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Are there sex differences in confidence and metacognitive monitoring accuracy for everyday, academic, and psychometrically measured spatial ability?[☆]

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ABSTRACT

The current study evaluated sex differences in (1) self-perceptions of everyday and academic spatial ability, and (2) metacognitive monitoring accuracy for measures of spatial visualization and spatial orientation. Undergraduate students completed the Paper Folding Test, Spatial Relations Test, and the Revised Purdue Spatial Visualization Test while making confidence judgments (CJs) for each trial. They also made global estimates of performance and rated their ability to perform several everyday and academic spatial scenarios. Across multiple spatial measures, female students displayed lower confidence in their item-level monitoring and global assessments of performance than did male students, even when no actual differences in spatial performance occurred. Women were also less confident in their self-assessments of their visual-spatial ability for scientific domains than were men. However, the absolute and relative accuracy of CJs did not differ as a function of sex suggesting that women can monitor their spatial performance as well as men.

1. Introduction

Spatial cognition is a multifaceted construct encompassing the mental operations involved in visualizing, remembering, manipulating, and reasoning about the location and orientation of objects and places (Carroll, 1993; Hegarty & Waller, 2005; Michael, Guilford, Fruchter, & Zimmerman, 1957). It is utilized in many everyday tasks such as remembering the location of your house keys, packing a suit case, assembling objects like furniture, and navigating to both familiar and unfamiliar locations. Spatial cognitive processing even facilitates learning and reasoning in science, technology, engineering, and mathematics domains (STEM), presumably because conceptual information in these domains requires one to think and reason spatially about important domain relevant information (Burnett, Lane, & Dratt, 1979; Kozhevnikov, Motes, & Hegarty, 2007; Newcombe, 2016; Orion, Ben-Chaim, & Kali, 1997; Pribyl & Bodner, 1987; Sanchez & Wiley, 2014; Uttal & Cohen, 2012; van Garderen, 2006; Wai, Lubinski, & Benbow, 2009). For example, identifying chirality in stereochemistry involves visualizing the mirror image of a molecule and mentally rotating it until it aligns on itself (see Uttal & Cohen, 2012). Understanding and applying Newton's first law in physics involves knowing how an object's speed and trajectory are impacted by other forces. Even understanding the biological structure of animal cells such as how the sodium potassium pump functions is an inherently spatial concept because it focuses on the movement and location of sodium and potassium ions in relation to the plasma membrane of cells.

Given the critical importance of spatial cognition for both every day and academic domains, people need to be able to accurately monitor their spatial cognitive performance. Inaccurate monitoring of one's spatial abilities could have several negative implications. One implication is that students who are underconfident in their spatial ability may choose not to use spatial strategies during learning. They may even be reluctant to pursue coursework or careers that require routine spatial thinking (e.g, STEM fields). This may be especially true for female students because (a) they believe they have lower spatial ability than male students (for a review, see Syzmanowicz & Furnham, 2011) and

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they are more likely to experience anxiety when engaging in spatial processing (Maloney, Waechter, Risko, & Fugelsang, 2012). Thus, identifying whether sex differences are present in metacognitive monitoring accuracy and how to improve monitoring accuracy in spatial domains could have important applied implications. The current study examined potential sex differences in metacognitive monitoring of spatial cognition in everyday, academic, and traditional psychometric measures of spatial cognition.

Extensive research has focused on understanding when and why sex differences are observed in spatial cognition (Halpern & Collaer, 2005; Maeda & Yoon, 2013; Voyer, Postma, Brake, & Imperato-McGinley, 2007; Voyer, Voyer, & Bryden, 1995; Voyer, Voyer, & Saint-Aubin, 2017). Substantial sex differences in performance favoring males over females are present for many measures of spatial processing (Halpern & Collaer, 2005). Males typically outperform female students on measures of visual spatial working memory, navigation, spatial orientation (e.g., mental rotation), and spatial visualization (one's ability to mentally transform objects into new forms). However, sex differences are not present for spatial tasks that focus on long-term object location memory. Women often outperform men on many episodic memory tasks; especially verbal memory tasks (Herlitz, Nilsson, & Bäckman, 1997; Herlitz & Rehnman, 2008).

Despite this large body of research examining sex differences in spatial cognitive performance, few experiments have focused on potential sex differences in metacognitive monitoring accuracy in spatial domains (e.g., Cooke-Simpson & Voyer, 2007; Estes & Felker, 2012). The available evidence suggests that female students may be less accurate at evaluating their spatial performance than male students. However, this evidence is based primarily on monitoring accuracy of confidence judgments for item responses on the Vandenberg and Kuse (1978) mental rotation test (Cooke-Simpson & Voyer, 2007). Sex differences in item-level monitoring accuracy have not been evaluated for any other spatial task. There is extensive research on sex differences in global self-assessments of spatial ability (for review, see Syzmanowicz & Furnham, 2011) and a few studies have evaluated age differences in monitoring accuracy for visual spatial working memory (Ariel & Moffat, 2018; Thomas, Bonura, Taylor, & Brunyé, 2012) and tasks measuring spatial visualization (e.g. Paper Folding Test), spatial orientation (mental rogation), and spatial navigation (Ariel & Moffat, 2018). The remaining research examining spatial performance monitoring has focused on monitoring accuracy for spatial judgments about length (Schraw, Dunkle, Bendixen, & Roedel, 1995) and spatial reasoning on the Raven's Progressive Matrices Test (Mitchum & Kelley, 2010; Schraw & Nietfeld, 1998) without considering potential individual differences.

Only a few studies have explored whether there are sex differences in metacognitive monitoring accuracy in non-spatial domains (Hertzog, Dixon, & Hultsch, 1990; Lichtenstein & Fischhoff, 1981; Lundeberg, Fox, & Punćcohań, 1994). Lichtenstein and Fischhoff (1981) evaluated sex differences in monitoring memory for general knowledge questions and found no evidence for sex differences in monitoring ability. Hertzog et al. (1990) examined sex and age differences in monitoring memory for categorized lists and narrative text recall. Women were more underconfident in their memory for categorized lists than were men but women were more accurate than men at monitoring their narrative text recall. Finally, Lundeberg et al. (1994) examined sex differences in memory for content from an undergraduate psychology research methods course. Male students were more overconfident in their memory for incorrect information than female students. Taken together, the limited available evidence suggests that sex differences may be present in some domains (memory for categorical lists, narrative text recall) and not others (general knowledge), and there does not appear to be clear evidence for a general male or female advantage in monitoring ability.

The limited research examining sex differences in monitoring spatial cognition is especially surprising because sex differences in spatial cognitive performance have been indirectly linked to metacognitive variables. For example, female students are more likely than male students to withhold low confidence responses that are accurate on the mental rotation test which contributes to observed sex differences in performance (Cooke-Simpson & Voyer, 2007). They also adopt different strategies than male students to solve spatial problems (Allen & Hogeland, 1978; Goldstein, Haldane, & Mitchell, 1990; Kail, Carter, & Pellegrino, 1979; Lohman, 1986; Miller & Santoni, 1986; Peña, Contreras, Shih, & Santacreu, 2008; Prinzel & Freeman, 1995; Raabe, Höger, & Delius, 2006; Tapley & Bryden, 1977). During mental rotation, males are more likely to use a holistic strategy that involves mentally rotating an entire object, whereas female students are more likely to use an analytic strategy that involves mentally rotating smaller pieces of an object and comparing each piece to components of potential response options (Raabe et al., 2006). These differences in strategy preference may be due to differences in the accuracy of monitoring strategy effectiveness.

Sex differences in spatial strategy use could also cause sex differences in item-level monitoring accuracy. Metacognitive monitoring is an inferential process that involves evaluating cues (e.g. item characteristics, processing fluency, etc.) that are present at the time of a monitoring judgment and applying beliefs or heuristics to infer the quality of these processes (Dunlosky & Tauber, 2014; Koriat, 1997; Schwartz, Benjamin, & Bjork, 1997). Different strategies can afford access to different cues during monitoring that vary in diagnosticity (Mitchum & Kelley, 2010). In spatial domains, holistic spatial strategy use may afford access to cues associated with generating and manipulating spatial representations for items (e.g., processing fluency, vividness of imagery, etc.) that would not be present when people use non-holistic analytical strategies. Thus, one mechanism that could produce sex differences in monitoring accuracy is differences in cue utilization caused by sex differences in strategy preferences.

Metacognitive monitoring accuracy is typically evaluated by comparing performance accuracy on multiple trials of a target task to metacognitive judgments of performance on those trials (e.g, confidence judgments). Absolute accuracy (also referred to as calibration) refers to whether the average magnitude of an individual's judgments corresponds to their overall level of performance. Relative accuracy refers to one's ability to discriminate between correct and incorrect spatial task decisions (i.e., manifest higher confidence for correct than for incorrect item responses). In the current experiment, we compared sex differences for both absolute and relative accuracy on measures of spatial orientation and spatial visualization.

In addition to examining monitoring accuracy in spatial visualization and spatial orientation tasks, we also included measures of visual spatial working memory (Symmetry Span, Oswald, McAbee, Redick, & Hambrick, 2015) which typically favor male students over female students (for a review, see Voyer et al., 2017) and general fluid intelligence (Raven's Progressive Matrices; Raven, Raven, & Court, 1998) which sometimes produce small sex differences also favoring males (Irwing & Lynn, 2005; Lynn & Irwing, 2004). Most important, we also examined sex differences in students' subjective assessments of their performance ability and experience in several contexts using a modified version of Salthouse and Mitchell's (1990) Spatial Experience Questionnaire. The Spatial Experience Questionnaire presents participants with spatial scenarios that one might encounter in their daily life (e.g., imagining different arrangements of furniture, visualizing travel directions, considering how a building would look from a different vantage point) and prompts them to rate their general ability, recent experience, and cumulative experience performing the specified spatial task. We modified it by adding four additional items to examine STEM related spatial thinking (e.g., visualizing mathematical relationships, micro-level concepts in biology or chemistry, concepts in physics, and locations/direction in anatomy). These new questions allowed us to contrast potential sex differences in perceptions of everyday spatial ability and academic spatial ability.

Students who are proficient in reasoning spatially during routine