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On the relation between math and spatial ability: The case of math anxiety☆

Amanda M. Ferguson [a,*], Erin A. Maloney [b], Jonathan Fugelsang [a], Evan F. Risko [a]

[a] Department of Psychology, University of Waterloo, Canada
[b] Department of Psychology, University of Chicago, USA

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ABSTRACT

Engaging with math can be especially difficult for individuals who experience math anxiety. Interestingly, recent research has demonstrated a negative association between math anxiety and small-scale spatial ability (i.e., mental rotation). The aim of the present study is to better understand this fundamental link between individual differences in math and space in three ways. First, we investigated the relation between math anxiety and self-reported sense-of-direction, a critical index of large-scale spatial ability thought to be distinct from small-scale spatial ability. Next, we investigated the relation between math anxiety and spatial anxiety (i.e., anxiety about environmental navigation). Then, we used behavioral measures of small- and large-scale spatial skills to further explore these abilities as a function of math anxiety. Results demonstrate that individuals high in math anxiety report a worse sense-of-direction, more spatial anxiety and general anxiety, and perform worse on behavioral tests of small- and large-scale spatial skills. Regression analyses suggest that spatial anxiety, general anxiety, and small-scale spatial skill are the most robust of the tested predictors of math anxiety. Implications for understanding math anxiety are discussed.

1. Introduction

Modern economies are becoming increasingly dependent on science, technology, engineering, and mathematics (STEM) fields. As such, understanding the factors that influence participation and success in STEM careers represents a critical goal in educational psychology. One major impediment to entry into a STEM career is math anxiety (Chipman, Krantz, & Silver, 1992), defined as feelings of fear and apprehension regarding mathematics (Richardson & Suinn, 1972). Math anxiety is associated with a host of negative outcomes including lower math grades, decreased enjoyment of math, and avoidance of math (e.g., Hembree, 1990).

Research on math anxiety has typically focused on its effects on math related activities, but recent evidence suggests the possibility that the "deficit" (defined as generally impaired performance) observed in math anxious individuals extends beyond math activities proper (Maloney, Waechter, Risko, & Fugelsang, 2012). Specifically, math anxiety appears to also be negatively related to spatial ability. This potential link with spatial ability is critical theoretically as it suggests the existence of deficits in the basic "building blocks" of mathematics (i.e., spatial ability; Fias & Fischer, 2005), rather than just math-specific tasks. Furthermore, spatial abilities predict STEM success independent of mathematics ability (Wai, Lubinski, & Benbow, 2009), suggesting that individuals with math anxiety might suffer from a more general and ultimately more limiting problem. Thus, a better understanding of the link between math anxiety and spatial abilities is critical. In the present investigation we further explore this link in the context of environmental spatial ability and spatial anxiety (defined as anxiety about environmental navigation).

1.1. Math anxiety

Math anxiety refers generally to negative emotions about mathematics (Ashcraft & Moore, 2009; Richardson & Suinn, 1972). Math anxiety is strongly negatively correlated with math achievement (e.g., Betz, 1978) and this negative association is independent of intelligence (Hembree, 1990). Math anxiety is also positively associated with other types of anxiety (general or trait anxiety, defined as a susceptibility or disposition to experience frequent anxiety; test anxiety; Ashcraft, 2002; Hembree, 1990) and negatively correlated with motivation and self-confidence in math (Ashcraft, 2002). These latter correlations are particularly troubling in light of our societal need to produce more individuals trained in STEM fields (Maloney & Beilock, 2012).

Early research investigating the cognitive aspects of math anxiety suggested that the impairments were specific to math problems that

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* Corresponding author at: Department of Psychology, University of Waterloo, 200 University Ave W, Waterloo, ON, N2L 3G1, Canada.
E-mail address: am2fergu@uwaterloo.ca (A.M. Ferguson).

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were heavily demanding on working memory (Ashcraft & Kirk, 2001). This impairment was attributed to a kind of anxiety-induced working memory deficit (i.e., worries about performance co-opted valuable working memory resources; Ashcraft & Kirk, 2001). For example, Ashcraft and Kirk (2001) demonstrated that math anxiety only impaired performance on math problems that required carrying (i.e., a working memory demanding operation). While this anxiety-induced working memory impairment likely contributes significantly to math anxious individuals performance in math related tasks, recent research has suggested that math anxious individuals' problems might stem from much more basic cognitive deficits. For example, recent research has demonstrated that math anxiety is related to difficulties with basic number skills including counting objects (Maloney, Risko, Ansari, & Fugelsang, 2010) and comparing numbers (Maloney, Ansari, & Fugelsang, 2011). Furthermore, recent research has demonstrated that math anxiety is negatively associated with skills, specifically spatial skills, which have no explicit relation to rudimentary math (e.g., foundational math skills like counting and addition that are the basis of complex mathematical concepts; Maloney et al., 2012).

1.2. The relation between math anxiety and spatial abilities

While it is perhaps not surprising that math anxiety is related to math achievement, spatial processing (which is non-numerical) is also a positive predictor of math achievement (e.g., Gunderson, Ramirez, Beilock, & Levine, 2012; Uttal et al., 2013). This relation is evident across a variety of spatial tasks (Delgado & Prieto, 2004; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Guay & McDaniel, 1977) and emerges early in development (de Hevia & Spelke, 2010; Kyttälä, Aunio, Lehto, van Luit, & Hautamaki, 2003). One explanation for the connection between spatial skill and math ability concerns the development of a mental number line (Dehaene, Bossini, & Giraux, 1993; Gunderson et al., 2012). For example, people tend to associate small numbers with space to their left and large number with space to their right (known as the spatial-numerical association of response codes [SNARC] effect; Dehaene et al., 1993). Importantly, performance on number line tasks has been shown to predict ostensibly non-spatial symbolic calculation ability (Gunderson et al., 2012). This suggests that a weak mental number line may lead to difficult and likely negative experiences with math, which may ultimately lead to math anxiety.

This link between spatial ability and math achievement in conjunction with the often-reported association between spatial ability and gender (e.g., Linn & Peterson, 1986), and math anxiety and gender (Hembree, 1990), led Maloney et al. (2012) to explore the possibility that math anxiety might be related to poor spatial processing. Consistent with this idea, across two independent samples, they found a strong negative correlation between the spatial scale of the Object Spatial Imagery Questionnaire (OSIQ; Blajenkova, Kozhevnikov, & Motes, 2006) and math anxiety. This correlation is particularly interesting theoretically given there is no math related content on the spatial scale of the OSIQ.

Spatial ability has long been argued to be composed of separable component skills or categories of spatial skills, though the nature of these components is a matter of some theoretical debate (e.g., Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Linn & Peterson, 1985; Uttal et al., 2013). In a recent investigation, Hegarty et al. (2006) argued for at least a partial dissociation between small-scale spatial abilities (such as those requiring mental transformation or manipulation of shapes or objects) indexed by, for example, mental rotation tasks, and large-scale spatial abilities (such as those requiring physical navigation through space) as indexed by, for example, learning the layout of a new environment. This distinction is similar to the distinction between intrinsic and extrinsic spatial skills recently proposed by Uttal et al. (2013), wherein intrinsic skills are those that require consideration of a single object and extrinsic skills are those that require consideration of relations among a group of objects. Critically, the spatial scale of the OSIQ, which Maloney et al. (2012) demonstrated was related to math anxiety, arguably cuts across both of these dimensions. As a result it is unclear whether the putative spatial deficit in math anxiety should be considered “general” (i.e., applies to both small- and large-scale spatial skills) or “specific” (i.e., particular to either small- or large-scale spatial skills, but not both). Thus, in order to move toward a more comprehensive theory of the relation between spatial abilities and math anxiety, we need to assess the relation between specific types of spatial skills and math anxiety.

In a series of recent studies, Maloney (2011) assessed the relation between math anxiety and mental rotation ability using the Vandenberg Mental Rotation Test (Vandenberg & Kruse, 1978). This paper-and-pencil task represents a model small-scale spatial task. Critically, across a number of experiments, Maloney found that high math anxious individuals performed worse on the paper-and-pencil mental rotation test than their low math anxious peers. Like the OSIQ, this demonstration is surprising given that the Vandenberg Mental Rotation Test, on its face, has no explicit tie to numbers or rudimentary math. With respect to the relation between math anxiety and component spatial skills, this research demonstrates that math anxiety is negatively associated with (at least) what Hegarty et al. (2006) would refer to as small-scale spatial skill. However, to our knowledge there is no research investigating the relation between math anxiety and large-scale spatial skill. Thus, in the present investigation we further explore the spatial impairment in math anxious individuals by assessing the relation between (1) math anxiety and self-reported sense-of-direction (i.e., perceived large-scale spatial ability; Study 1), (2) math anxiety and spatial anxiety (i.e., anxiety about environmental navigation, a large-scale spatial ability; Study 2), and (3) math anxiety and actual small- and large-scale spatial ability (i.e., as indexed by behavioral tests of spatial skill; Study 3 and 4).

2. Study 1: Sense-of-direction and math anxiety

In order to explore the relation between large-scale spatial abilities and math anxiety, we assessed the relation between responses on the Abbreviated Math Anxiety Scale (AMAS; Hopko, Mahadevan, Bare, & Hunt, 2003) and the Santa Barbara Sense of Direction Scale (SBSODS; Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). Critically, individual differences in sense-of-direction, as measured by the SBSODS, are unrelated to performance on the Vandenberg Mental Rotation Test (Hegarty et al., 2002, 2006). Thus, according to Hegarty et al. (2006) “Self-report sense-of-direction is therefore largely independent of small-scale spatial ability and appears to reflect an ability to update one's location in a space as a result of self-motion.” (p. 157).

The dissociation described by Hegarty et al. (2006) provides a unique theoretical opportunity. Given the lack of any correlation between mental rotation ability and sense-of-direction, the presence of a negative correlation between math anxiety and sense-of-direction would suggest that individuals with math anxiety may suffer from a general problem in spatial ability (i.e., one that extends across both small- and large-scale spatial abilities).

On the other hand, a lack of a correlation between math anxiety and sense-of-direction would suggest that individuals with math anxiety may suffer from a specific problem in small-scale spatial ability. An answer to this question will have both theoretical and practical implications in that it will afford both a deeper understanding of the spatial deficit in math anxiety and guidance on remediation of spatial skill in this population (e.g., should training be targeted to one particular type of spatial skill or to spatial skills in general?).

2.1. Method

2.1.1. Participants and procedure

Two thousand two hundred and fifteen undergraduate students from the University of Waterloo completed each measure as part of a large battery administered online to a number of large psychology