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Sex differences in mental rotation and spatial rotation in a virtual environment

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Abstract

The visuospatial ability referred to as mental rotation has been shown to produce one of the largest and most consistent sex differences, in favor of males, in the cognitive literature. The current study utilizes both a paper-and-pencil version of the mental rotations test (MRT) and a virtual environment for investigating rotational ability among 44 adult subjects. Results replicate sex differences traditionally seen on paper-and-pencil measures, while no sex effects were observed in the virtual environment. These findings are discussed in terms of task demands and motor involvement. Sex differences were also seen in the patterns of correlations between rotation tasks and other neuropsychological measures. Current results suggest men may rely more on left hemisphere processing than women when engaged in rotational tasks.

Keywords: Virtual reality; Cognition; Neuropsychological assessment; Gender differences; Mental rotation task; Neuropsychology

1. Introduction

The ability to mentally rotate an object has been found to produce one of the largest sex differences in the cognitive literature (Linn & Petersen, 1985). In the first studies of mental rotation, Shepard and Metzler (1971) reported a near perfect linear relationship between the reaction time to decide if two drawn objects were the same or different, and the degree of rotational difference between the objects. Using block drawings based on Shepard and Metzler's work, Vandenberg and Kuse (1978) created the mental rotations test (MRT). This test uses line drawings of block stimuli and consists of two 10-item sections in which the subject is required to match two of the four choices to a target figure.

Voyer, Voyer, & Bryden's (1995) meta-analysis of sex differences in spatial abilities, found that the average difference (using Cohen's $d = (M_1 - M_2)/\sigma$) between men and women on the (MRT; Vandenberg & Kuse, 1978), was 0.94 (this represents a very large effect), indicating that men perform nearly one standard deviation above the average performance of women.

A number of explanations have been advanced for the existence of the gender difference in mental rotation. One line of research considers environmental and socio-cultural explanations for sex differences in mental rotation (Sharps, Welton, & Price, 1993). It has been argued that Western cultures perceive spatial tasks as masculine in nature, and that differences in spatial ability might be minimized by engendering the perception that spatial tasks are appropriate for female participants as well as male participants (Lunneborg, 1984; Richardson, 1994; Subrainmanyam & Greenfield, 1994). A second type of explanation for MRT sex differences has emphasized the role of performance factors—task variables that might spuriously inflate the male performance advantage in mental rotation (Goldstein, Haldane, & Mitchell, 1990; Stumpf, 1993). Potential performance factors explored in the literature include task difficulty, previous task exposure, time limits, and weighted scoring systems (Stumpf, 1993; Collins & Kimura, 1997).

Task difficulty is one potential performance factor that has been explored (Bryden, George, & Inch, 1990; Collins & Kimura, 1997). Prinzel and Freeman (1995) found that females demonstrated a speed-accuracy tradeoff as the difficulty of the spatial task increased from 90 to 180°. Increasing the difficulty of the task resulted in a greater gender

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difference when conventional scoring procedures were used. Collins and Kimura studied the role of task complexity in mental rotation by designing a two-dimensional rotation task. They found support for the effects of task difficulty as their more difficult two-dimensional rotations produced a male advantage as large as that seen on the MRT. There is, however, no consensus as to the role of task complexity on gender differences in mental rotation. Bryden, George, and Inch manipulated complexity in several ways, and found that while women consistently showed slower rotation performance, rate of mental rotation did not relate to figural complexity.

Biological factors have also been discussed as potential causes for this difference. Biological theories stress the importance of genetics, hormonal influence, brain organization, and maturational factors. Biological explorations of the factors involved in mental rotation include studies of cerebral involvement. Brain imaging studies often suggest mental rotation involves activation of parietal regions (Bonda, Petrides, Frey & Evans, 1995). Alivisatos and Petrides (1997) looked at regional cerebral blood flow with positron emission tomography while young male subjects were performing a mental rotation task. Their findings indicated specific activity within the left inferior parietal region and the right head of the caudate nucleus. Another study utilized time-resolved functional magnetic resonance imaging (fMRI) to investigate brain activity during mental rotation in five female subjects (Richter, Ugurbil, Georgopoulos, & Kim, 1997). Results suggested activation throughout the parietal lobe during the entire period of mental rotation.

When brain imaging studies are done on subjects performing mental rotation tasks, there is some evidence of activation in motor areas of the brain. Cohen et al. (1996) conducted fMRI in 8 subjects and found increased activation in the parietal lobe, but also the middle frontal gyrus and the premotor cortex. Their results suggest that mental rotation engages cortical areas not only involved in direct perception, but brain areas involved in tracking objects in motion and encoding spatial relations. In other words, when their subjects performed a mental rotation task of a non-moving stimulus, they engaged a region of the brain usually associated with processing objects in motion. Kosslyn, Digirolamo, Thompson, & Alpert (1998) monitored cerebral blood flow with positron emission tomography and found the expected increase in parietal region for mental rotation of both blocks and drawings of hands. But they were also able to demonstrate activation of motor areas while subjects mentally rotated the drawings of hands. They suggest this might indicate two different mechanisms used in mental rotation, one that involves areas that prepare motor movements and another that does not.

The distinct hormonal environments of men and women may play a role. For example, cognitive performance differences do not emerge between boys and girls until early adolescence, which is consistent with hormonal theories (Voyer et al., 1995; Maccoby & Jacklin, 1974), although it is possible that gender differences simply increase as a function of biological development. Further support for a constant and uniform biological explanation comes from studies that find similar effect sizes for gender across cultures (Silverman, Phillips, & Silverman, 1996).

The functional organization of the brain may also play a role in gender differences. The timing of hormonal effects on cognitive functioning remains unclear. One possibility may be that prenatal exposure to sex hormones has an organizing effect on the developing brain (Grimshaw, Sitarenios, & Finegan, 1995). It is commonly accepted that the human brain is functionally asymmetrical, with the left hemisphere supporting verbal functions, and the right hemisphere supporting nonverbal functions, including spatial ability (Bryden, 1982; Kolb & Whishaw, 1996). Some studies, however, suggest that women have a greater degree of bilateral processing for spatial tasks (Harris, 1978; McGlone, 1980; Howard, Fenwick, Brown, & Norton, 1992; Turkheimer & Farace, 1992), perhaps using left hemisphere processing to solve both verbal and nonverbal tasks. Men, on the other hand, may have more specialized hemispheric lateralization (Inglis & Lawson, 1982). Mental rotation certainly involves spatial ability, and it has often been shown to be a task dependent on the right hemisphere (Jones & Anunza, 1982; Ditunno & Mann, 1990). The lateralization theories would then suggest that men solve such tasks using mainly right hemisphere processing, whereas women employ a more bilateral approach using the left hemisphere as well. Indeed, it has often been suggested that women's performance deficits on spatial tasks, such at the MRT, may be a result of using a slower verbal strategy to solve spatial problems and encode spatial displays (Vandenberg & Kuse, 1978; Kolb & Whishaw, 1996).

Another possibility is that hormones have an activating effect on cognitive functioning in adulthood (Janowsky, Oviatt, & Orwoll, 1994). Van Goozen et al. (1994, 1995) report that exposure to androgens in adulthood dramatically affects both verbal and spatial ability in adults undergoing sex-reassignment surgery. Research suggests that adult estrogen levels may also relate to mental rotation and spatial ability in both men and women (Silverman et al., 1995; Silverman & Phillips, 1993; Hampson, 1990).

1.1. Virtual reality (VR) assessment

Understanding the extent to which biological and performance factors underlie sex difference in mental rotation has proven to be a difficult task. However, emerging technologies, such as computer generated virtual reality (VR), may assist researchers in getting more reliable, valid, and precise information about cognitive processes involved in mental rotation.

Virtual reality has been defined as an advanced computer interface that allows humans to become immersed within a computer-generated simulated environment (Rizzo et al., 1998). Potential VR use in assessment and rehabilitation of