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The Role and Implications of Executive Functions on Learning and Performing Math in High School Algebra I Students

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THE ROLE AND IMPLICATIONS OF EXECUTIVE FUNCTIONS ON LEARNING AND PERFORMING MATH IN HIGH SCHOOL ALGEBRA I STUDENTS

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Committee Members' Signatures:

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Abstract

Current research is largely lacking in the areas of math, math learning deficits, and math-specific interventions. Even less available is research and interventions specific to high school learners. Some research addresses these areas with a specific focus on executive functions and how they may relate to student learning and performance. The present study sought to determine the relationship between three specific executive functions, Shift, Inhibit, and Working Memory, on learning and performance in math. Other executive functions, as measured by BRIEF rating scales and including Planning and Organization, Initiate, and Monitor, were also reviewed. Results of the present study found no relationship between Shift and Inhibit with learning and performance measures (e.g., homework completion, test/quiz grades) and a relationship between Working Memory and learning and performance measures (i.e., homework completion). A relationship was also found between Initiation, Planning and Organization, and Working Memory as having a relationship with student learning and performance. Based on these findings, future studies should look specifically at what learning behaviors and skills students demonstrate that lead to adequate math performance and how these skills relate to executive functions. Essentially, starting with relating basic math behaviors and skills (e.g., math fluency or algebra skills) to academic performance (e.g., test grades, homework completion, standardized test results) in math and then relating these results to measurable executive functions, which may be an indicator of how one learns math. This information would help demonstrate how actual skills translate to student performance and achievement and could then be related to the learning of math in a classroom, which tends to tax executive skills. This information would be helpful to support student

learning and allow for the development of appropriate and effective interventions that meet the needs of students struggling to keep up with grade level academic materials.

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Chapter 1: Introduction

Underachievement in learning and performing math has a significant impact on an individual's performance in school as well as on his or her ability to employ numeracy skills in functional situations throughout adulthood (Cragg & Gilmore, 2014). A growing body of research is uncovering the many factors that impact a learner's ability to achieve and perform math successfully and efficiently (Agostino, Johnson, & Pascuale-Leone, 2010; Berninger & Richards, 2002; Feifer & De Fina, 2005; McCloskey, Perkins, & Van Divner, 2009). Much of the current research discusses the role and impact of executive functions on learning math (Frank & Brown, 1992; Kotsopoulos & Lee, 2012; McCloskey et al., 2009; Toll, Van der Ven, Kroesbergen, & Van Luit, 2010). However, research is still limited on exactly how executive function deficits impact learners, and therefore, targeted interventions are also limited. Further limited is research surrounding adolescent learners. The current study intends to look at the educational relationship of executive functions on learning and performing in math on high-school learners.

Statement of the Problem

Underachievement in math is a significant problem for school-aged learners today and follows them into adulthood (Carlin, 2013; Cragg & Gilmore, 2014; Swanson & Jerman, 2006. Furthermore, math learning disabilities occur in approximately 6% of students, just as often as reading disabilities, yet they are far less understood and researched, thus making them an important topic of conversation for educators throughout the country (Swanson & Jerman, 2006). Math learning disabilities, often referred to as *dyscalculia* (i.e., lack of numerical cognition/number sense), can manifest in children throughout their primary- and secondary-school years, or they may become prevalent later on as academic demands increase (Carlin, 2013). Children today are faced with learning a number of new skills and concepts very rapidly in the traditional public school setting. Many factors play a role in a child's ability to learn; one of the more important factors, in addition to cognitive abilities, is their executive functions. Essentially, abilities in planning, updating, sequencing, retrieving, pacing, focusing, monitoring, correcting, shifting, and inhibiting/disinhibiting together impact how well a child learns and subsequently demonstrates that learning (McCloskey et al., 2009). The various skills necessary for learning math can be grouped in two domains: math calculation or math reasoning (Proctor, Floyd, & Shaver, 2005). Essentially, math calculation encompasses applying math operations to solve problems while math reasoning encompasses numerical relationships, quantitative concepts, and problem solving through applying math knowledge (Proctor et al., 2005). Application of these skills is determined by the efficiency of a child's executive functioning (Proctor et al., 2005). For children who present with executive functioning deficits, learning can be challenging.

The three executive functions implicated in learning and performing math concepts are working memory (sometimes referred to as updating), shifting, and inhibition (Deseote & Weerdt, 2013; Peng, Congying, Beilei, & Sha, 2012; Toll et al., 2010). These executive functions play a role in the optimal and successful execution of the previously mentioned cognitive factors associated with one's ability to learn math. Specifically, an understanding of numerical magnitude is required for many math concepts, such as accurate placement and connecting number symbols with their quantities (Kolkman, Hoijtink, Kroesbergen, & Leseman, 2013). Proper development of numerical magnitude calls upon updating, which is responsible for monitoring, coding, and revising stored information (Kolkman et al., 2013). When solving problems and computing calculations, the brain must employ goal setting, coordination of multiple math operations, sequencing and monitoring of steps, and cuing working memory—this process is where shifting attention between rules/strategies and inhibition of irrelevant cues must be activated (Berninger & Richards, 2002; Kolkman et al., 2013).

Further research implicates the role of executive functions in the manifestation of math disabilities. Without proper development and efficacy of shifting, updating, and inhibition, a child is limited in his or her problem-solving abilities (Kotsopoulos & Lee, 2012). Errors in updating cause a child's difficulty with recognizing or recalling somewhat familiar math concepts within a presented math problem—the child may recognize the concepts but be unable to execute the necessary skills to complete the steps (Kotsopoulos & Lee, 2012). This executive function may be the most relevant for learning math as it is responsible for storing and manipulating new information and concepts in isolation or with previously learned concepts (Van der Ven, Kroesbergen, Boom, & Leseman, 2012). Updating is also closely related to working memory, and some studies even consider them to be the same functions (Lee, Fong Ng, Bull, Lee Pe, & Ho Moon Ho, 2011); throughout the following review, the term *working memory* will be used to discuss this function. Without this ability, a child will have difficulty keeping pace with the instruction in a general education setting. Errors in inhibition cause difficulty with following steps to calculate or solve math problems (Kotsopoulos & Lee, 2012). Children may employ incorrect steps, leave steps out, misread operation signs, or misplace number values if their inhibition abilities are faulty (McCloskey et al., 2009).

Finally, errors in shifting cause difficulty with solving word problems and checking one's work, thus in turn leading to a faulty understanding of the concept(s) (Kotsopoulos & Lee, 2012). Some research suggests that inhibition and shifting may be indistinguishable executive functions regarding math learning, as their impact on performance is shown to be similar (Van der Ven et al., 2012). Self-monitoring is also a key executive function that if not working or cued properly, will cause children difficulty when solving more complex, multistep problems that require them to apply previously learned strategies (Agostino, Johnson, & Pascuale-Leone, 2010).

Learning math is a complex task that with a solid foundation from an early age can be easily built upon over time. Further fostering of successful math learning and subsequent academic performance of math depend on optimally developed executive functions, specifically working memory, shifting, and inhibition (Agostino et al., 2010; Assel, Landry, Swank, Smith, & Steelman, 2003; Kotsopoulos & Lee, 2012). Proper development and execution of these functions enhance students' learning and their ability to demonstrate their learning when necessary. Without proper development and use of executive functions, children will have great difficulty in learning new concepts and demonstrating their learning of math. Such skills as problem solving, calculating, understanding numerical magnitude, sequencing of steps, and recalling facts and procedures are all implicated. Further research is necessary and expected to continue building educators' understanding of the manifestation and impact of math deficits, as well as of executive function weaknesses, while building interventions to benefit struggling learners.

Purpose of the Study

The purpose of the current study is to determine the relationship between executive-function deficits, specifically inhibition, shifting, and working memory, as implicated by the research, on adolescent learners in high school math classes. This research intends to further support the current body of research on executive functions and learning, particularly in math, where research is lacking, to help determine areas for targeted interventions in the future.

Chapter 2: Literature Review

Executive Functions

Executive functions are a major factor in everyday performance across all tasks, including learning and performing in academics. Executive functions are essentially the overarching neurocognitive processes that control, direct, or coordinate other mental processes, such as perception, emotion, and behavior (Lee et al., 2011; McCloskey & Perkins, 2013). Most researchers agree that executive functions continue to develop throughout the lifespan (Berninger & Richards, 2002; Feifer & De Fina, 2005; McCloskey & Perkins, 2013). However, some debate exists regarding how to categorize and study executive functions because of researchers' budding understanding of this concept.

McCloskey et al. (2009) and McCloskey and Perkins (2013) outlined many of these theories and attempted to organize and define executive functions as a neuropsychological construct that is inherently multidimensional. Executive functions, according to these authors, typically include four arenas of involvement: intrapersonal, interpersonal, environment, and symbol system use. Essentially, an individuals' behaviors can vary based on their self-regulatory needs in a given situation. So, for intrapersonal, an individual is responding to his or her own internal state; for interpersonal, the individual is responding in relation to others; for environment, the individual is responding in relation to environmental factors; and, finally, for symbol system use, the individual is responding in relation to cultural or systematic factors. These authors also outlined six interconnected concepts to conceptualize and understand executive functions for the purposes of efficient and accurate assessment:

1. Executive functions are multiple in nature; they do not represent a single, unitary trait;

2. Executive functions are directive in nature, that is, they are mental constructs that are responsible for cueing and directing the use of other mental constructs;

3. Executive functions cue and direct mental functioning differentially within four broad construct domains: perception, emotion, cognition, and action;

4. Executive functions use can vary greatly across four arenas of involvement: intrapersonal, interpersonal, environment, and symbol system use;

5. Executive functions begin development very early in childhood and continue to develop at least into the third decade of life and most likely throughout the life span; and

6. The use of executive functions is reflected in the activation of neural networks within various areas of the frontal lobes. (pp. 8-9)

Executive functions are responsible for how well an individual can learn and perform in all tasks of everyday functioning, not just academics. Executive functions, for example, are responsible for filtering relevant from nonrelevant information in the environment, planning a problem-solving approach, organizing information for solving problems or completing tasks, storing previously learned information, embedding new information with previously learned information, and judging social situations and perception (McCloskey et al., 2009; McCloskey & Perkins, 2013).

One should note here that some of the literature refers to the executive functions working memory and updating as being the same cognitive process, particularly in regard to the impact on learning and performing in math (Lee et al., 2011). On a functional level, the two concepts seem to be essentially the same mental process. By definition, updating is revising information in working/active memory with newer, relevant information, as well as maintaining information to be readily accessible (Lee et al., 2011; Mabbott & Bisanz, 2008; McCloskey & Perkins, 2013). For the purposes of this paper, working memory will be the term used to describe this function.

Brain Structures and Systems

Before discussing executive functions and their implications for learning math, one must understand the structural components and networks that comprise and support their utility. Generally speaking, researchers and educators refer to the frontal lobe as the most important structure in supporting executive functions; however, much of the research evidences the role of a broader network of anterior and posterior brain structures (Bettcher et al., 2016; Takeuchi et al., 2013). A study by Bettcher et al. (2016) found that a significant amount of prefrontal grey matter associated with neurocognitive measures of shifting, inhibition, and working memory did not independently predict executive functioning. The corpus callosum and cingulum were also implicated in the executive function responses measured in this study, indicating that executive functions should not be viewed in isolation and that more distributed grey and white matter affect executive function performance. This information is important because it highlights the need for understanding other brain functions as implicated in optimal executive functioning (Bettcher et al., 2016).

Takeuchi et al. (2013) suggested that other regions of the brain in addition to the orbitofrontal cortex are implicated in executive functions. This study used brain-imaging technology and personal questionnaires to measure associations between brain structures and executive functioning patterns. This study suggests that because the orbitofrontal cortex is connected to various regions of the brain, those other regions are necessary for optimal executive function performance. Executive functions require various inputs, such as sensory information from the temporal or gustatory cortices, affective data from the amygdala, and drive from the hypothalamus, to determine the appropriate output. Though this input and the functions of these brain structures are not executive in any way, these systems help to organize the input to allow the executive system to determine effective and appropriate output. Essentially, the central executive must rely on optimally functioning brain structures for accurate input to determine the optimal output. This information brings to light the importance of recognizing these other structures and their functions when studying how learners are supported in their learning (Carlson, Faja, & Beck, 2016). When considering education and learning of any task, one must recognize and understand many brain systems and functions (Carlson, Faja, & Beck, 2016). Without the optimal functioning of multiple systems together, the executive functions and output will not be optimal. Executive functions involve a network of brain regions because of the required input needed to produce appropriate and optimal output.

Brain Structures and Math

The prefrontal cortex is generally responsible for executive functions: The specific neuroanatomical components necessary for their processes are housed within this brain region (Feifer & De Fina, 2005). The prefrontal cortex is composed of three distinct areas: the dorsolateral circuit (responsible for organizing behavioral responses to a problem solving task), the orbitofrontal cortex (responsible for mediating socially appropriate behaviors/responses), and the anterior cingulate cortex (responsible for attention to task; Feifer & De Fina, 2005). However, as noted earlier regarding executive functions, these systems are part of a broader network of systems to enhance the overall functioning and output (Bettcher et al., 2016; Carlson et al., 2016; Takeuchi et al., 2013).

Studies using fMRI technology have revealed many of the components of the brain and how they work together and/or independently in performing various math processes (see Table 1; Berninger & Richards, 2002). Studies have identified different areas of the brain that are activated and may be implicated while the individual is performing math calculations or other math-related tasks (Price, Mazzocco, & Ansari, 2013; Swanson & Jerman, 2006). When one learns math, specifically identified areas are responsible for memory and retrieval, procedural problem solving and numerical magnitude, and procedural calculation. When one engages in tasks relying on memory and retrieval, attention (directing and sustaining, gating relevant from non-relevant stimuli), and recognizing similarities in context, the left inferior parietal lobe (LIP), anterior cingulate cortex, left basal ganglia, and thalamus are implicated (Blumenfeld, 2010; Carlin, 2013; Price et al., 2013; Swanson & Jerman, 2006). When one engages in tasks relying on procedural problem solving and/or numerical magnitude, the right intraparietal sulcus is implicated (Carlin, 2013; Price et al., 2013; Swanson & Jerman, 2006). Finally, when one engages in tasks relying on procedural calculations, visual-spatial working memory, and spatial orientation, the left intraparietal sulcus, superior parietal lobe, bilateral insula, and bilateral frontal gyri are implicated (Price et al., 2013;

Swanson & Jerman, 2006). Berninger and Richards (2002) outlined a specific map for construction of a math/computing brain based on what they conceptualized as arousal units (of the reticular activating system and its connecting pathways): quantitative knowledge, arithmetic, visual-spatial, visual notation, geometrical, grapho-motor, and math lexicon and their coordinating brain structures, such as the right parietal lobe, Broca's area, left premotor area, occipital to temporal pathways, bilateral occipital cortex, left hippocampus, right cerebellum, and limbic structures. The prefrontal cortex is highly implicated in math calculation owing to the involvement of executive functions, especially for retrieval of math facts and sequential problem solving (Hale & Fiorello, 2004). Responses and brain functioning are optimal when all of these systems work together to sort and process input to determine the correct output.

Table 1

Brain Functions and Processes

Quantitative Knowledge: Number concepts/quantity; counting/1:1 correspondence; number line/analog understanding of numbers; place value; part-to whole relationships	Right superior parietal lobe; inferior paritetal cortex bilaterally; right superior temporal gyrus; middle temporal bilateral gyrus; left frontal parietal network; occipital cortex bilaterally; supplementary motor area; left precentral gyrus; Broca's area; left premotor; left prefrontal cortex
Arithmetic: Math facts; addition; subtraction; multiplication	Lenticular nucleus; left language and subcortical areas; left inferior frontal and parietal areas; right orbital frontal; right insula; left frontal parietal network; left premotor; inferior parietal gyri bilaterally; left fusiform and lingual gyri; right cuneus; supplementary motor area
Visual Notation System/Symbolic Representation: Representing numbers in numerals; *what* and *where* pathways for spatial relationships and linear arrays	Right fusiform gyrus; bilateral occipital-temporal areas; left fusiform and precentral gyri; right precentral and inferior parietal regions; occipital to temporal cortex, occipital to parietal cortex
Executive System/Functions	Prefrontal cortex; orbital frontal cortex
Memory and Storage: phonological short term storage (loop)	Prefrontal association areas; temporal cortex; left hippocampus; left inferior parietal cortex; left submarginal gyrus; Broca's area; right cerebellum
Attention	Reticular activating system and striatum; frontal cortex; anterior cingulate; orbital frontal cortex

Note: Adapted from Berninger & Richards, 2002

Executive Functions and Learning

Executive functions have been studied in conjunction with learning and learning difficulties in math to help determine the cause of the difficulties and to determine the best interventions. As discussed earlier, executive functions represent many cognitive processes that control higher level processes, such as judgement, planning, sequencing, coordinating, inhibition, shifting, updating, organizing, and monitoring. (Feifer & De Fina, 2005; McCloskey et al., 2009; Swanson & Jerman, 2006).

The impact of executive dysfunctions on math learning disabilities has helped researchers to understand some of the causes of learning difficulties and to determine interventions. Some studies show that working memory is the strongest predictor of learning and performance in math (Desoete & Weerdt, 2013; Toll et al., 2011). The role of working memory is significant, as it can function independently or as part of a more complex brain system, such as a visual system, an auditory system, or a motor system. Working memory tends to rely on other neurological systems in order to function properly, such as those that are referred to as the phonological loop (phonological/auditory storage and retrieval), the visual-spatial sketchpad, and the central executive (attentional control), and on several executive functions, including inhibition, updating, and switching (Baddeley, 1992; Peng et al., 2012). Research has shown that children with math difficulties also have deficits with storage and inhibition, with inhibition potentially causing the deficits with the function of storage (Peng et al., 2012).

Further, studies that look at children with specific disorders, such as Turner syndrome or fragile X syndrome, have been helpful in isolating specific executive functions implicated in learning and learning disorders. Students with Turner syndrome have shown difficulty with math performance over and above children without learning disabilities or other disorders (Mazzocco, 2001). The characteristics of Turner syndrome, such as attentional issues, visual-perceptual and visual-motor impairments, and working memory deficits, contribute to the difficulties that these learners demonstrate when performing academically (Mazzocco, 2001).

Desoete and Weerdt (2013) looked at executive functioning, described as the general control mechanisms that coordinate, regulate, and control behaviors and responses and are localized in the central executive control system of working memory. These authors measured working memory, inhibition, and naming speed in 22 children between the ages of 8 and 12 years who had math disabilities. They also looked at 17 children with reading disorders and 45 children without any identified learning disabilities. They found that the central executive measure of working memory was the most significant predictor of performance on such tasks as naming speed, recall of word or digit lists (forward and backward), and spatial span. A study by Toll et al. (2010) used a longitudinal design to study whether shifting, inhibition, and working memory (three specific executive functions) could be used to identify students with later identified math learning disabilities. The study included 227 children between the ages of 5.9 and 7.7 years from 10 different schools. Various math and executive function tests were used to measure the students' skills and abilities over the course of the study (over first and second grade). Overall, working memory was shown to be the strongest predictor for students with learning disabilities. These studies demonstrate that executive function deficits impact a child's ability to learn and perform, particularly on math or math-related concepts, in school.

Executive Functions and Math

Executive functions are very important in math, as they allow learners to develop an understanding of multiple quantitative dimensions and problem solve with these dimensions simultaneously (Berninger & Richards, 2002). Executive functions are also responsible for creating goals and a plan for executing those goals, monitoring on-task performance, and controlling working memory, all very relevant functions for learning and appropriately performing and learning math (Kolkman et al., 2013; Kotsopoulos & Lee, 2012; Latzman, Elkovitch, Young, &Clark, 2010; Lee et al., 2011; Van der Ven et al., 2012). When considering math specifically, the previous research has consistently highlighted working memory, inhibition, and shifting as the three most prominent functions for adequate learning and performance (Kolkman et al., 2013; Kotsopoulos & Lee, 2012; Latzman et al, 2010.; Lee et al., 2011; Van der Ven et al., 2012).

Working memory has been shown relevant in proficient learning and performance of algebraic equations and problems, word problems, and basic arithmetic computations (Lee et al., 2011). A study by Lee et al. (2011) looked at the relationships between updating (working memory), number patterns, and computational fluency and their relationships with algebraic proficiency. The study found a direct relationship between number patterns and computational proficiency with algebra, while updating was related to number patterns and computational proficiency. Essentially, indicating that updating has an indirect impact on algebra through pattern recognition, the same way that the concept of working memory does. This study supports that updating and working memory are essentially the same executive function construct.

Math and the Brain

When considering the necessary brain functions for learning and performing in math, one finds that phonological storage plays a significant role in these tasks, as it is responsible for basic counting and very simple arithmetic (Peng et al., 2012).

Phonological storage relies on a function referred to as the phonological loop within working memory, which briefly stores verbal information using a rehearsal strategy (Baddeley, 1992). In addition, executive functions work closely with the phonological loop during learning and performance of math tasks involving dual-task performance, mental math procedures, and problem solving, as these tasks require inhibition and updating (Peng et al., 2012). Phonological storage via the phonological loop is important in supporting these higher level math skills (Baddeley, 1992; Peng et al., 2012).

From a neurological perspective, most brains are equipped with the necessary wiring to think in numerical or mathematical concepts. Piaget is well known for his theory of cognitive development, and much of his theory drives teachers, particularly preschool and early-elementary school teachers, in helping children to develop and learn today. The four stages outlined by Piaget, specifically the concrete operational stage, help educators to understand how children understand, learn, and perform in math (Hale & Fiorello, 2004). Children are first introduced to math concepts by concrete means, such as through tangible objects (e.g., number lines, counting blocks), but later these concepts are expected to become internalized and become semi-abstract through the introduction of symbols.

Learning and Math

An historical body of research supports the existence of number sense in infancy (Sousa, 2008). Babies are born with the ability to count and to recognize symbols as representing numeric quantities (Sousa, 2008). A classic experiment conducted by Starkey and Cooper (1980) demonstrated that babies could discriminate between groupings of two and three items by measuring how long they fixated on presented slides.

Geary (2011) discussed four different types of innate numeric abilities with which human brains are equipped to learn math: subitizing, which is the ability to determine the quantity of a small set of items without actually counting; ordinality, which is a basic understanding and visual recognition of more than and less than; counting, as in a preverbal counting system; and, finally, arithmetic, which is a basic understanding of combining and decreasing quantities of sets. Secondary to these innate abilities is the ability of the brain to develop and understand number counting using words/symbols, arithmetic computations through memorization of mathematical facts and procedures, and solving word problems through mathematical procedures (Geary, 2011). Once babies/toddlers move past just hearing numbers or rote counting, they begin to associate number representations for objects as caregivers demonstrate one-to-one correspondence (Berninger & Richards, 2002). As babies grow into children and enter school for formalized learning of math, the learning process becomes much more complex and potentially muddled for some learners. Many other factors, including emotional factors, instructional match (teacher and content), prior exposure of concepts, and brain functioning, specifically executive functions and memory, contribute to how a child learns and performs in math (Assel et al., 2003; Koziol & Budding, 2008; Proctor et al., 2005).

Early on, children are not expected to automatically understand calculations and arithmetic procedures for reasoning; however, early signs exist of numeracy and understanding basic mathematical concepts, such as less and more (Carlin, 2013). Since many math concepts rely on some sense of numeracy, recognizing delays in these early skills and immediately intervening is key, as such delays could further impair math learning if left untreated (Carlin, 2013). When children are first learning math, they are taught through concrete, tangible methods that include manipulatives, pictures, number lines, and other visual cues (Price et al., 2013). As children get older, these methods are typically faded; the children are expected to develop arithmetic fluency and maintain and apply such concepts, potentially through the frontostriatal system, where higher order processing becomes more automatic and can be considered more stimulus based (Koziol & Budding, 2008; Price et al., 2013).

Many studies discuss the cognitive predictors of achievement in math over time. Human brains are largely understood to grow and develop rapidly over the first 5 years of life, with continued growth and development through the lifespan as humans experience new tasks and challenges. A look at academic learning, and math in particular, reveals that several aspects of cognition are more closely related to achievement than others. As discussed earlier, numeracy is a major developmental factor that can predict how well a person will achieve in math over time (Kroesbergen, Van Luit, & Aunio, 2012).

Research also demonstrates the importance of well-developed working memory in learning and performing math, as the general expectation is to hold information in memory, retrieve information about procedures and calculations, and perform a function with that information to produce a correct answer (McCloskey & Perkins, 2013; Peng et al., 2012; Toll et al., 2010; Van der Ven et al., 2012). Often, educators can look at the types of errors a child is making to determine where the potential deficit lies within his or her cognitive functioning; for example, when a child makes a math fact error, a teacher might determine that he or she is not able to automatically retrieve that fact from memory if it is something he or she previously learned (Hale & Fiorello, 2004).

Learning in general encompasses many different aspects of cognition, from attention to memory and executive functioning to intelligence, as well as social and emotional factors. Understanding how the brain is equipped to learn and how deficits can impact learning can help educators to predict how well a child will perform on a given task, as well as how to best intervene when a child shows signs of difficulty or when testing predicts that he or she will have difficulty. However, with the rise in the recognition of how children learn and of how differently many of them learn from one another, more research is necessary to understand the overall manifestation and cause of learning difficulties to best intervene. The research available on reading learning disabilities is abundant, while the research on math is still emerging.

Executive Functions, Learning, and Math

As discussed earlier, much of the research centers around working memory, inhibition, and shifting as the main executive functions implicated in learning and performing math. These executive functions play a role in the optimal and successful execution of the cognitive functions necessary for adequate math learning and performance. Numerical magnitude is required for many math concepts, such as accurate placement and connecting number symbols with their quantities (Kolkman et al., 2013). Proper development of numerical magnitude requires an adequate working memory capacity to effectively monitor, code, and revise stored information (Kolkman et al., 2013). When solving problems and computing calculations, the brain also employs the goal setting capacity to coordinate multiple math operations, sequence and monitor steps, and cue working memory. At this point, shifting is required to shift attention between rules/strategies and inhibit the interference of irrelevant cues (Berninger & Richards, 2002; Kolkman et al., 2013).

Without proper development and efficacy of shifting, working memory, and inhibition, success of a learner is limited, thus limiting his or her problem solving abilities (Kotsopoulos & Lee, 2012). Errors in working memory cause a child difficulty with recognizing or recalling somewhat familiar math concepts within a presented math problem; the child may recognize the concepts but will be unable to execute the necessary skills to complete the steps, thus causing poor computational skills (Kotsopoulos & Lee, 2012; Lee et al., 2011). Poor working memory capacity is also linked to difficulties in recognizing general rules about patterns, thereby impacting algebraic reasoning skills (Lee et al., 2011). Working memory is responsible for storing and manipulating new information and concepts in isolation or with previously learned concepts (Van der Ven et al., 2012). Without this ability, the child will have difficulty keeping pace with the instruction in a general education setting. Errors in inhibition cause difficulty with following steps to calculate or solve math problems (Kotsopoulos & Lee, 2012). Children may employ incorrect steps, leave steps out, misread operation signs, or misplace number values if their inhibition abilities are faulty (McCloskey et al., 2009).

Inhibition and updating have been shown to be closely related in impacting a learner's ability to perform math tasks; inhibition is necessary for properly mapping cues from the presented math problem, despite the wording of the text (Lee et al., 2011). Finally, errors in shifting cause difficulty with solving word problems and checking one's work, thus leading to a faulty understanding of concepts (Kotsopoulos & Lee, 2012).

Some research suggests that inhibition and shifting may be indistinguishable executive functions regarding math learning as their impact on performance has been shown to be similar (Van der Ven et al., 2012). Self-monitoring is also a key executive function that if not working or cued properly will create difficulty for children solving more complex, multistep problems that require them to apply previously learned strategies (Agostino et al., 2010).

Generally, math demands problem solving skills, which require a well-developed working memory capacity (Berninger & Richards, 2002). A study specifically looking at preschoolers determined that working memory had the most significant impact on a child's math skills over other factors, such as age, vocabulary development, inhibition (an executive function), and social understanding (Miller, Muller, Giesbrecht, Carpendale, & Kerns, 2013). Conflicting studies demonstrate inhibition as a strong predictor of math achievement. Fortunately, many visual cues are available to learners to alleviate some of the working memory load, such as number lines, paper and pencil to work out the computations, and/or calculators. However, the learner still needs to be able to determine which functions to implement and how to implement them accurately using a higher level of cognition.

A study by Latzman et al. (2010) investigated which executive functions most strongly predicted performance in different academic areas. They specifically looked at monitoring, conceptual flexibility, and inhibition. Inhibition was found to be most predictive of student performance in math and science. These authors proposed that studying the relationships of executive functions to academic achievement of typically developing students is a necessary first step in understanding the role executive function deficits play in educational attainment, especially for those with learning disabilities or other cognitive deficiencies. The further study of executive functions and their impact on academic achievement appears to be paramount in the development of effective and efficient interventions. Latzman et al, looked at 174 male adolescents with average IQs to measure and correlate their executive functioning using the Delis-Kaplan Executive Functions System (D-KEFS) and their basic academic skills using the Iowa Tests of Basic Skills and Iowa Tests of Educational Development (ITBS/ITED). This study looked specifically at Conceptual Flexibility, Monitoring, and Inhibition along with Reading, Math, and Science. For the interests of the current study, only findings related to math are discussed. Inhibition was found to have a significant main effect for math.

Measuring Executive Functions

The many theories and definitions of executive functions found throughout the literature vastly differ. Some theories break down executive functions into many individual functions or conceptualize them as a multidimensional concept, such as outlined by McCloskey and Perkins (2013), while others seem to group various behaviors under a smaller number of executive function “umbrellas.” As a result, various instruments, such as the Delis-Kaplan Executive Function System—D-KEFS or NEPSY-II (direct), rating scales (indirect), and observational methods (structured and unstructured), are available for measuring executive functions.

One of the more common direct measures includes rating scales/checklists, such as the Behavior Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000). The BRIEF was used for the current study to measure executive function data. In developing this scale, both clinical and normative data sets were used to determine reliability and validity of the BRIEF. Parent and Teacher Forms demonstrated high internal consistency (measured by Chronbach's alpha), ranging from .80 to .98. Ratings between teacher and parent on the same child were lower, with a correlation range of .30 to.50; however, ratings between teachers or two parents on the same child were generally higher. These differences were accounted for by the degree of difference between the home and school setting, as well as the home and school demands. Test-retest reliability correlations ranged from .72 to .92 across scales for parent and teacher scales; just teacher scales correlations ranged from .83 to .92, indicating teachers' ratings were more consistent across administrations. The BRIEF was designed to have strong content validity through agreement among 12 pediatric neuropsychologists and the authors as to the fit of each item within each particular scale. Inter-rater reliability was measured for each individual item on the BRIEF; items ranged from .41 to .87. Construct validity was measured by correlating BRIEF scores to convergent and divergent scales.

The BRIEF is a tool that tends to categorize many behaviors under broader executive function scales. This widely used tool measures eight different clinically derived scales of executive function (i.e., inhibit; shift; emotional control; initiate; working memory; plan/organize; organization of materials; and monitor) across different environments and from different perspectives (i.e., self, parent, student) using 86 different items. For the purposes of this research, the focus was on three of those eight scales: inhibit, shift, and working memory (often referred to as updating by other researchers) with three more added later: planning and organization, initiate, and monitor. Raters of the BRIEF are requested to complete the scale based on the prior 6 months of experiences with the student by indicating the frequency of certain occurrences as described in each item (1-*NEVER*; 2-*SOMETIMES*; 3-*OFTEN*). The following includes descriptions of the three relevant scales for the current study based on the definitions purported by the BRIEF:

Inhibit: This scale measures inhibitory control, or the ability to not act on impulse, as well as the ability to stop one's own behavior appropriately.

Shift: This scale measures the ability to move freely from one situation, activity, or aspect of one problem to another. This scale also includes such behaviors as transitioning, flexible problem solving, alternating or switching attention, and changing focus.

Working Memory: This scale measures the capacity to hold information for the purpose of completing a task in a short time period. Working memory is necessary for following multistep directions, carrying out multistep activities, or working through multistep problems.

High School Learners and Need for Further Research

Current research supports the impact of executive functions on learning and academic performance, though little is available at this specific level. More specifically, little research is available regarding high school math learning on students with disabilities and appropriate and effective interventions (Latzman et al., 2010).

Some studies have shown that inhibition, along with monitoring and conceptual flexibility, is strongly linked to academic performance; more specifically, inhibition was uniquely shown to support performance in math and science at the high school level (Latzman et al., 20010).

Studying the relations between executive functions and academic achievement of typically developing students is a necessary first step in understanding the role executive function deficits play in educational attainment (Latzman et al., 2010). The further study of executive functions and their impact on academic achievement appear to be paramount in the development of effective and efficient interventions.

As learners get older and progress through the levels in school, more factors may come into play impacting learning and the efficiency of executive functions, such as sleep emotional impact, performance anxiety, and internal and/or external motivation (Feifer & De Fina, 2005). Studies have found that an overactive anxiety system can impair working memory, thus impacting a student's academic performance (Hopko, Ashcraft, Gute, Ruggiero, & Lewis, 1998).

Summary of Literature Review

Learning is a complex construct that varies from task to task and by individual ability and/or skill. Learning math in particular is even more complex because of the various types and levels of math performance. Executive functions are necessary components to learning, as they are generally responsible for cueing and directing neurocognitive processes based on perception, emotion, cognition, and action while depending on individual factors and the environment (McCloskey & Perkins, 2013). Various brain structures, such as emotional systems, sensory systems, and motivational systems, are implicated in supporting executive functions (Carlson et al., 2016). These other systems are important to understand when considering any type of behavior but especially learning behaviors when the goal is to meet the needs of all learners, no matter their abilities or inabilities, so that they can successfully learn and perform in math. Each of these functions plays a part in how a child learns, and when all functions are performing optimally, the learner can learn optimally given appropriate learning opportunities.

As previously outlined, learning math calls upon various brain structures, including the prefrontal cortex, occipital lobe, Broca's area, hippocampus, and cerebellum, as well as upon three specific executive functions, working memory, shifting, and inhibition. These three executive functions are necessary for optimally learning and performing math (Kolkman et al., 2013; Kotsopoulos & Lee, 2012; Latzman et al., 2010; Lee et al., 2011; Van der Ven et al., 2012). Other cognitive processes implicated include numerical magnitude, number sense, and the phonological loop (Berninger & Richards, 2002; Carlin 2013; Kotsopoulos & Lee, 2012; Miller et al., 2013).

In conducting this review, limited research was available regarding high school learners and interventions appropriate for those presenting with difficulties or deficits (Latzman et al., 2010). Therefore, the current study explores the role and relationship of working memory, shifting, and inhibition on performance in math.

Hypotheses and Research Questions

A) Research Questions

   1) The current study was designed to address the following question: In what ways do deficits in inhibition, shifting, and working memory relate to academic achievement in learning and performing high school algebra?

B) Hypotheses

1) Deficits in inhibition predict academic achievement in learning and performing high school algebra. Elevated scores on the inhibition scale of the BRIEF will correlate with low test, homework, class participation, final exam, and PARCC (Partnership for Assessment of Readiness for College and Careers) scores in high school Algebra I.

2) Deficits in shifting predict academic achievement in learning and performing high school algebra. Elevated scores on the shifting scale of the BRIEF will correlate with low test, homework, class participation, final exam, and PARCC scores in high school Algebra I.

3) Deficits in working memory predict academic achievement in learning and performing high school algebra. Elevated scores on the working memory scale of the BRIEF will correlate with low test, homework, class participation, final exam, and PARCC scores in high school Algebra I. Working memory will have the most significant relationship with academic performance in Algebra I.

C) Summary and Transition

Based on the research, not enough information exists regarding the relationship between specific executive function deficits and learning and performing math. Even less information is available regarding how this information translates to classroom performance. Such information would enhance a teacher’s understanding of how to recognize and remediate math learning difficulties; particularly at the high school level where evidence-based interventions are largely lacking.

Chapter 3: Method

Data Source

The current study used archival data collected as part of a class-wide intervention conducted by the school psychologist in a suburban high school in New Jersey. The math department supervisor requested the assistance of the school psychologist in managing behavior and learning problems in the classroom. The data were collected to assist the general and special education teachers in an Algebra I course to develop more effective teaching strategies for the classroom. The data set included 20 students, 16 participating in the general education curriculum and four identified as requiring special education services in math. All students in the class were included in the data set and consent was not required. Teachers were given a set of BRIEF forms with instructions on completing the ratings for each student in the class.

Setting

The current setting was a regional high school district, serving students in Grades 9 through 12, with approximately 1,000 students of whom 200 were classified as receiving special education services. Fifty-four percent of students were White, 18% Black, 15% Hispanic, 6% Asian, 6% Multiracial, and less than 1% Other. Thirty-four percent of students were considered low income and/or received government assistance. The school was run by a superintendent, building principal, two assistant principals, a director of guidance, and a director of special services, as well as by the board of education and business administrator. These students came from two different towns/school districts upon enrollment at Monmouth Regional High School (MRHS):

Tinton Falls, which is considered upper-middle class, and Eatontown, which is considered middle- to lower-middle class and very diverse in ethnic make-up.

Measures and Materials

BRIEF

The data were collected using the Behavior Rating Inventory of Executive Function (BRIEF) Teacher Form. The BRIEF Teacher Form is a standardized measure of a teacher's perception of a student's executive functions in the school environment (Gioia, Isquith, Guy, & Kenworthy, 2000). In developing this scale, both clinical and normative data sets were used to determine reliability and validity of the BRIEF. Parent and Teacher Forms demonstrated high internal consistency (measured by Chronbach's alpha) ranging from .80 to .98. Ratings between teacher and parent on the same child were lower, with a correlation range of .30 to .50; however, ratings between teachers or two parents on the same child were generally higher. These differences are accounted for by the degree of difference between the home and school setting, as well as between home and school demands. Test-retest reliability correlations ranged from .72 to .92 across scales for parent and teacher scales; correlations for just teacher scales ranged from .83 to .92, indicating teachers' ratings are more consistent across administrations. The BRIEF was designed to have strong content validity through agreement among 12 pediatric neuropsychologists and the authors as to the fit of each item within each particular scale. Interrater reliability was measured for each individual item on the BRIEF; items ranged from .41 to .87. Construct validity was measured by correlating BRIEF scores to convergent and divergent scales.

The BRIEF is a tool that tends to categorize many behaviors under broader executive function scales. This widely used tool measures eight different clinically derived scales of executive function (i.e., inhibit, shift, emotional control, initiate, working memory, plan/organize, organization of materials, and monitor) across different environments and from different perspectives (i.e., self, parent, student) using 86 different items. For the purposes of this research, the focus was on three of those eight scales: inhibit, shift, and working memory (often referred to as updating by other researchers), though other scales were noted for relevance later. Raters of the BRIEF were requested to complete the scale based on the prior 6 months of experiences with the student by indicating the frequency of certain occurrences as described in each item (1-*NEVER*; 2-*SOMETIMES*; 3-*OFTEN*). The following includes descriptions of the three relevant scales for the current study based on the definitions purported by the BRIEF, as well as the three other areas chosen to be included after initial analysis:

Inhibit: This scale measures inhibitory control, or the ability to not act on impulse, as well as the ability to stop one's own behavior appropriately.

Shift: This scale measures the ability to move freely from one situation, activity, or aspect of one problem to another. This scale also includes such behaviors as transitioning, flexible problem solving, alternating or switching attention, and changing focus.

Working Memory: This scale measures the capacity to hold information for the purpose of completing a task in a short time period. Working memory is necessary for following multistep directions, carrying out multistep activities, or working through multistep problems.

The following includes descriptions of the other scales included for additional data analysis:

Plan/Organize: This scale measures the ability to manage current and future-oriented tasks. Planning involves imagining or developing a goal and then strategically determining the most effective steps to reach that goal. Organizing involves the ability to bring order to information and understand written and oral communication effectively. This scale also involves the ability to scan a visual array of stimuli and keep track of items (e.g., homework).

Initiate: This scale measures the ability to begin a task and independently generate ideas, responses, or strategies for solving problems.

Monitor: This scale measures "work-checking" habits, as well as the ability to keep track of how one's own behavior might impact others.

Grade Book and PARCC Data

Data from teacher grade books were used to measure actual student performance in Algebra I. Grade book data from the Algebra I class were obtained using the school's online grade recording data system, Genesis, for outcome measures. Grade book information included percentage (out of 100) for homework grades (graded based on completion each day), test and quiz grades, class participation (attention, participating in class discussions, participating in group activities)/classwork grades (completion of in-class work), and grade level-expectation testing using PARCC scores (on a scale from 1-5).

At this particular school, grades ranged from letters A to E, with 92-100 falling within the A range, 84-91 falling within the B range, 77-83 falling within the C range, 70-76 falling within the D range, and 69 and below falling within the E range.

The PARCC is the standardized measure used by the state of New Jersey to determine student progress and teacher performance. Students' scores can range between one (1) and five (5). Level 1 indicates *Did Not Yet Meet Expectations*; Level 2 indicates *Partially Met Expectations*; Level 3 indicates *Approached Expectations*; Level 4 indicates *Met Expectations*; and Level 5 indicates *Exceeded Expectations*.

Procedure

For this study, the researcher analyzed data that were collected and used to develop in-class interventions for a high school Algebra I class. Correlations were used to analyze BRIEF scores with grade book, final exam, and PARCC scores. The general education teacher was given a set of BRIEF forms with instructions for completion. The teacher was given the forms in a confidential envelope. These forms were returned within 1 week in a sealed confidential envelope. The forms were then scored using BRIEF scoring software, and results were printed and stored in confidential envelopes in a locked cabinet in the school psychologist's office. Grade book data were obtained by searching the school's Genesis website and downloading grade books for each of the students in the class. Grade books were printed and stored in a locked cabinet in the school psychologist's office. PARCC scores were obtained through the school's guidance department, printed, and stored in a locked cabinet in the school psychologist's office.

Data Analysis

A correlational research design was used to assess relationships between executive function scores on the Inhibit, Shift, and Working Memory scales of the BRIEF Teacher Forms and grade book scores on homework, classwork, and assessments. Owing to the limited significance found in the initial analyses with these three scales, correlations on the following scales were also included: Planning and Organization, Initiation, and Monitoring. Correlations were used to analyze the relationships between the factors listed previously.

Further, a series of crosstabulations was later generated to calculate sensitivity, specificity, and kappa values for comparing the BRIEF scales' clinical classification with performance levels for each of the math learning and performance variables, excluding PARCC scores. (All participants scored a 3 or above on the PARCC, indicating adequate mastery on that measure.) BRIEF scale clinical classifications were based on scale T scores; T scores of less than 60 were classified as Not Clinically Significant, whereas T scores greater than or equal to 60 were classified as Clinically Significant. Performance on each math criterion variable was classified as Proficient with scores greater than or equal to 80 and Not Proficient with scores less than 80. Sensitivity, specificity, and kappa values are tabled as percentages in the Results section of this study. Sensitivity values indicate the percentage of students who were classified as Clinically Significant on the BRIEF scale and who also were identified as Not Proficient on the math criterion variable. Specificity values indicate the percentage of students who were classified as Not Clinically Significant on the BRIEF scale and also were classified as Proficient on the math criterion variable. Kappa values reflect the overall accuracy of both sensitivity and specificity classifications expressed as a percentage of improvement over random assignment to categories.

Chapter 4: Results

Demographic Data

The archival data sample was initially collected as part of a class-wide program to assist a general education Algebra I teacher in implementing appropriate and effective learning and behavioral strategies for an in-class resource setting Algebra I class. The sample included 20 students, all rated on BRIEF teacher rating scales and student grade books by the general education teacher. The sample included six male students and 14 female students between the ages of 14 and 15 years. Seven of the students were 14 years old and 13 were 15 years old at the time the data were collected for the program. Within the sample, four students were classified as requiring special education supports and services in math, while 16 students were enrolled under general education. Only the general education teacher was asked to complete the BRIEF rating scales for each student.

Descriptive Statistics

The following outlines the hypotheses and research questions included within this study (see Appendix for study data). It was hypothesized that students with at-risk or clinically significant scores on the Inhibit scale would demonstrate difficulties in their academic performance as measured by their grade book grades and PARCC scores. Data from the current sample did not support this hypothesis. It was also hypothesized that students with at-risk or clinically significant scores on the Shift scale would demonstrate difficulties in their academic performance as measured by their grade book grades and PARCC scores. Data from the current sample did not support this hypothesis. Further, it was hypothesized that students with at-risk or clinically significant scores on the Working

Memory scale would demonstrate difficulties in their academic performance as measured by their grade book grades and PARCC scores. Data from the current sample demonstrated a relationship only for homework grades. Further analysis was conducted to determine whether other executive functions (i.e., Planning and Organization, Initiate, and Monitoring) demonstrated a relationship with math learning and performance. Monitoring demonstrated no relationship with the learning and performance measures studied; however, Planning and Organization demonstrated a relationship with Homework and Class Participation while Initiate demonstrated a relationship with Homework, Class Participation, and Test/Quiz grades. These results will be discussed further later in this section.

Reported in Table 2 are descriptive statistics for the sample for the BRIEF variables. For this sample, the average T Score for Inhibit and Working Memory fell within the average range, though the range of scores included individuals in the at-risk and clinically significant range. The average T Score for Shift, Planning and Organization, and Monitoring fell within the at-risk range, yet also included a range of scores within the average and clinically significant ranges. The Shift scale tended to have the largest standard deviation and more dispersion among the scores while Monitoring had the lowest standard deviation and less dispersion among the scores.

Table 2

Means and Standard Deviations for BRIEF T- Scores

BRIEF scale	*M*	*SD*	Range
	T-Scores		
Inhibit	56.70	15.631	45-99
Shift	61.70	19.596	45-122
Working Memory	58.15	13.724	43-84
Planning and Organization	60.85	12.453	43-88
Initiation	70.50	12.618	52-97
Monitoring	64.85	12.571	44-87

Note. BRIEF = Behavior Rating Inventory of Executive Function.

Table 3 outlines the descriptive statistics for the learning and performance variables for the study sample. The average score for Marking Period 4 (MP4) Homework fell within the A range with scores falling between 67 and 100, with 15 students earning As, four earning Bs, and one earning an E, indicating that most students performed well on homework. The average score for MP4 Tests/Quizzes fell within the C range, with scores falling between 64 and 99, with one student earning an A, eight earning a B, six earning a C, four earning a D, and one earning an E. The average score for MP4 Class Participation fell within the C range, with scores falling between 63 and 98 and with two students earning an A, four earning a B, six earning a C, six earning a D, and two earning an E. The average score for Final Exam Grade fell within the B range, with scores falling between 67 and 98 and with five students earning an A, three earning a B, eight earning a C, three earning a D, and one earning an E. The average score for PARCC fell within the approaching expectations range, with nine students earning a 4 (Met Expectations) and 10 students earning a 3 (Approached Expectations). One student out of the class of 20 did not participate in PARCC testing; therefore, only 19 scores are accounted for in these data.

Table 3

Means and Standard Deviations for Learning and Performance Variables

Variable	*M*	*SD*	Range
	Scores		
MP4 Homework	95.20	7.938	67-100
MP4 Tests/Quizzes	82.80	9.518	64-99
MP4 Class Participation	79.95	9.594	63-98
Final Exam Grade	82.70	9.663	67-98
PARCC Test Score	3.47	.513	3-4

Research Question/Hypotheses 1-4

The correlations reported in Table 4 illustrate the relationships between the BRIEF scales and the learning and performance variables. For this sample and these variables, Shift and Inhibit did not demonstrate a significant relationship with any of the performance variables measured. Working Memory demonstrated a significant relationship only with MP4 Homework (r = -.460, p < .05) and did not demonstrate a significant relationship with any other performance variables in this study.

Other BRIEF scales were included in the analyses, and a significant relationship was found among several other variables. A significant relationship was found between Planning and Organization and MP4 Homework ($r = -.548$, $p < .05$) and MP4 Class Participation ($r = -.414$, $p < .05$); but no significance was found for the other learning and performance variables in this study. A significant relationship also was found between Initiate and MP4 Homework ($r = -.483$, $p < .05$), MP4 Class Participation ($r = -.552$, $p < .05$), and MP4 Tests/Quizzes ($r = -.485$, $p < .05$); but no significance was found for Final Exam Grade and PARCC scores. The BRIEF scale Monitor was also examined, but no significant relationships were found among this scale and the math learning and performance variables in this study.

Table 4

Correlations for BRIEF Scales and Math Learning and Performance Scores

	Math learning and performance scores				
	MP4 HW	MP4 CP	MP4 T/Q	FE Grade	PARCC
BRIEF Scale (T)	*r*	*r*	*r*	*r*	*r*
Inhibit	.219	-.105	-.096	.238	.107
Shift	.087	-.072	-.079	.162	.367
Working Mem.	-.460*	-.421	-.250	-.115	.390
Planning/Org.	-.548*	-.526*	-.414	-.287	-.015
Initiate	-.483*	-.552*	-.485*	-.314	-.073
Monitor	-.164	-.375	-.268	-.027	.001

Note. N = 20. BRIEF Scales based on T scores. MP4 HW = Marking Period 4 Homework grade (average). MP4 CP = Marking Period 4 Class Participation grade (average). MP4 T/Q = Marking Period 4 Test/Quiz grades (average). FE Grade = Final Exam grade.
*$p < .05$.

A series of crosstabulations was generated to calculate sensitivity, specificity, and kappa values for comparing the BRIEF scales' clinical classification with performance levels for each of the math learning and performance variables, excluding PARCC scores. (All participants scored a 3 or above on the PARCC, indicating adequate mastery on that measure.) BRIEF scale clinical classifications were based on scale T scores; T scores less than 60 were classified as Not Clinically Significant, whereas T scores greater than or equal to 60 were classified as Clinically Significant. Performance on each math criterion variable was classified as Proficient or Not Proficient based on the decision criteria described in Chapter 3. Sensitivity, specificity, and kappa values are tabled as percentages. Sensitivity values indicate the percentage of students who were classified as Clinically Significant on the BRIEF scale and who also were identified as Not Proficient on the math criterion variable. Specificity values indicate the percentage of students who were classified as Not Clinically Significant on the BRIEF scale and also were classified as Proficient on the math criterion variable. Kappa values reflect the overall accuracy of both sensitivity and specificity classifications expressed as a percentage of improvement over random assignment to categories.

For Homework grades (see Table 5), when compared to BRIEF scales, Inhibit and Shift demonstrated no sensitivity at 0%. Yet, Inhibit demonstrated moderate specificity at 74%, and Shift demonstrated specificity (58%) only slightly better than classification based on random assignment. With the low specificity values and no sensitivity demonstrated, the kappa values for the Inhibit and Shift Scales were at less than 0%. Working Memory demonstrated high sensitivity with 100% and 55% specificity, but these values resulted in a kappa value of only 10%. Planning and Organization demonstrated high sensitivity with 100% and 53% specificity with a kappa value of only 10%. Initiate and Monitor both demonstrated high sensitivity at 100% and only 26% specificity with a kappa value of 3%.

Table 5

Crosstabulations for BRIEF Scales and Homework Grades (percentages)

BRIEF Scale	Sensitivity	Specificity	Kappa
Inhibit	0	74	<0
Shift	0	58	<0
Working Memory	100	55	10
Planning and Org.	100	53	10
Initiate	100	26	3
Monitor	100	26	3

Note. BRIEF = Behavior Rating Inventory of Executive Function.

For Test and Quiz grades (see Table 6) when compared to BRIEF scales, Inhibit demonstrated no sensitivity at 0%, yet it showed moderate specificity at 74%; however, the kappa value was less than 0%, indicating no overall improvement in classification over random assignment. Shift demonstrated low sensitivity at 30% along with specificity at 58% and a resulting kappa value of less than 0%. Working Memory demonstrated high sensitivity at 100% combined with low specificity at 47%, producing a kappa value of only 8%. Planning and Organization demonstrated high sensitivity at 100% but low specificity at 58% with a kappa value of only 12%. Initiate and Monitor both demonstrated high sensitivity at 100% and only 26% specificity with a kappa value of 3%.

Table 6

Crosstabulations for BRIEF Scales and Test and Quiz Grades (percentages)

BRIEF Scale	Sensitivity	Specificity	Kappa
Inhibit	0	74	<0
Shift	30	58	<0
Working Memory	100	47	8
Planning and Org.	100	58	12
Initiate	100	26	3
Monitor	100	26	3

Note. BRIEF = Behavior Rating Inventory of Executive Function.

For Class Participation grades (see Table 7) when compared to BRIEF scales, Inhibit demonstrated 50% sensitivity and moderate specificity at 72%, but these values resulted in a kappa value of only 12. Shift demonstrated high sensitivity with 100% and specificity (56%) only slightly better than classification based on random assignment. These values resulted in a kappa value of only 20%. Working Memory demonstrated high sensitivity at 100% and specificity (56%) only slightly better than classification based on random assignment. These values resulted in a kappa value of only 20%. Planning and Organization demonstrated high sensitivity at 100% and specificity at 50%, resulting in a kappa value of only 17%. Initiate and Monitor both demonstrated high sensitivity at 100% but only 22% specificity, resulting in a kappa value of 5%.

Table 7

Crosstabulations for BRIEF Scales and Class Participation Grades (percentages)

BRIEF Scale	Sensitivity	Specificity	Kappa
Inhibit	50	72	12
Shift	100	56	20
Working Memory	100	44	14
Planning and Org.	100	50	17
Initiate	100	22	5
Monitor	100	22	5

Note. BRIEF = Behavior Rating Inventory of Executive Function.

For Final Exam grades (see Table 8) when compared to BRIEF scales, Inhibit demonstrated very low sensitivity at only 13%, yet specificity (67%) was slightly better than classification based on random assignment. However, these values resulted in a kappa value at less than 0%. Shift demonstrated low sensitivity (38%) and specificity

(58%) only slightly better than classification based on random assignment. These values resulted in a kappa value at less than 0%. Working Memory demonstrated moderate sensitivity at 75% and specificity (67%) slightly better than classification based on random assignment. These values resulted in a kappa value of 40. Planning and Organization values for sensitivity (63%) and specificity (67%) were both only slightly better than classification based on random assignment; these values resulted in a kappa value of only 2. Initiate demonstrated high sensitivity at 88% and specificity at only 50%, resulting in a kappa value of only 3. Monitor demonstrated moderate sensitivity at 75% and very low specificity (33%). These values resulted in a kappa value of only 7.

Table 8

Crosstabulations for BRIEF Scales and Final Exam Grades (percentages)

BRIEF Scale	Sensitivity	Specificity	Kappa
Inhibit	13	67	<0
Shift	38	58	<0
Working Memory	75	67	40
Planning and Org.	63	67	29
Initiate	88	50	34
Monitor	75	33	7

Note. BRIEF = Behavior Rating Inventory of Executive Function.

Chapter 5: Discussion

A major goal of this study was to measure the relationship between three specific executive functions, Shift, Inhibition, and Working Memory (as measured by the BRIEF), and various types of school-based performance and learning measures. Other BRIEF scales were also included for additional data regarding learning and performing in math and other executive functions that may be involved since little significance was found in the relationships between the original three executive functions being studied. Shift and Inhibit demonstrated no significant relationships, and Working Memory demonstrated significance for homework only. These results were beneficial in helping to better understand the role of executive functions in learning and performing math.

Generally, the sample population of students was rated as having more executive function difficulties than one would expect given their learning and performance grades.

Research Question 1: In what ways do deficits in inhibition, shifting, and working memory relate to academic achievement in learning and performing high school algebra?

It was hypothesized that deficits in inhibition would relate to academic achievement in learning and performing high school algebra; high scores on the Inhibition scale of the BRIEF would correlate with low test, homework, class participation, final exam, and PARCC scores in high school Algebra I. Results of the study demonstrated no relationship between the Inhibit scale and learning and performance measures.

Further, it was hypothesized that deficits in shifting would relate to academic achievement in learning and performing high school algebra; high scores on the Shift scale of the BRIEF would correlate with low test, homework, class participation, final exam, and PARCC scores in high school Algebra I. Results of the study demonstrated no relationship between the Shift scale and learning and performance measures. Some research highlights that Shift and Inhibit are indistinguishable, therefore making them difficult predictors of academic performance (Van der Ven et al., 2012) and perhaps providing an explanation for the lack of significance found in the current study.

Finally, it was hypothesized that deficits in working memory would relate to academic achievement in learning and performing high school algebra; high scores on the Working Memory scale of the BRIEF would correlate with low test, homework, class participation, final exam, and PARCC scores in high school Algebra I. Working memory was anticipated to have the most significant relationship on academic performance in Algebra I. Of the three main scales studied, Working Memory did demonstrate a relationship, but only for homework grades. Working Memory demonstrated no relationship with any other learning or performance measure for this sample.

This study was opened to additional analysis after initial study findings found only one relationship for Working Memory and Homework grades. Interestingly, some of the other scales included proved to have more of a relationship than the initial three scales with some of the learning and performance measures. For example, findings demonstrated an unexpected relationship between Test and Quiz grades with Initiation, as well as between Class Participation and Planning and Organization and Initiation.

Findings also found no relationship between PARCC and Final Exam grades for any of the BRIEF executive function measures examined. Students tended to perform higher on these measures than on ongoing learning and performance measures during the fourth marking period. So, despite some students being rated as having deficits in various executive functions, they performed well enough on math learning and performance measures to not highlight any significance or concerns. This tendency indicates that despite performance throughout the fourth marking period, students were actually learning and could demonstrate adequate learning on more summative measures, such as a final exam or PARCC test.

Results indicate that the three main executive functions of this study (Shift, Inhibit, and Working Memory) may not have as strong a relationship, if any at all, on student learning and performance in math as previous research has found. However, a strong relationship was found among other executive functions (Planning and Organization and Initiate) based on the results of this study, with only one for Working Memory. Evidence shows that planning and organization and initiation have a strong relationship with overall student learning and performance across academic subject areas (Rabin, Fogel, & Nutter-Upham, 2011). Among other noted executive functions, planning/organization and initiation have been linked to procrastination in previous research, with an emphasis on the detrimental effects procrastination has on learning and performance across all academic areas (Rabin et al., 2011). The current study found strong relationships between student learning and performance and elevated scores on Planning and Organization and Initiate, indicating that students demonstrating difficulty with these two areas demonstrated difficulty on academic tasks as well.

The data were explored further using crosstabulations for sensitivity and specificity to determine if the BRIEF scales were sensitive enough to determine which students demonstrated valid executive function concerns and if the scales were specific enough to rule out students who did not demonstrate concerns or academic difficulties. The intent was to determine if any specific trends existed between different groups of students (groups based on their BRIEF scores and their math performance grades). These data indicated that executive functions do not have as much of a relationship on student performance or learning as previously thought. Generally, the students in this class performed well, despite indications of executive function deficits as rated by the general education teacher (see Appendix). Perhaps the teacher was biased in her ratings, possibly perceiving most of her students to be more executively impaired than they actually were when compared to their academic performance.

The specificity values tended to be low, indicating that the teacher tended to rate students as having executive deficits, despite their actually performing well in math. However, of note was that class participation tended to have the best levels of sensitivity for the executive function measures, likely because this math criterion is the only one solely based on teacher perception and is not as objective as actual grades on work completed or test/quizzes. In general, the teacher likely believes only her top-achieving students demonstrate adequate executive functions, and therefore, students doing just “okay” or “average” appear to have impaired executive functions. During consultation, the teacher would often describe several of her students as lazy or disengaged. While the teacher generally presented as objective and fair in her observations and grading of her students, by the end of the school year, she appeared somewhat frustrated and “burnt out,” possibly contributing to her negative ratings. A number of other factors, including changes in administration and thus increased administrative directives, pressures of PARCC testing, and the stricter teacher ratings protocols being introduced by the district, may have contributed to her overall frustration. All of these factors may have contributed to the increased ratings on the BRIEF scales. Further, additional potential reasons for the ratings to be as they were include the tendency for this particular school district to informally report that students regard math as a challenging or “boring” subject matter, thus causing them to appear disengaged during class time.

Implications of Findings

Results of this study demonstrated a significant relationship between Working Memory and homework performance, indicating that Working Memory was most closely related to a student’s ability to complete homework consistently, a finding that is consistent with previous research (Landberg et al., 2016). Initiation and Shifting, the other two areas expected to have a relationship, did not demonstrate a significant correlation. Further, and unexpected, was the relationship that Planning and Organization had on homework performance. In context, indicating that students benefit from solid planning and organization skills in regard to completing homework accurately and consistently in order to maintain an acceptable grade. Initiation also demonstrated a relationship with homework, indicating that this skill is important for students in completing homework. These executive functions are apparently required for any type of homework and are not just exclusive to math performance. When these data were being used to assist in the classroom intervention, the psychologist suggested that the teacher focus on embedding planning and organization skills within the lessons to help students learn how to prepare themselves for work completion, particularly when doing work at home, to maximize their performance. Planning instruction has been shown to be a beneficial intervention for academic performance (Naglieri & Gottling, 1997). The psychologist also recommended that the teacher check the homework for accuracy in addition to completion. Homework completion alone does not indicate mastery, though it does help to reinforce and support learning when completed correctly (Jensen, 2005; Landberg et al., 2016; Merriman & Codding, 2008), and some students demonstrated difficulties on tests/quizzes when they had perfect, or nearly perfect, homework scores. In theory, the teacher was using homework as a grade booster and did not want to score it for accuracy, but checking it and making corrections during class time is a helpful way for students to reinforce learning and to deter incorrect learning (Landberg et al., 2016; Merriman & Codding, 2008).

The lack of relationship between Shift and Inhibit on any of the correlations may be indicative of several phenomena. First, a review of the data clearly showed that most of the students in this class performed quite well in most areas, with a few exceptions. The teacher's perceptions of the students may have been more negatively skewed overall, thus raising executive function concerns that do not truly exist for these students. Therefore, their actual performances may be better than expectations based on BRIEF ratings. These results could be due to most students' general disinterest or their negative feelings toward math, as mentioned in consultation with the teacher (i.e., students reporting upon entering the classroom that they do not like the class or remarking "I hate math") and in discussions in the previous literature (Feifer & De Fina, 2005). Observations of the classroom and teacher reports indicated that students often appeared bored or disengaged when they may have actually been paying attention and retaining the lessons presented.

Limitations

Given the very limited sample size, in this case restricted to a single Algebra I class in one school district, generalization of these findings to the broader population of high school math learners is difficult. The small sample size also appeared to impact the overall significance of the findings. Including a larger sample size may have yielded stronger data with more significant results for analysis. For example, only five of the 20 students scored at-risk or clinically significant for Inhibit and only eight scored at-risk or clinically significant for Shift (see Appendix). The small sample size tended to limit the variability of the data as well. Perhaps with more students of varying ability levels (and more students who tended to underperform in math), the study would have yielded more significant results.

Further, the study was limited by looking only at Algebra I and not including pre-Algebra, Geometry, Statistics, Trigonometry, Calculus, and even basic “everyday” math. A broader array of math topics may relate differently to various executive functions required for learning and performance. Including a wider range of courses could have provided even further specific skills and behaviors for a better understanding of how executive functions relate to math learning.

Another limitation is that only one teacher completed the rating scales, making the perspective of subjective data for each student very narrow. The teacher also seemed to have a more negative perception of students’ executive functions than was shown by their performances (particularly for working memory, planning and organization, and initiation), further limiting the already very narrow data. For example, during consultation appointments, the teacher reported that her class was well behaved, yet many of the students appeared lazy or unmotivated to complete work. When looking at the students' actual grades, most did quite well, despite the at-risk, or even clinically significant, ratings by the teacher. During classroom observations, most students clearly were disengaged and may have appeared lazy, with a few exceptions.

Further, the academic and classroom performance measures of the study possibly were not solid enough to warrant measuring what they purported to be measuring. While homework and class participation are generally recognized as measuring a student's performance, perhaps the scores were biased in one direction or another.

A final limitation of the study is the nature and quality of the BRIEF. While it is a solid and well-respected measure, it does not actually objectively measure executive functions but instead measures a teacher's perceptions of behaviors that may reflect a student's executive function capacity.

Future Directions

In general, research is lacking in the areas of executive functions, math, math learning disabilities, and math interventions. Future studies should focus on these areas to broaden and deepen the body of knowledge to help better support all students' learning. Future studies could look at more specific basic math behaviors that predict successful learning and performance of math to pinpoint the skills students need, as well as to determine the executive functions that are required for success, perhaps by looking more to a cognitive skills basis rather than, or in addition to, an executive function basis. For example, what learning behaviors demonstrate particular executive functions? Findings of the current study highlighted initiation, planning and organization, and working memory specifically as having a relationship with student learning and performance. Future studies could look specifically at the math learning behaviors and math skills students demonstrate that lead to adequate performance and how these skills relate to executive functions. Essentially, these studies could back up a step to relate behaviors and skills to academic performance in math and then relate to measurable executive functions. This information would help demonstrate how actual skills translate to student performance and achievement, which could then be compared to executive functions. This information would be helpful to support student learning and allow for the development of appropriate and effective interventions that meet the needs of students struggling to keep up with grade level academic materials.

Another direction for future research could be to broaden the breadth of students included in the study to ensure participants actually demonstrate difficulties in math performance and learning. A study that includes more students with difficulties may yield more consistent results in comparison to results from executive function measures. It may also be beneficial for the teacher (or teachers) to delineate categories of students as high achievers, average achievers, or low achievers to analyze with executive function scores or skills to compare with executive function scores rather than comparing to grade book data.

Further, teacher ratings of executive functions are student behaviors, so perhaps using the teacher ratings of the BRIEF was a disadvantage, and in the future a test or measure that demonstrates a higher level of sensitivity for determining actual executive function deficits, such as a performance measure, should be used. In this case, the BRIEF served an appropriate purpose in collecting data for the assistance requested, but perhaps it was not sensitive or specific enough for the needs of the current study. Future studies may benefit from measuring specific executive functions in a more precise manner, rather than from using a rating scale of a teacher's perceptions of student behavior. In addition, future studies may benefit from looking at pre-Algebra skills or even more basic math skills in high school learners. Having the teacher categorize students based on his or her perceptions of their "quality" as a math student (i.e., high achiever, average achiever, low achiever) and comparing to executive function scores also may be beneficial.

Also, considering the results of the data, further studies that include other executive functions, such as the relationship of Planning and Organization and Initiation, may be beneficial in highlighting the specific behaviors and skills students require for successful learning and performance in math. Some researchers argue that very little true evidence exists of causal or predictive associations between executive functions and achievement, meaning that other factors need to be included or controlled for in studies with the goal of determining directions for targeted interventions (Jacob & Parkinson, 2015). In general, the executive function measure could be used as a tool to help develop and/or define the specific behaviors required for learning so that more specific strategies, such as various cognitive strategies or cognitive skills instruction, can be implemented. Since the current study demonstrated difficulty in showing significance between learning and performance measures with related executive functions, this type of study may be a more useful way to analyze and interpret those data.

Future studies would benefit from including more classes, more teachers' ratings, and different ways of measuring math learning behavior, rather than using specific executive functions from a rating scale. A larger sample size would also be beneficial in potentially increasing variability and allowing researchers to analyze the data more closely, as well as in generalizing findings to the broader population of learners.

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Appendix: Data Set

Part #	Gend	Age	MP 4 HW	MP 4 T/Q	MP 4 CP	FE	PARCC score	Inhibit	Shift	WM	Plan/Org	Initiate	Monitor
1	M	15	89	76	66	77	4	53	62**	60**	66**	72**	65**
2	F	15	100	90	70	95	3	46	50	51	69**	73**	58
3	M	15	90	87	75	84	3	58	54	67**	72**	72**	68**
4	F	14	95	85	77	87	3	53	55	51	46	68**	62**
5	M	14	100	64	73	67	4	45	54	67**	72**	80**	65**
6	F	14	100	71	87	80	3	63**	66**	61**	59	73**	80**
7	F	15	97	72	83	78	3	84**	66*	68**	65**	77**	80**
8*	F	15	92	89	77	78	3	46	50	71**	78**	81**	65**
9	F	15	67	72	74	70	4	46	55	81**	88**	97**	76**
10*	F	15	100	99	96	96	4	53	55	45	50	56	47
11	F	15	100	91	76	94	3	46	45	48	59	73**	62**
12*	F	14	100	90	83	83	3	46	45	45	43	52	44
13*	M	15	97	75	63	83	4	99**	122**	84**	75**	88**	87**
14	M	14	100	91	80	98	3	69**	62**	80**	66**	84**	71**
15	F	15	94	88	91	78	4	46	55	45	43	52	47
16	F	14	100	92	81	95	4	57	81**	45	50	56	62**
17	F	14	100	91	91	91	4	84**	101**	45	53	56	87**
18	F	15	100	82	71	80		46	45	45	50	56	58
19	F	15	86	80	98	70	3	46	66**	61**	59	68**	62**
20	M	15	97	71	87	70	4	48	45	43	54	76**	51

*Indicates student with IEP

**Indicates at-risk or clinically significant BRIEF score