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Mental rotation ability in relation to self-perceptions of high school geometry

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ABSTRACT

The study examined relations among mental rotation ability, mathematics achievement and mathematical self-perceptions among 113 high school students. Each participant completed a mental rotations test, an assessment of self-perceptions of geometry and self-perceptions of algebra. Geometry and algebra grades along with a standardized geometry test were used as measures of mathematics achievement. Significant relations emerged between mental rotation and both geometry grades and the standardized geometry measure; no significant relation emerged between mental rotation and algebra grades. A significant relation also emerged between mental rotation and self-perceptions of doing well in geometry and algebra, but not between mental rotation and self-perceptions of either liking geometry or algebra. Implications pertaining to the improvement of spatial thinking as they relate to encouraging students' interests in mathematical and scientific careers are addressed.

1. Introduction

Spatial ability refers to an individual's ability to generate, retain, retrieve and transform well-structured visual images (Lohman, 1996). Its use is obvious in many facets of life from leisure (e.g., puzzles, model building, craftwork) to occupational choice (e.g., architecture, cartography, radiology). Proficiency in spatial ability is often associated with success in cognitively demanding disciplines, such as engineering and science (Shea, Lubinski, & Benbow, 2001) that are quantitatively driven. Although spatial ability has been found to be strongly related to quantitative ability (Lubinski & Humphreys, 1990) but distinct from verbal ability (Dixon, 1983), it is believed to function in combination with both in the acquisition of new knowledge (Gardner, 1993). In other words, it is complementary in the process of learning. Given what is then known, spatial ability is a key dimension in human capability that affords unique information in a portrait of cognitive diversity.

Reasons why individuals differ in spatial ability vary in that some argue in favor of a biological predisposition (e.g., Thomas & Kail, 1991), whereas others favor environmental influences (e.g., Sanz de Acedo Lizarraga & Garcia Ganuza, 2003), or both (e.g., Casey, Nuttall, & Pezaris, 1999). The two latter positions assume that spatial ability can be improved with experience. Along these lines, Ericsson, Nandagopal, and Roring (2005) have proposed that the development of enhanced performance in any domain may very well be a reflection of relevant experiences that involve extended practice. In the effort to explain why students with well-developed spatial ability are more likely to perform better in mathematics (e.g., Battista, 1990; Battista, Wheatley, & Talsma, 1982; Casey, Nuttall, & Pezaris, 1997; Delgado & Prieto, 2004), it may be that these individuals have had a greater repertoire of experiences to nurture this ability. For instance, research has shown that participation in certain spatially oriented activities (e.g., playing videogames, the piano, or soccer) relates to strength in types of spatial skills (e.g., Cherney, 2008; Rauscher, 1999; Weckbacher & Okamoto, 2012). If this assertion is correct, then efforts to improve spatial ability may well lead to improved performance in geometry — a weaker content areas in mathematics among US students (Battista, 1999; Corbishley & Truxaw, 2010; Gonzales et al., 2009; Mullis, Martin, Gonzalez, & Chrostowski, 2004).

1.1. Mental rotation ability and geometry

Types of spatial ability are well documented (e.g., Hermelin & O'Connor, 1986; Linn & Petersen, 1985; Lohman, 1996; McGee, 1979); however, some spatial abilities tend to be far more studied than others likely due to their relevance to certain aspects of performance, such as mathematics achievement. One pertinent example is mental rotation. This type of spatial thinking involves the ability to mentally rotate two- or three-dimensional objects encountered in everyday life, including figural depictions in mathematics textbooks. In considering the variety of factors that could potentially influence mathematics achievement, mental rotation has been frequently cited as a factor in determining successful problem solving performance, notably geometry (e.g., Battista; 1990 Battista et al., 1982; Casey et al., 1997; Casey, Nuttall, Pezaris, & Benbow, 1995; Delgado & Prieto, 2004; McGee, 1979).

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Among the general population, a male advantage in mental rotation ability is a well-established finding (e.g., Battista, 1999; Casey et al., 1995; Casey et al., 1997; Cherney, 2008; Delgado & Prieto, 2004; Hult & Brous, 1986; Linn & Petersen, 1985; Vandenberg & Kuse, 1978; Voyer, 1998). Thus, in light of males' superior mental rotation ability, studies that examined the relation between this skill and performance in geometry often draw equal attention to the role of gender. For instance, according to Casey et al. (1997), geometry items account for approximately one-third of the items on some SAT-M tests, and these items tend to have the largest gender difference of all the items on the test (Rosser, 1989). In their study that explored the basis for the gender difference in the SAT-M, Casey et al. (1997) applied path analytic techniques to trace the causal pathways of key variables that might function as possible mediators of the gender–SAT-M relation. They determined that mental rotation, in comparison to math self-confidence, math anxiety and geometry grades, is the most critical factor contributing to a gender difference in SAT-M. On the other hand, Delgado and Prieto also investigated the mediating role of mental rotation within the context of gender. They predicted that mental rotation would mediate mathematical abilities (e.g., geometry) typically favoring males. Interestingly, no statistically significant gender differences surfaced in regard to the participants' performance in geometry. At a descriptive level only, females performed better than males in arithmetic, males performed better than females in geometry and word problems. Though mental rotation added to the prediction of performance in geometry, it accounted for little variance. Similarly, Friedman's (1995) meta-analysis of correlations concerning spatial abilities (including mental rotation) and geometry showed little evidence of gender differences.

The inconsistency in the findings reported above suggests that there is good reason to assume that mental rotation is merely one variable that may influence performance in geometry. Even though males tend to outperform females in mental rotation, the patterns of findings with respect to geometry are less clear cut. According to Casey et al. (1997), this is not surprising given how such studies vary widely in age, the ability level of participants, the choice of instruments for measuring both spatial and math abilities as well as the choice of variables studied. With respect to the latter, one variable that has been well investigated pertains to students' self-perceptions of their mathematics achievement, yet seemingly little research has been conducted in the area of geometry.

1.2. Self-perceptions of mathematics achievement

Differences in any area of mathematics performance, however, should not be interpreted as the byproduct of ability alone. There is a good deal of research that has shown how mathematics performance is also related to students' self-perceptions of their quantitative abilities. Conceptually speaking, the study of self-perceptions in mathematics can be considered multifaceted. Mathematics self-concept (i.e., knowledge and perceptions about oneself with respect to mathematics) and mathematics self-efficacy (i.e., convictions about oneself with respect to mathematics performance) are two domain-specific constructs that have been shown to predict motivation, emotion, and performance in mathematics to varying degrees (Bong & Skaalvik, 2003). An interrelated dimension is mathematics attitude (e.g., Ganley & Vasilyeva, 2011; Vandecandelaere, Speybroeck, Vanlaar, De Fraine, & Van Damme, 2012) that takes into account how confidence and anxiety can affect performance. According to Utley (2007), students begin to develop an attitude toward mathematics as soon as they are exposed to it; these attitudes can therefore have an effect on subsequent mathematical learning. In sum, findings have revealed that students who hold positive attitudes toward mathematics tend to have higher mathematics course grades (e.g., House, 1993) with greater achievement expectancies (e.g., Wong, 1992) and stronger participation in advanced mathematics coursework (e.g., Ma, 2006).

In Ma and Kishor's (1997) meta-analytic review of the relation between attitude and achievement in mathematics, findings showed that the relation between attitude toward mathematics and achievement in mathematics is similar for both males and females. Moreover, there were no significant interactions among gender, grade and ethnic background in their attempt to detangle this complex relation. Grade level, however, did emerge as a significant influence. In line with Utley's (2007) argument that students develop an attitude toward mathematics from an early age, Ma and Kishor target junior high school (i.e., 7th and 8th grades), as the time that a student's liking or disliking of mathematics begins to stabilize. As a result, achievement in mathematics can be significantly influenced. This suggests that a negative attitude toward mathematics prior to high school can adversely affect a student's performance in any or all subsequent mathematics courses, and therefore be a major factor in the choice of undertaking advanced courses in both high school and college.

Within studies that focus on students' self-perceptions of mathematics, a number of instruments have been employed (e.g., direct observation, interviews, questionnaires) to assess various affective variables as they relate to students' mathematics achievement. These variables include motivation (e.g., Marat, 2005), self-efficacy (e.g., Lopez, Lent, Brown, & Gore, 1997), and attributes for success (House, 2006) to name just a few. What is lacking, however, is a focus on how certain affective variables relate to a *specific* mathematical content area (e.g., “I like geometry.”) because students are likely to vary in both their self-perceptions as well as their performance in one area of math (e.g., algebra) versus another (e.g., geometry). Aside from the development of a few scales, such as the Utley Geometry Attitude Scale (Utley, 2007), which has yet to be tested with school-age students, there seems to be little effort to minimize this gap.

The need to explore a relation between students' self-perceptions and performance in geometry is clear as evidenced in a study (Corbishley & Truxaw, 2010) regarding the mathematical readiness of entering college freshmen. Findings revealed that university faculty members perceive average freshman students as mathematically unprepared, partly in the area of geometry. For instance, mean skill levels were found to be poor to adequate for finding the area of two-dimensional objects and from very poor to poor for three-dimensional analysis — skills that should be mastered at the middle school and high school levels respectively (National Council of Teachers of Mathematics, 2000). It is reasonable to speculate that prior to college, these students, and well likely others, may not have felt particularly strong about mathematics and their mathematical abilities. In corroborations with this view, there is a growing need to nurture students' interest and performance in geometry given the continual lack of preparation in the US for careers that tend to be very much rooted in geometric and spatial-type thinking (Armstrong, 2003; National Science Board, 2009), otherwise known as STEM (science, technology, engineering and mathematics).

1.3. Significance and purpose of the study

The current study draws attention to the significance of spatial ability as it relates to students' self-perceptions of their performance in geometry, a fundamental subject area that is intimately tied to many STEM fields. However, geometry tends to be a weaker content domain among US students (e.g., Gonzales et al., 2009), which may partly explain why the US is lagging with respect to conferred degrees in STEM compared to other countries (Bharucha, 2008; Hughes, 2009). By nurturing students' spatial ability from an early age, it is possible that with extended and deliberate practice (Ericsson et al., 2005), “high-space” individuals may be more apt to capitalize on their intellectual strengths with a greater appreciation for math–science expertise throughout their education (Webb, Lubinski, & Benbow, 2007). This effort lends support toward modifying educational curricula for spatially talented students who can potentially help meet the growing demand of STEM fields in the US.

To date, it seems that researchers have made few attempts to simultaneously investigate both cognitive and affective influences on