Chapter 12
The Use of Eye-Tracking in Spatial Thinking Research

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ABSTRACT

This chapter highlights the benefits of eye-tracking technology in spatial thinking research, specifically in the study of complex cognitive processes used to solve spatial tasks including cognitive strategy selection, cognitive strategy flexibility and spatial language processing. The consistent sex differences found in spatial thinking research (i.e., mental rotation), with males outperforming females, is concerning given the link between spatial ability and success in the STEM fields. Traditional methods like self-reports, checklists and response times methods may not be sufficient to study complex cognitive processes. Advances in eye-tracking technology make it possible to efficiently record and analyze voluminous eye-gaze data as an indirect measure of underlying cognitive processes involved in solving spatial tasks. A better understanding of the cognitive processes underlying spatial thinking will facilitate the design of effective training and educational pedagogy that encourages spatial thinking across both males and females.

INTRODUCTION

Spatial thinking is an overarching cognitive construct composed of several distinct skills including, but not limited to, retaining and transforming mental images, navigating and way-finding, and reading maps, graphs and diagrams. Spatial thinking is present in varying degrees in many everyday tasks like assembling and rearranging furniture, backing out of a driveway, navigating an unfamiliar route, and even playing organized sports like basketball. Recent research on spatial thinking suggests that it predicts success in scientific domains like Physics, Chemistry, Geology and Mathematics, domains that are typi-

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cally classified as Science, Technology, Engineering, and Mathematics disciplines (STEM; e.g., Casey, Nuttall, & Pezaris, 1997; Coleman & Gotch, 1998; Kozhevnikov, Motes, & Hegarty, 2010; Lubinski, 2010; Wai, Lubinski, & Benbow, 2009). For example, performance on a mental rotation task, where individuals are usually asked to determine whether two figures that are either rotations or mirror images of each other match or do not match, is significantly correlated with anatomy examination performance (Guillot, Champely, Batier, Thiriet, & Collet, 2007; Hoyek et al., 2009). Research using mental rotation tasks sheds light on the complex cognitive processes involved in mental representation and in spatial thinking (Pylyshyn, 2003; Shepard & Metzler, 1971). Importantly, mental rotation research provides insight into inter-individual differences in cognitive strategy selection; that is, whether individuals adapt their cognitive strategy use, using several cognitive strategies to solve the task when item complexity changes (Khooshabeh, Hegarty & Shipley, 2012). Adaptive spatial thinking, sometimes referred to as spatial intelligence, has received national attention in the United States in recent years with a call for including spatial thinking in school curriculum (Hegarty, 2010; National Research Council, 2006).

In light of the importance of spatial thinking to success in the STEM disciplines, it is of concern that spatial thinking research consistently shows sex differences, with males outperforming females on mental rotation tasks (e.g., Linn & Petersen, 1985; Nazareth, Herrera, & Pruden, 2013; Newcombe, Bandura, & Taylor, 1983; Peters et al., 1995; Voyer, Voyer, & Bryden, 1995; Wittig & Petersen, 1979). These sex differences are attributed to a number of factors including biological/hormonal factors (Gaulin, 1992; Halari et al., 2005), social/experiential factors (Baenninger & Newcombe, 1989; 1995; Nash, 1975; Nazareth et al., 2013; Wraga, Helt, Jacobs, & Sullivan, 2007), cognitive factors (Khooshabeh, Hegarty, & Shipley, 2012; Quaiser-Pohl, Rohe, & Amberger, 2010) and linguistic factors (Cartmill, Pruden, Levine & Goldin-Meadow, 2010; Pruden & Levine, 2015; Pruden, Levine, & Huttenlocher, 2011). There is now a growing body of evidence to support that spatial thinking is malleable (Uttal et al., 2013). Studies show that with training and instruction performance on spatial tasks, such as a mental rotation task, can be improved (Hoppe et al., 2012; Miller & Halpern, 2013; Sander, Quaiser-Pohl, & Stigler, 2010; Spence, Yu, Feng, & Marshman, 2009; Wright, Thompson, Ganis, Newcombe, & Kosslyn, 2008). Furthermore, early exposure to spatial experiences through video gaming (i.e., tetris; Terlecki & Newcombe, 2005) and spatial activity experience (Baenninger & Newcombe, 1989; Nazareth et al., 2013; Signorella, Krupa, Jamison, & Lyons, 1986; Terlecki, Newcombe, & Little, 2008) contributes to the malleability and development of spatial thinking. While we are fairly certain about the malleability of spatial thinking, there are still questions about the development of spatial thinking that remain unanswered. What is the underlying *cognitive mechanism* that develops as a consequence of spatial training and spatial activity experience that results in individual and sex differences in performance? One might argue that exposure to spatial content through training or spatial activities results in altering an individual's preferential or habitual manner of processing spatial information (i.e., the individual's *cognitive strategy* selected to solve spatial problems). The underlying complex cognitive processes involved in selection of different cognitive strategies to solve spatial tasks are not fully understood. Eye-tracking technology provides an indirect measure of the cognitive processes involved in cognitive strategy selection that not only complements traditional methods of data collection but also allows for the examination of individual and sex differences in cognitive strategy flexibility, a little-studied aspect of cognitive strategy selection.

In addition to spatial activity experience, another important contributor to the development of spatial thinking and a potential mediator of sex differences in spatial thinking is spatial language. Spatial language consists of words that describe both *where* an animate or inanimate entity or space is located (i.e., location, direction and orientation terms; e.g., near, far, between, upside-down, vertical, flip, rotate),