated WM processes by maintaining and processing as many items as possible. This procedure allows for extending the span measured in a WM task. More cerebral connections increase processing, which would drive span. According to Salthouse (1992), PS affects the efficiency of WM by limiting the amount of simultaneously active information.

Therefore, students struggle with higher cognitive functions such as abstraction and integration of information as a result of disintegrating the outcomes of early processing before finishing the next processing.

Interchangeably, a larger WM capacity facilitates PS at the same time, which causes faster PS. The current finding provides more evidence of the effect of WM components, particularly visual WM and the central executive in PS. However, until now, it is not clear which is the cause and which is the effect, whether it is the increased activation or the faster speed of activation (Mella, Fagot, Lecerf, & Ribaupierre, 2015).

Studies have indicated a relationship between WM, attention, and PS. However, the effect of one cognitive function on the other is not clear. Magimairaj and Montgomery (2012) and Kunimi and Kojima (2014) suggested that short-term memory and PS contributed to the difference in WM performance, but attentional control was not affected by them. WM performance was strongly predicted by short-term storage and PS.

If we look closely at the results of the current study, they reveal that WM components and attention are a significant predictor of PS of letter and number in fifth grade, but in first and fifth grades, different functions emerge as the best predictors of the PS of number and letter in fifth grade. At first grade, attention and central executive functions appeared as the best predictors of PS function in fifth grade. Verbal WM also appears as a marginal predictor of PS of only number in fifth grade. On the other hand, visual WM in fifth grade emerges as the best predictor of PS of number and letter in fifth grade, while attention becomes a less significant predictor of PS of only number in fifth grade and the central executive and verbal WM do not predict PS of number and letter any more.

These results are consistent with several studies that have implicated a shift in different roles of WM components during elementary school (Geary et al., 2004). Meyer et al. (2010) suggest that WM systems differentially contribute to students' math performance in second and third grades. They suggested that in second grade, the student's score in math reasoning performance was significantly predicted by the central executive and the phonological loop. However, in third grade the student's score in math was not correlated with the central executive or phonological loop. Alternatively, math scores in third grade were significantly predicted by the visuospatial sketchpad. More importantly, they showed the same relationship between WM and math achievement in raw scores and age-normed scores, which provides even more evidence of their findings.

The current results are also supported by Geary et al. (2004), who found that the central executive predicted counting verbally with fingers in first grade, but not in third and fifth grades. They found that only second grade compared to third and fifth grade showed correlations between verbal WM and mathematical reasoning abilities. Similar to the current findings, the contribution of verbal WM was weaker than that of the central executive.

According to Meyer et al. (2010), one explanation is that converting word problems into a numeric, symbolic format is facilitated by the combination of the central executive and phonological loop, which might be most prominent in second grade. Numerical information in third grade is more readily decipherable. Thus, the central executive and phonological loop are not necessary to convert word problems to a number and symbol to facilitate the math problem.

Although previous studies indicated the shifting role of WM components in predicting math reasoning, the current study extended this result to PS of letter and number. Meyer et al. (2010) suggested that the period between second and third grades is an important window of transformation from reliance on the central executive and verbal WM to visuospatial WM ability. The current findings extended these results by showing that PS of letter and number required greater reliance on visual WM in fifth grade.

The current findings also suggest that neurocognitive studies can explain the shifting roles of WM components. Neurocognitive studies have indicated a developmental shift in brain activation as mathematical skills improve with age. Students showed shifting from prefrontal cortex functions to those mediated by the parietal cortex (Menon, 2010). This might be applied to the current findings. The shifting role of different cognitive functions in correlation with PS might be correlated with shifting in areas of the brain. According to Rivera, Reiss, Eckert, and Menon (2005) and Ischebeck et al. (2006), and Ischebeck et al. (2007), the shifting from central executive function relies on prefrontal cortex to more specialized mechanisms in the posterior parietal cortex.

A small number of brain imaging studies investigating brain injury have emphazised the fundamental contribution of different areas of the brain in performing math efficiently including the posterior parietal cortex, more specifically a more dorsal IPS region, and a more ventral angular gyrus. Skills such as processing number, fact retrieval, and low-level computation are significantly affected by the posterior parietal cortex (Ansari, 2008; Meyer et al., 2010). However, skills like cognitive sequencing, executive control, making decisions, and attention processes while doing complex calculation are driven by the prefrontal cortex (Menon et al., 2000; Meyer et al., 2010).

According to Meyer et al. (2010), based on student ability and knowledge, a certain degree of these processes are involved. For example, since second grade students rely more on the central executive and phonological rehearsal (Geary et al., 2004; Meyer et al., 2010) the prefrontal cortex is most involved when they perform tasks. This can be applied to PS in the current study, but not for the central executive and verbal WM in first grade. On the other hand, more parietal cortex is involved with visuospatial representations during improvement of math skills in third graders. Again, this can also be applied to visual WM in predicting PS in fifth grade, but further study needs to examine brain functioning in both first and fifth graders during PS performance, as well as WM.

According to Meyer et al. (2010), shifting from the central executive process allows the prefrontal cortex of the brain to process higher cognitive functions like problem solving and reasoning instead of low levels of calculation.

H3, H4: Changes in WM components (visual WM, verbal WM, and central executive memory) and PS (letter and number) from first to fifth grades are significantly different among boys and girls.

The results indicated that the correlations of the dependent variables were sufficient to support the MANOVA. Box’s test of the equality of the variance-covariance matrices was not significant, suggesting that the matrices were equal. The multivariate effect of gender was not statistically significant. This finding implies that WM component change and PS component change from first to fifth grades did not differ between boys and girls.

Camarata and Woodcock (2006) compared girls and boys in cognitive function across the lifespan. Boys showed lower PS, which is initially small in kindergarten but increases through high school. In addition, PS tasks that required digits, letter, and rapid naming appeared to be better in females than in males, (i.e., females gave more accurate responses), but males showed faster reaction time with finger tapping (Roivainen, 2011). However, we cannot conclude that Camarata and Woodcock's (2006) finding is contrary to our finding. Basically, their study identified the gender difference between boys and girls in PS across different grade levels, while our study was interested in the difference between boys and girls in the change of PS function from first to fifth grades.

Several studies in the literature provide evidence that PS improves rapidly in childhood, starts to slow down in early adolescence, and eventually, in mid-adolescence, reaches mature levels (Fry & Hale, 2000; Kail, 2007; Miller et al., 2011). Our study meant to extend this finding and compare boys and girls in the rate of change from early to late elementary years.

Many studies have suggested gender differences in several cognitive functions such as memory, verbal fluency, spatial ability, and PS (Jansen-Osmann & Heil, 2007), but there is a lack of studies that examine gender differences in the changing rate in cognitive functions. A study of the function of the brain indicated a gender difference in the level of cognitive function, which showed better memory function and speed in women, while men showed outperformance on spatial abilities and reasoning (Aartsen et al., 2004). Other studies suggested that men are better in processing mental rotation tasks than women are (Clark et al., 2013). However, Jansen-Osmann and Heil (2007) did not find a significant difference between females and males in the speed of mental rotation that used stimuli (i.e., neither for characters, Primary Mental Ability [PMA] symbols, PMA animal drawings, nor PMA cube figures). Again, this does not assure that the rate of change in WM and PS from first to fifth grades is not different between boys and girls.

Aartsen et al. (2004) investigated gender differences in the level and change of cognitive functioning. Like the current study, they aimed to determine gender differences in the rate of change of cognitive functioning by describing variability in change in these functions among males and females over six years, at three waves of the study. Females showed a higher level of memory functioning than males did. However, both the speed of processing and non-verbal reasoning change did not differ in males and females. These findings are consistent with the current study, which shows no difference between boys and girls in the change from first grade to fifth grade in WM and PS functions. However, the main population of Aartsen et al.'s survey consisted of adults, who might be cognitively stable or even declining, compared to the current sample. Therefore, further studies of the same sample need to be done.

Examination of the hypotheses in the current study provides six major findings:

1. Attention was identified as a negative predictor of PS of letter and number in fifth grade.

2. Central executive was identified as a negative predictor of PS of letter and number in fifth grade.

3. Verbal WM in first grade was a marginal predictor of PS of number only, not letter, in fifth grade.

4. Visual WM in fifth grade was identified as a negative predictor of PS of letter and number in fifth grade.

5. Attention was a marginal predictor of the PS of number in fifth grade.

6. Changes in WM components (visual, verbal, central executive) and PS components (letter and number) from first to fifth grades did not differ between boys and girls.

Conclusions of the Study

Results from this study revealed that the correlation between attention and PS of number and letter in first grade is moderately negative, but the correlation with PS in fifth grade is weakly negative. Attention was moderately correlated with visual WM and verbal WM in both first and fifth grades. In addition, attention was moderately correlated with the central executive in first and fifth grades.

The correlation between the central executive and PS of number and letter in first grade is moderately negative, while the correlation between central executive in first grade and PS of number and letter in fifth grade is weakly negative. Also, the central executive in first grade is moderately correlated with visual WM and strongly correlated with verbal WM in first grade. The central executive in fifth grade is moderately correlated with visual WM and verbal WM in fifth grade.

The results specifically revealed that attention and central executive in first grade are the best predictors of PS of letter and number in fifth grade. This does not indicate that other mechanisms like WM and gender are not important in PS. Although the findings indicated that attention and the central executive are unique contributors to PS among elementary students, verbal WM in first grade is also identified as a marginal predictor of PS of number only, not letter, in fifth grade.

These findings suggest that PS in fifth grade can be affected by the students' attentive behavior in first grade. Paying more attention requires less time to process information. Therefore, children's inattentive behavior may slow PS during performance. Consequently, slow PS may affect the ability to maintain attention to rapidly and efficiently integrate information and smoothly accomplish tasks.

Dornbush and Pruitt (2009) and Schmidt, Benzing, and Kamer (2016) examined physical effort separately or combinedly and cognitive engagement influence on primary school children's attention. Even though

> physical exertion had no effect on children's attentional performance, cognitive engagement was the crucial factor leading to increased focused attention and enhanced processing speed. Mediational analyses showed that changes in positive affect during the interventions mediated the effect between cognitive engagement and focused attention as well as between cognitive engagement and processing speed. (Schmidt et al., 2016, p. 1)

The analysis of the current study also revealed that visual WM in fifth grade is the best predictor of PS of letter and number in fifth grade. These findings suggest that students in fifth grade rely more on visual WM to process information faster. However, attention was a marginal predictor of the PS of number in fifth grade. This does not mean that other components like WM and gender are not important in faster PS. However, the results indicated that visual WM is a unique contributor to PS in fifth-grade students.

McAuley's (2008) study supports the correlation found in the current study between WM and PS through a developmental model that demonstrates the relationship between PS, inhibition, and WM during typical development. According to McAuley, these cognitive functions are separable abilities, but interrelated. Unlike our findings, which suggested the effect of attention and WM in PS, his model suggested that PS directly influences inhibition, WM storage, and WM updating. Inhibition is partly mediated by PS which has effects on WM. His model additionally indicated that interrelationships are stable over a wide range of age, which led to the assumption that the connection among these functions started at early childhood, and development does not affect this interrelationship. However, the cognitive abilities involved in the current study matured at different rates during development.

An alternative explanation to this finding is that visuospatial WM is more sensitive to age compared to verbal WM, which can be observed among both children and adults (Brown et al., 2012; Jenkins et al., 2000; Johnson et al., 2010; Kemps & Newson, 2006; Leonards et al., 2002). When contemporaneous measures of PS, executive function, and spatial WM were used to predict visual WM, only verbal fluency was not significantly associated with visual WM, while PS had the largest correlation ($r = .53$, $p < .001$; Brown et al., 2012). In linear regression analysis, performance of visual WM was predicted by PS and the visuospatial executive. This means that PS might influence visual WM in older adults, particularly the ability to encode or the rate of rehearsal speed.

Salthouse (1996) suggested that two operations that might be affected by PS are elaborations and rehearsals during visual WM tasks. During encoding time, slower elaboration may occur, and during the delay period slower rehearsal speed may occur; thus, both might cause a weaker recall.

Results from the current study also indicated that the students show improvement in the following cognitive functions: visual WM, verbal WM, the central executive, PS of number, and PS of letter from first to fifth grades, but there is no gender difference in cognitive change between boys and girls.

This finding is consistent with Jansen-Osmann and Heil (2007), who did not find significant differences between females and males in PS during tasks of mental rotation. However, according to Aartsen et al. (2004), there are differences between males and females in the level and change of cognitive functioning over three years. Females showed higher levels of memory functioning than males did, but both PS and non-verbal reasoning changes did not differ in males and females.

Significance of the Study

The findings and discussions of the current study make a significant contribution to the field of cognitive development by clarifying how the following cognitive functions—attention, visual WM, verbal WM, the central executive, and PS of number and letter—are related to each other. These findings are significant because they provide details about how these cognitive functions change and relate to each other during the concrete operational stage of a student's life.

Basically, this stage is during elementary school, which ranges from around six to eleven years old. Around this stage students develop rational thinking. At this stage children establish logical or operational thought which only applies to physical objects. The current study investigated which cognitive functions in early elementary students in first grade, compared to late elementary students in fifth grade, are the best predictors of PS in fifth grade.

In addition, different cognitive abilities have been suggested as correlates to gender differences. However, there has been relatively little data revealing cognitive gender differences, specifically over developmental time. The current study is the first to investigate the development of PS and WM components in the concrete operational stage by comparing first to fifth grade abilities in boys and girls.

These findings are significant since they contribute to the field of school psychology regarding the development of PS and how it can be predicted by other cognitive abilities like WM components and attention in both genders of elementary students. The findings may guide the field to participate in further research, including the development of cognitive functions and how these various functions affect each other.

These findings could be used by educators to consider and include more stimuli for attention and visual WM when designing curricula according to the grade level of the students. Teachers may also benefit from the findings by designing the appropriate lesson plan that considers the cognitive functions at each grade level.

The results of this study further indicated that boys and girls did not differ in cognitive development, at least in the following functions: visual WM, verbal WM, the central executive, PS of letter, and PS of number. However, literature has indicated that there is an effect of gender on brain anatomy, chemistry and function (Aartsen et al., 2004; Cahill, 2006). Previous studies also demonstrated there is a gender affect in cognitive functions such as memory, PS, and reasoning (Aartsen et al., 2004; Camarata & Woodcock, 2006; Clark et al., 2013). The current study provides more explanation to the contradictory findings in the literature. The effect of gender difference offers a comprehensive understanding of the cognitive development which facilitates the field of psychology in particularly measurement, intervention, and diagnosis.

Limitations

Future studies will benefit from addressing some limitations of the present study. The study was limited to elementary students who are not enrolled in any special program in school. The students were taken from a previous longitudinal study by Li and Geary (2017), in which twelve elementary schools were invited to join in a longitudinal prospective study in Missouri. It only included two grade levels, first and fifth. Further studies may focus on one grade at a time and include more cognitive functions like executive function, long-term memory, and more components of PS like subject, color, and motor speed. Focusing on one grade level and the students' cognitive functioning process will benefit teachers. Most elementary school teachers here in the United States teach a specific grade level in which students are around the same age. Moreover, some states require teachers to be certified to teach a specific grade. Therefore, understanding more of the students' abilities and development in one specific grade level will help teachers build the foundation for a well-rounded education overseen by following students closely through their development.

Since the study relies on preexisting longitudinal data, only certain cognitive functions were included (visual WM, verbal WM, the central executive, PS of letter, and PS of number) that have been suggested in the literature as fundamental functions in fluid intelligence and learning. The present study examined whether PS in fifth grade can be predicted by gender, attention, visual WM, verbal WM, and the central executive in both first and fifth grades. Other studies may consider including PS in first grade and compare predictors of PS in both first and fifth grades.

Another limitation of the study is that students were qualified based on their grade levels, not their ages. Variations of the age of both first and fifth grade elementary students may have influenced their performance. Further studies may involve age as one of the variables that may predict PS.

Recommendations for Further Research

After reviewing the literature, there is clearly a gap in considering cognitive development in elementary students, particularly in PS function. Even though this study contributed to fill in the gap, it is not enough, especially in terms of how WM, attention, and PS are related to each other. Further research needs to be done using different grade levels and comparing these different cognitive functions in predicting PS.

Including other cognitive functions such as executive function, long-term memory, reasoning, and language when examining elementary students' cognitive development will contribute to attaining a comprehensive conception of how these cognitive functions relate to and affect each other. In addition, the current study included only two PS components of RAN that are recognized to be crucial for student performance in elementary school. Further study may consider involving all sub-scales of RAN when measuring PS or more cognitive functions, such as executive function and long-term memory.

The current study identified the unique contributions for visual WM, the central executive, and attention in PS based on the grade level of the students from first grade or fifth grade. This conclusion needs to be validated by more experimental study. It is unclear why certain cognitive functions are more powerful in predicting PS in first grade or fifth grade. Using experimental study may identify which types of information students quickly process and which cognitive functions they may rely on more.

Academic achievement can be involved in further studies to examine the role of cognitive function development in elementary students' performance. Current findings indicated the important role of attention, the central executive, and visual WM in PS of number and letter in fifth grade, but what about the role of these cognitive functions in certain subjects like reading, writing, math, and science? Moreover, these important functions can be used to design interventions that target academic achievement in elementary students.

Another possibility for future study is to examine the role of cognitive functions in clinical groups such as students with learning disabilities and to indicate which cognitive functions are the best predictors of these learning disabilities, compared to typically developing students. Cognitive functions such as attention, WM, and PS are fundamental skills that impact special education groups like children with learning difficulties. Cognitive functions are attractive topics in fields of psychology, not just because of their influence in those special education groups, but also because of the role they play in learning and improving those in special education to be able to function adequately in society. A better understanding of those special groups and their needs is important to creating special educational programs. For example, if these children need more exposure to visual or phonological components of WM, further studies can reveal the appropriate exposure conditions that would facilitate learning (Toffalini, Marsura, Garcia, & Cornoldi, 2018).

Neurophysiological methods constitute another research area that may significantly contribute to investigating cognitive development and the relationship between WM, attention, and PS. This method offers a more sufficient measure of PS compared to the traditional instruments that assessed individual differences in PS and control for the confusion of motor response delays. Neurophysiological methods also indicated specific brain regions involved in processing information using a variety of cognitive functions.

Most of the research has interest in WM as general function or verbal WM components, compared to studies investigating visuospatial WM and its role in cognitive functioning (Brown et al., 2012) and academic achievement. According to the current finding, further study needs to be conducted to determine the effect of visual WM on student performance.

Recommendations for Practice

Findings in this study can be used to provide several recommendations for teachers, administrators, and psychologists. PS is a fundamental skill that students need to master. Being able to process information accurately is not enough. Students should process this information as fast as they can. In many situations, they must deal with dual activities that have to be solved in a specific time. Therefore, curriculum committees and lesson plans for elementary students must target cognitive functions such as attention, visual WM, verbal WM, and central executive, which can help the students process the information quickly and effectively.

Psychologists' Assessments

1. There are some valuable implications for psychological practice, such as considering the essential contributor to these cognitive functions when evaluating these special groups.

2. When administrating achievement or cognitive tests to elementary students, psychologists should improve that assessment by applying more visual representation and an attractive attentional tool that matches the students' interests.

3. Designing an appropriate intervention that targets attention, WM, and PS. In addition, these interventions help children develop effective strategies that cope with their cognitive limitations. For example, rehearsal, grouping, and visualization may improve traditional linguistic interventions.

Curriculum Design

1. The elementary curriculum should increase the students' attention by breaking learning materials into small chunks that help them stay focused.

2. The curriculum should also avoid traditional and boring tasks by considering more creative tasks that attract students. For example, instead of rewriting words, search for words in a puzzle.

3. The curriculum in elementary school should plan to include tasks that enhance WM components. This can be done by avoiding WM overload in structured learning activities.

4. Textbooks should include rich and vivid sensory language. When introducing new concepts to elementary students, photographs and images should be attached to them.

5. Connect new passages or stories with previous readings and emphasize tasks that require students to either find the differences between characteristics in the stories or create their own.

6. Visualized reading helps students understand and remember the subject matter.

Teaching and Assessment:

1. Teachers should use multiple senses when teaching new material. Using visual or auditory cues simultaneously when processing information can enhance WM. For example, write the tasks down with different colors, read them out loud, and apply this information to physical activities.

2. Teachers should break tasks into small time intervals that will allow students to focus on tasks without feeling overwhelmed.

3. Teachers should avoid long lectures and engage the students in class discussion by regularly asking for responses to the subject being discussed.

4. Teachers may give the students both verbal and visual instructions, then ask them to repeat the instructions.

5. Encourage students to create visual images for the information that needs to be processed. For example, by picturing a math problem, a student can break the problem into small pieces, and this visualization strategy can be applied to solving the problem.

6. Different methods of assessment must be used during and after the learning process.

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APPENDIX A

TABLE OF DEFINITIONS

Variable	Conceptual	Instrument	Operational
PS ability number	The ability to quickly, accurately, and fluently complete a simple cognitive or academic task (Floyd et al., 2008)	• The Rapid Automatized Naming (RAN) task (Denckla & Rudel, 1976) • A stopwatch	• The child needs to read stimuli of five numerals (2,6,9,4,7) correctly. • The first is presented to determine if the child can read the stimuli correctly. • A 5×10 matrix of incidences of these numerals is presented to the child to name them as quickly as possible without making any mistakes. • The reaction time (RT in sec) is measured using a stopwatch.
PS ability letter	The ability to quickly, accurately, and fluently complete a simple cognitive or academic task (Floyd et al., 2008)	• The Rapid Automatized Naming (RAN) task (Denckla & Rudel, 1976) • A stopwatch	• The child needs to read stimuli of five lower- case letters (p,o,d,a,s) correctly. • The first is presented to determine if the child can read the stimuli correctly. • A 5×10 matrix of incidences of these letters is presented to the child to name them as quickly as possible without making any mistakes. • The reaction time (RT in sec) is measured using a stopwatch.
Gender	Boys and girls who are in elementary school from first to fifth grades	Boys and girls who are in elementary school from first to fifth grades	Boys and girls who are in elementary school from first to fifth grades
Attention	A cognitive process in which a person selectively concentrates on a particular aspect of information, whether subjective or objective, while ignoring other perceivable information (Anderson & John, 2004)	The Strength and Weaknesses of ADHD–Symptoms and Normal-Behavior (SWAN) (Swanson et al., 2008)	• The nine items to assess the child's close attention to detail and avoidance of careless mistakes • Teachers rate the behavior of the children in second, third, and fourth grade relative to other children of the same age. The scale is from 1 to 7, with 1 (far below) and 7 (far above).

Variable	Conceptual	Instrument	Operational
Visual WM	The study will adopt Baddeley's (2012) definition for Visuo-Spatial Sketchpad (VSS). VSS is also utilized as a navigation system in which it stores and processes material in a visual or spatial form.	Working Memory Test Battery for Children (WMTB-C) Manual (2001). The Block Recall is used to assess sequential visuospatial memory as assessed by Kyttälä & Lehto (2008).	• The Block is a board with nine blocks. • The blocks are presented to the child in random arrangement. • The blocks have numbers on one side that can only be seen from the experimenter's perspective. • The experimenter taps a block (or series of blocks), and the child's task is to duplicate the experimenter's sequence. • The child is presented a maze with more than one solution, and a picture of an identical maze with a path drawn for one solution. • The child's task is to duplicate the path in the response booklet.
Verbal WM	According to Baddeley (2012), the phonological loop is responsible for verbal WM and it has two fundamental features: the first is the phonological store, which conserves word in speech-based form for 1-2 seconds. The second is the articulatory control process which is used to rehearse and hold verbal information from the phonological store.	Working Memory Test Battery for Children (WMTB-C) Manual (2001): Recalling Span Tasks Digit Recall, Word List Recall, and Nonword List	• The four-subtest measurements: Recalling Span Tasks Digit Recall, Word List Recall, and Nonword List Recall assess the child's precise memory for phonological sounds by tasks including different content stimuli. • The child is required to recall words spoken in the same order as presented in the subtests. • In the Word List Matching task, a series of words, beginning with two words, is presented to the child. Then after presenting the same word in either the same or different order, the child identifies whether the list is in the same or different order.
Central executive	A supervisory system that flexibly controlling and regulating cognitive processes. It is also responsible for directing attention and keeping specific information in WM active and linking it with long term memory (Wongupparaj et al., 2015).	Working Memory Test Battery for Children (WMTB-C) Manual (2001): Listing Recall, Counting Recall, and Backward Digit Recall	• The measurement requires maintaining one set of information in mind, and processing another set of information at the same time. • In Listing Recall, the child has to determine whether a sentence is true or false. • Out of those series of sentences the child recalls the last word in each sentence. • In Counting Recall, the child has to count a set of 4, 5, 6, or 7 dots on a card. • The child recalls the number of counted dots at the end of a series of cards. The Backward Digit Recall is a standard backward digit span.

Variable	Instrument	Operational
Change in PS ability number	• The Rapid Automatized Naming (RAN) task (Denckla & Rudel, 1976) • A stopwatch	The change in PS ability numbers from first grade to fifth grade was calculated by subtracting fifth grade from first grade. A negative score indicates growth in students' performance.
Change in PS ability letter	• The Rapid Automatized Naming (RAN) task (Denckla & Rudel, 1976) • A stopwatch	The change in PS ability letter from first grade to fifth grade was calculated by subtracting fifth grade from first grade. A negative score indicates growth in students' performance.
Change in Visual WM	Working Memory Test Battery for Children (WMTB-C) Manual (2001). The Block Recall is used to assess sequential visuospatial memory as assessed by Kyttälä & Lehto (2008)	The change in visual WM from first grade to fifth grade was calculated by subtracting fifth grade from first grade. A negative score indicates growth in students' performance.
Change in Verbal WM	Working Memory Test Battery for Children (WMTB-C) Manual (2001): Recalling Span Tasks Digit Recall, Word List Recall, and Nonword List	The change in verbal WM from first grade to fifth grade was calculated by subtracting fifth grade from first grade. A negative score indicates growth in students' performance.
Change in Central executive	Memory Test Battery for Children (WMTB-C) Manual (2001): Listing Recall, Counting Recall, and Backward Digit Recall	The change in Central executive from first grade to fifth grade was calculated by subtracting fifth grade from first grade. A negative score indicates growth in students' performance.

APPENDIX B

Andrews University
Office of Research & Creative Scholarship

March 04, 2019

Monih Alshehri
Tel. 570-991-2191
Email: monih@andrews.edu

RE: APPLICATION FOR APPROVAL OF RESEARCH INVOLVING HUMAN SUBJECTS
IRB Protocol #:18-016 **Application Type:** Original **Dept.:** Graduate Psychology & Counseling
Review Category: Exempt **Action Taken**: Approved **Advisor:** Nadia Nosworthy
Title: Can working memory, attention, and gender predict processing speed in elementary students.

Your IRB **modification** application for approval of research involving human subjects entitled: "*Can working memory, attention, and gender predict processing speed in elementary students"* IRB protocol # 18-016 has been evaluated and determined Exempt from IRB review under regulation CFR 46.101 (b) (2). You may now proceed with your research.

Please note that any future changes (see IRB Handbook pages 12) made to the study design and/or informed consent form require prior approval from the IRB before such changes can be implemented. Incase you need to make changes please use the attached report form.

While there appears to be no more than minimum risks with your study, should an incidence occur that results in a research-related adverse reaction and/or physical injury, (see IRB Handbook pages 18-19 this must be reported immediately in writing to the IRB. Any research-related physical injury must also be reported immediately to the University Physician, Dr. Katherine, by calling (269) 473-2222.

We ask that you reference the protocol number in any future correspondence regarding this study for easy retrieval of information.

Best wishes in your research.

Sincerely,

Mordekai Ongo
Research Integrity and Compliance Officer

Institutional Review Board – 8488 E Campus Circle Dr Room 234 - Berrien Springs, MI 49104-0355
Tel: (269) 471-6361 E-mail: irb@andrews.edu

VITA

Monih Alshehri

Educational Background

2019 Ph.D., Educational Psychology
Andrews University, Berrien Springs, Michigan

2008 Master of Social Science in Counseling Psychology
Al-Imam Muhammad Ibn Saud Islamic University, Riyadh, Saudi Arabia

2004 Bachelor of Science of Psychology
King Saud University, Riyadh, Saudi Arabia

2000 High School Alabna, Riyadh

Professional Experience

2008 Teaching Assistant, Psychology department
Al-Imam Muhammad Ibn Saud Islamic University Riyadh, Saudi Arabia

2009 Counselor, Al-Imam Muhammad Ibn Saud Islamic University

2009 Lecturer, Al-Imam Muhammad Ibn Saud Islamic University

2005 Clinical Psychologist Trainee, Security Forces Hospital Program Riyadh, Saudi Arabia

Conferences Attended

2019 First annual GPC Research Symposium, Andrews University, Michigan

2019 31st APS Annual Convention, Washington D.C

2016 Midwestern Psychological Association Annual Meeting, Chicago

2009 Psychology Departments in Institutions of Higher Education Al-Imam Muhammad Ibn Saud Islamic University, Riyadh, Saudi Arabia

2006 Early Childhood Characteristics and Need in Kingdom of Saudi Arabia
Ministry of Education, Riyadh, Saudi Arabia

2005 Physical, Psychological and Social Challenges in Renal Failure Patients
Security Forces Hospital, Riyadh, Saudi Arabia

Training Attended

2010 Quality Program Evaluation and Self-study
Batterjee Medical College, Jeddah, Saudi Arabia

2009 Quality Self-study
Al-Imam Muhammad Ibn Saud Islamic University, Riyadh, Saudi Arabia
(Commission for Academic Accreditation and Assessment).

2009 Quality Specification and Program Curriculum
Al-Imam Muhammad Ibn Saud Islamic University, Riyadh, Saudi Arabia

2009 Research Techniques and Skills in Electronic Sources
Prince Nayef Institute for Research and Advisory Services, Riyadh, Saudi Arabia

2008 Teaching Methods in an Education-oriented Knowledge-based Economy
Prince Nayef Institute For Research and Advisory Services, Riyadh, Saudi Arabia