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Studying preservice teacher math anxiety and mathematics performance in geometry, word, and non-word problem solving

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ABSTRACT

Research shows that mathematics anxiety and mathematics achievement present a challenge for many educators, particularly elementary school teachers who usually have lower mathematics content knowledge and higher math anxiety levels than average college students. This study investigated education majors' cognitive abilities and mathematics perceptions that affect their mathematics performance in geometry, word problem-solving, and non-word problem-solving. We examined relationships between mathematics problem-solving and math anxiety in each of the three mathematical domains as a function of working memory (WM), spatial ability, and attitudes toward learning mathematics. Math anxiety, WM, and spatial ability explained 62% of the variance in student overall mathematics performance with math anxiety being the highest (negative) predictor. Although relationships between math anxiety and mathematics performance varied by mathematical domain, the negative effects of math anxiety were equally detrimental in each of the three mathematical domains, even after controlling for the effects of WM performance and spatial ability.

1. Introduction

Mathematics anxiety and mathematics performance have received a lot of attention from the research community over the last four decades. Mathematics anxiety is often described as "the apprehension or fear aroused when placed in a situation in which maths must be performed" (Hembree, 1990, p. 34). Mathematics anxiety has consistently been found to inhibit an individual's mathematics performance and attitudes toward mathematics including interest and confidence in learning mathematics. High math anxiety combined with negative attitudes toward mathematics are usually among the major factors that steer people away from participating in mathematics classes and pursuing STEM-related careers.

Resent research on student academic success and involvement in STEM disciplines examined the role of elementary teachers in preparing children for STEM careers and influencing their beliefs and attitudes toward STEM (Beilock & Maloney, 2015; Lubinski & Benbow, 2006). Teacher's mathematics competence and math anxiety appear to strongly correlate with their student's mathematics achievement and fears about mathematics, particularly among girls (Beilock, Gunderson, Ramirez, & Levine, 2010; Hadley & Dorward, 2011). High math anxiety combined with negative attitudes toward mathematics is particularly troubling among education-majors, especially pre-service elementary teachers (PSETs), who usually have the highest math anxiety levels and below average mathematics proficiency among college majors (Hembree, 1990; Rech, Hartzell, & Tephens, 1993). Many education majors, especially PSETs, lack mathematics skills that are necessary for their graduation and employability, which further perpetuates the issue (Ma, 1999). For instance, recent changes in the Praxis Core math exam, a required competency examination in mathematics for prospective teachers, require teacher candidates not only to be able to solve math problems in one particular way but also to demonstrate a deep conceptual understanding and high mathematics competency, which poses considerable challenges for pre-service teachers (Silver, Ghousseini, Gosen, Charalambous, & Strawhun, 2005). Moreover, an increasing emphasis on high-stakes testing and evaluation of teachers by their students' test scores contribute even further to education majors' already high math anxiety levels and negative attitudes toward mathematics.

The negative impact of math anxiety among education majors might go well beyond their own mathematics achievement. Highly anxious elementary pre-service teachers tend to have lower mathematics teaching self-efficacy and generate negative teacher attitudes (Gresham, 2007). Furthermore, math-anxious female elementary school teachers tend to negatively affect mathematics achievement of their female students (Beilock et al., 2010).

Psychometric literature clearly shows that mathematics anxiety is closely related to mental processing. Prominent effects of high

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mathematics anxiety include decreased WM processing abilities that consequently hinder mathematics performance and increase error rates (Ashcraft & Krause, 2007; LeFevre, DeStefano, Coleman, & Shanahan, 2005; Raghubar, Barnes, & Hecht, 2010). Moreover, confidence in learning mathematics and motivation to engage in mathematics-related activities were found to negatively correlate with math anxiety as well (Ashcraft, 2002). Researchers argue that the relationships between WM and mathematics achievement are complex and are likely mediated by other factors such as individual's skill level, age, math problem presentation, instruction, and type of mathematical skills, and empirical evidence connecting WM and mathematical processing is relatively sparse (LeFevre et al., 2005; Raghubar et al., 2010).

Spatial abilities appear to also play an important role in individuals' mathematics learning and math anxiety (e.g., Ferguson, Maloney, Fugelsang, & Risko, 2015). Spatial abilities are believed to function as the basic "building blocks" of mathematics and therefore often linked to successful math performance (Fias & Fischer, 2005). The relation between spatial processing, mathematics achievement and mathematics anxiety is particularly critical among elementary education majors, most of whom are females and have considerably lower spatial abilities than males (Linn & Petersen, 1986). Recent investigations have demonstrated a strong negative correlation between math anxiety and spatial abilities with spatial skills mediating the relationship between gender and math anxiety (Maloney, Waechter, Risko, & Fugelsang, 2012).

Although the research on the relationships between mathematics anxiety, mathematics performance, and spatial abilities factors has received some attention, more systematic research examining such relationships across various mathematics tasks and domains is needed. Particularly scarce is research that examines how cognitive and non-cognitive factors including participants' background, and mathematical domains and knowledge types, mediate the relationships between math anxiety and mathematics performance (LeFevre et al., 2005; Raghubar et al., 2010). Based on the available research on the relationships between math anxiety and mathematics achievement and teacher's role in influencing children's attitudes and anxieties, selecting educational practitioners as the target population for this line of research is critical (Beilock et al., 2010).

Our work aims to empirically examine the relationships between PSET's mathematics anxiety and mathematics performance in three distinct areas: geometry, word problem-solving, and non-word problem-solving. Working memory, spatial ability, confidence in learning mathematics, and student academic background were explored as possible factors that mediate the relationships between mathematics anxiety and mathematics performance in each of the three mathematical domains (geometry, word problem-solving, and non-word problem-solving). The study places us in a unique position to provide meaningful insight into the current climate of PSETs, which can in turn provide practical implications for teacher preparation programs.

Our interest in examining the relationships between mathematics anxiety and mathematics performance across the three distinct mathematical domains stems from the fact that mathematical tasks and skills are believed to mediate such relationships (Ashcraft & Krause, 2007; Maloney et al., 2012; Raghubar et al., 2010). However, a more systematic investigation of the involved cognitive processes is needed in order to understand the degree(s), to which various cognitive processes influence mathematics problem solving in adult participants (LeFevre et al., 2005). In order to assess education majors' mathematics performance in geometry, word problem-solving, and non-word problem-solving areas, we developed a mathematics performance assessment instrument that mirrored Praxis II exam questions (a licensure exam in mathematics for pre-service elementary teachers), systematically covering each of the three types of problems from the elementary school mathematics curriculum.

1.1. Geometry, word, and non-word problem solving

Geometry knowledge is believed to be founded on the representations of the large-scale navigable surface layouts, shapes, and small-scale movable objects (Spelke, Lee, & Izard, 2010). Successful geometry problem solving involves interpreting geometry problems that are often presented in a language form, processing of geometry and arithmetic concepts and facts, and consequently applying them to solve the problem (Giofrè, Mammarella, Ronconi, & Cornoldi, 2013). Geometry academic achievement was found to correlate with high WM and spatial abilities and is critical to student academic and professional success (Giofrè, Mammarella, & Cornoldi, 2014; Presmeg, 2006).

Word/story problem solving requires an individual to comprehend the contextual situation described in the problem, keep track of the incoming information, embed the numerical values in the relational storyline structure, and finally perform arithmetic calculations (Swanson, 2004; Thevenot & Barrouillet, 2014). Due to considerable storage and processing of information associated with reading/hearing the word problem, WM is critical to the successful task performance (Swanson, 2004; Swanson & Sachse-Lee, 2001).

Solving non-word multistep computation and arithmetic problems involves considerable WM resources, such as selecting and updating new input, retrieving relevant information from the long-term memory, maintaining and integrating both new and retrieved message, and information processing. It involves executions of the carry operations and manipulations of the mental number line, thereby placing significant demands on spatial WM processing (Ashcraft & Kirk, 2001; Maloney et al., 2012).

1.2. Working memory and mathematics achievement

Several recent comprehensive literature reviews explored the nature of the relationships between mathematics performance and WM. WM was often used to explain the effect or variance of mathematics cognition in numerous studies (LeFevre et al., 2005; Raghubar et al., 2010). However, the literature presents mixed results with regard to the role of WM in mathematics achievement. Raghubar et al. (2010), in their comprehensive review on WM and mathematics, asserted that empirical research with both children and adults across experimental and cross-sectional studies confirmed the relationship between WM and mathematics performance. However, such relationships are complex as they tend to be mediated by numerous factors, such as individual's skill level, age, math problem presentation, instruction, and type of mathematical skills. Raghubar et al. (2010) argue that "what is currently lacking in the field is a sufficiently comprehensive model of mathematical processing, particularly in relation to skill acquisition, that can handle current findings on working memory as well as provide the basis from which to guide new discoveries and inform practice" (p. 119). Specifically, future research should systematically manipulate various mediating factors, including mathematics task complexity, mathematics domain specific knowledge, response requirement, and mathematics knowledge type (e.g., factual, conceptual, or procedural).

Numerous studies examined the relationships between WM and mathematics performance across a variety of mathematical tasks, including arithmetic problems (Ashcraft & Kirk, 2001; Trbovich & LeFevre, 2003), word problems (LeBlanc & Weber-Russell, 1996; Swanson & Beebe-Frankenberger, 2004), general problem solving (Bühner, Kröner, & Ziegler, 2008), and geometry (Giofrè et al., 2014). However, the research examining such relationships was neither comprehensive, nor systematic (DeStefano & LeFevre, 2004; Raghubar et al., 2010). Particularly scarce is research on WM and geometry (Giofrè et al., 2014). We were able to find only one research study that examined the relationship among geometry and WM in elementary school students (Giofrè et al., 2014). The authors found that student academic geometry achievement depended largely on WM. To our knowledge, there has been no research on WM and geometry with adult