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Suitable stimuli to obtain (no) gender differences in the speed of cognitive processes involved in mental rotation ☆

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Abstract

Gender differences in speed of perceptual comparison, of picture-plane mental rotation, and in switching costs between trials that do and do not require mental rotation, were investigated as a function of stimulus material with a total sample size of $N = 360$. Alphanumeric characters, PMA symbols, animal drawings, polygons and 3D cube figures were used with an otherwise completely equivalent experimental design in which age and speed-based IQ were comparable across male and female groups. Small gender-related differences in speed of perceptual comparison were found with the magnitude as well as the direction depending upon the stimulus material. Polygons were the only material that produced substantial and reliable gender differences in mental rotation speed, and additionally revealed gender differences in switching costs. Thus, whereas gender differences in paper–pencil mental rotation tests constitute an empirical reality, the generalization that men outperform women in the speed of mental rotation was not supported in the present experiment.

Keywords: Mental rotation; Spatial cognition; Gender differences; Perceptual comparison; Maintaining readiness; Switching costs

1. Introduction

The cognitive process of imagining an object turning around is called mental rotation (Shepard and Metzler, 1971) and constitutes one important operation in the general class of mental transformations as well as a critical ingredient in spatial intelligence. Thanks to the many research areas dealing with mental rotation, a body of evidence has accumulated. Mental rotation seems to be a cognitive process implemented in the parietal cortex (e.g., Jordan, Heinze, Lutz, Kanowski, and Jäncke, 2001) and involves what Shepard and Chipman (1970) refer to as a "second order isomorphism" between the physics of real rotation and imagined rotation. In particular, rotations are continuous (e.g., Heil, Bajric, Rösler, and Hennighausen, 1997) and proceed through intermediate angles (Cooper, 1976).

Many authors claim, based on existing evidence that whereas females outperform males on e.g., measures of verbal fluency, males outperform females on certain tests of spatial ability (e.g., Halpern, 1992; Petrusic, Varro, and Jamieson, 1978). This male advantage is largest on mental rotation tasks (Linn and Petersen, 1985; Voyer, Voyer, and Bryden, 1995), where gender effects were usually investigated on the basis of paper–pencil tests. With the Vandenberg–Kuse Mental Rotation Test (MRT, Vandenberg and Kuse, 1978) that uses Shepard–Metzler 3D cube figures, the gender differences amount to one standard deviation (see, e.g., Voyer et al., 1995). The 2D Card Rotation Test (CRT, Ekstrom, French, and Harman, 1976), however, yielded a substantially smaller effect-size of 0.3, indicating the importance of the stimulus material used. Nevertheless, neither the underlying causes (e.g., Voyer et al., 1995) of

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nor even the performance mechanisms (e.g., Peters, 2005) responsible for this large effect-size are understood. In particular, it is still unclear whether the male advantage on mental rotation is caused by a speed superiority in the pure process of mentally rotating a stimulus, and if so, whether this superiority is dependent upon the type of stimuli to be mentally rotated or not.

Therefore, in the present paper we decompose the mental rotation task into information processing components to determine whether or not their durations are affected by gender. Therefore, the speed of three different components of information processing (a full description follows later) were investigated in detail: *Perceptual comparison* (i.e., the time to compare visual stimuli in a context where mental rotation is never required), *rotational uncertainty* (the cost of being in a context where some trials require mental rotation but where on the given trial no mental rotation is needed, see Ilan and Miller, 1994; Jansen-Osmann and Heil, 2006, in press) and *mental rotation speed* itself (i.e., the speed to mentally rotate a stimulus, expressed as °/s). Moreover, given that a wealth of evidence demonstrates that differences in stimulus materials can greatly affect the size (or even the sheer existence) of gender differences in mental rotation (see, e.g., Collins and Kimura, 1997), 5 different types of stimulus material were used for rotation in the picture plane: Alphanumeric characters, PMA symbols (Thurstone, 1958), animal drawings, polygons, and Shepard–Metzler 3D cube figures with otherwise completely equivalent experimental design.

1.1. Gender differences in paper–pencil mental rotation tests

The most common paper–pencil measure of mental rotation function is the Vandenberg and Kuse (1978; see Peters, Laeng, Latham, Jackson, Zaiyouna & Richardson, 1995) MRT, which uses depictions of 3-D cube figures designed by Shepard and Metzler (1971) that mentally are to be rotated in depth. The speed test consists of 24 items, and each item consists of a row of 1 standard cube figure and 4 comparison ones. Two comparison figures are correct matches rotated in depth; the remaining 2 are incorrect matches. Men typically outperform women on this task by as much as one standard deviation (Linn and Petersen, 1985; Voyer et al., 1995).

While the existence of the gender differences in the MRT is of no doubt, the causes and even the mechanisms responsible for differences in test performance are less well understood. Two broad classes of explanations are the "psycho-social" variety and the "biological-neuronal" variety. Examples of the "psycho-social" variety are stereotype threat (e.g., Shih, Pittinsky, and Ambady, 1999), sex role identification (e.g., Signorella and Jamison, 1986), or differential experience and socialization (e.g., Baenninger and Newcombe, 1989). Examples of the "biological-neuronal" variety are rate of maturation (Sanders and Soares, 1986), genetic complement (McGee, 1982), sex hormone level (e.g., Imperato-McGinley, Pichardo, Gautier, Voyer, and Bryden, 1991) and cerebral lateralization (e.g., McGlone, 1980).

Without doubt, the determination of the root causes for any gender effects observed is a challenging endeavor, and will require further research to uncover. Unfortunately, however, the performance mechanisms that yield the gender differences are also not understood yet (see, e.g., Voyer and Saunders, 2004). Goldstein, Haldane, and Mitchell (1990) reported findings that the gender difference on the MRT disappears when subjects were allowed sufficient time to attempt all items or when the scoring procedure controlled for the number of items attempted. In contrast to Goldstein et al., and in line with the majority of the published data (see, e.g., Delgado and Prieto, 1996; Resnick, 1993), Masters (1998) showed that the gender difference was not affected by performance factors, neither by the scoring method nor by the time limits used, a result which was also obtained by Peters (2005). Peters (2005) obtained evidence that although females attempted fewer items than males under standard timing condition, the magnitude of the gender difference did not change when subjects did the MRT with double the usual time allowed for the test. To sum up, the cognitive mechanisms that yield the gender differences are not understood yet.

Empirical evidence suggests that the dimensionality of the task (depth rotation versus picture plane rotation and 3D versus 2D objects) is not crucial with respect to the size of the male advantage (Collins and Kimura, 1997). Studies have failed to converge, however, on an unambiguous conclusion whether or not the magnitude of the gender difference may be a function of the difficulty of the test (with "difficulty" defined either as overall error rate or mean RT). The male advantage for the Spatial Relations subtest of the Primary Mental Abilities Battery (PMA; Thurstone, 1958), depicting picture plane rotations of 2D objects, is, on average, less than one half of that of the MRT (Voyer et al., 1995). Collins and Kimura (1997), however, introduced a test depicting picture plane rotations of 2D objects (some of them were PMA symbols) with different levels of task difficulty within this test. A male advantage (at least) as large as that seen on the MRT was found for the difficult version while for the easy version the male advantage missed significance. These data suggest that neither depth rotations nor 3-D objects are required to elicit substantial gender differences in mental rotation, but that the difficulty of the task might be crucial. Peters et al. (1995), however, compared the standard MRT with a very difficult version which required subjects to rotate the cube figures around two axes. Overall, performance on this more difficult version was about 30% lower than on the MRT, and gender differences were reduced by half compared to the MRT. This suggests that the magnitude of the gender difference might be a function of test difficulty for picture plane rotations only but not so for depth rotations, but more data are definitely needed.