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Gender differences in pre-adolescents' mental-rotation performance: Do they depend on grade and stimulus type?

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ABSTRACT

In psychometric mental-rotation tasks, adult male participants usually outperform females. A large body of evidence suggests that this effect is reliable, quite stable over lifespan and one of the largest cognitive gender differences. However, there are controversial findings regarding the age in which the male advantage emerges. The present study aimed at contributing to a systematic developmental research of mental rotation by examining two grades and three stimulus types in order to determine how these variables influence the gender difference. Second and fourth graders ($n = 432$) were tested with a paper–pencil mental-rotation task in three stimulus conditions (animal pictures, letters, cube figures). Whereas fourth graders showed a small, but significant, stimulus-independent gender difference favoring males, there was no effect of gender on the mental-rotation performance of second graders. Fourth-grade *boys* performed better than second-grade boys in all stimulus conditions. Fourth-grade *girls*, in contrast, outperformed second-grade girls in the animal pictures condition and the letters condition, but not in the cube-figures condition. Results are discussed with regard to implications for causal mechanisms underlying the gender difference in mental rotation.

1. Introduction

Mental rotation, the ability to rotate two- or three-dimensional objects in mind (Shepard & Metzler, 1971), has been intensively investigated in different fields of psychology. One of the most consistent findings is a gender difference favoring male participants (Linn & Petersen, 1985; Maccoby & Jacklin, 1974; Masters & Sanders, 1993; McGee, 1979; Voyer, Voyer, & Bryden, 1995). The existence of the male advantage in psychometric mental-rotation tasks is well documented in adults, but there are controversial findings about the age in which this gender difference emerges. This question is of considerable interest, as an answer could shed some light on the causal mechanisms underlying the greatest documented cognitive gender difference (Linn & Petersen, 1985).

At least three hypotheses concerning the first occurrence of the gender difference in mental rotation can be distinguished: Maccoby and Jacklin (1974) assumed puberty to be the crucial time period for the male advantage to emerge. They reviewed studies showing a male advantage in adolescents and adults, but not during childhood. However, a number of studies contradict the adolescence-hypothesis. After summarizing 172 articles about sex differences in spatial abilities, Linn and Petersen (1985) conclude that "males tend to outperform females on mental rotation at any age where measurement is possible" (Linn & Petersen, 1985, p. 1489). This statement is based on a meta-analysis of studies with participants between 10 and 60 years. Since children below the age of 10 were not examined in the analyzed studies, the assumption made by Linn and Petersen (1985) might be a false conclusion from research with older children. Several studies using simplified versions of adult mental-rotation tasks show that it is possible to measure rotation skills below age 10 (e.g. Foulkes & Hollifield, 1989; Marmor, 1975). Some of these studies support the assumption of a male advantage from early childhood or even from birth onwards: Levine, Huttenlocher, Taylor, and Langrock (1999), for example, report a gender difference favoring male participants in four-year-old preschoolers. Using a habituation paradigm, Quinn and Liben (2008) found a male superiority in infants' mental-rotation ability. Furthermore, gender differences in the functional cerebral asymmetry of preschoolers solving mental rotation tasks have been reported (Hahn, Jansen, & Heil, 2010). Such early gender differences are usually taken as arguments for hereditary origins of the male advantage. Indeed, there is evidence for the influence of an X-linked, recessive gene on spatial abilities (e.g. Bock & Kolakowski, 1973), but some authors also point to the role of environmental differences in early childhood and even in infancy (Quinn & Liben, 2008). Aside from the adolescence-hypothesis

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and the early childhood/birth-hypothesis, there is a third idea about the emergence of the gender difference in mental rotation, suggesting a crucial time slot for the development of the male advantage before adolescence at about 10 years. Support for this idea comes from Johnson and Meade (1987), who report a reliable male advantage from 10 years onwards, but not before, and from Quaiser-Pohl (2003), who tested 4–6-year-old preschoolers with the "Picture Rotation Test" and found no gender difference. In a recent study using the "Mental Rotation Test" of Peters et al. (1995), Titze, Jansen, and Heil (2010) found a large, significant male advantage in an older group of fourth graders (mean age: 10.3 years), but only a small and non-significant gender difference in younger fourth graders (mean age: 9.3 years). Titze et al. (2010) offer a biological and a socio-cultural explanation for the emergence of the gender difference at this age. The biological explanation refers to the beginning of pubertal-hormonal changes. Testosterone level has been shown to influence mental-rotation performance in adults (Hausmann & Güntürkün, 2000), and it can be argued that older fourth graders are already influenced by sex hormones. The socio-cultural explanation mentioned by Titze et al. (2010) argues that domain-specific self-concepts of ability influence achievement (e.g. Marsh & Craven, 2006; Trautwein, Lüdtke, Köller, & Baumert, 2006), and that major steps in the development of self-concept occur during elementary-school years (Berk, 2004; Ruble, 1987).

In addition to biological and self-concept based explanations, gender differences in spatial experience might explain the male advantage (Baenninger & Newcombe, 1989; Pezaris & Casey, 1991; Sander, Quaiser-Pohl, & Stigler, 2010). Females gather, on average, fewer spatial experiences in childhood (e.g. playing with building blocks, see Connor & Serbin, 1977), adolescence (e.g. playing action video or computer games, see Quaiser-Pohl, Geiser, & Lehmann, 2006) and adulthood (e.g. choosing technical or scientific professions, see Quaiser-Pohl & Lehmann, 2002).

In adults, the gender difference in mental-rotation performance is influenced by stimulus characteristics (Jansen-Osmann & Heil, 2007). One explanation for this finding refers to gender differences in the mental-rotation strategy, which is already present in fifth-grade school children (Geiser, Lehmann, Corth, & Eid, 2007). Men usually rotate in a holistic manner, whereas women prefer an analytic, piecemeal strategy (Cochran & Wheatley, 1989; Janssen & Geiser, 2010). Consequently, a higher stimulus complexity slows the rotation speed of female participants to a greater degree than the rotation speed of male participants, so that gender differences are larger when more complex stimuli are used (Heil & Jansen-Osmann, 2008). Furthermore, some stimuli (e.g. letters) are more likely processed holistically than others (e.g. abstract figures) because of their familiarity, which activates the cognitive representation of the object as a unit (Bethell-Fox & Shepard, 1988). Familiar, well-known stimuli might therefore result in the use of holistic strategies in both sexes, whereas the processing of more unfamiliar stimuli in females might be dominated by their tendency to use analytic strategies. The influence of stimulus material on the gender difference can also be explained by the fact that some stimuli are more gender-stereotyped than others: Blocks, dominoes and cube puzzles, for example, are more prevalent in boys' environment (Connor & Serbin, 1977; Etaugh, 1983). The use of different stimulus material provides one explanation for the diverging results concerning the age in which gender differences in mental-rotation performance emerge.

1.1. Questions and hypotheses

The present study aimed at answering two questions: (1) At which age does the male advantage in mental-rotation performance emerge? (2) Does the male advantage in pre-adolescents' mental-rotation performance depend on stimulus type? Based on the finding of Titze et al. (2010), we expected a gender difference in fourth graders, but not in second graders. We expected a more pronounced male advantage in tasks with cube figures than in tasks with animal pictures and letters because cube figures are more gender-stereotyped and they are more likely to activate the female tendency for analytic, piecemeal processing.

Furthermore, we expected a better rotation performance of fourth graders compared to second graders due to an increase in general processing speed (e.g. Kail, 1993) and rotation rate (Kail, Pellegrino, & Carter, 1980) with age. Cube figures should produce the largest grade difference because they are the most abstract and unfamiliar stimulus type. Animal pictures should produce the lowest grade difference because they are more concrete and familiar than the other two stimulus types.

2. Method

2.1. Participants

The sample consisted of 432 elementary-school children whose parents gave their written, informed consent. One half of the participants ($n = 216$) were second graders (mean age: 7.8 years, $SD = 0.45$, range: 6.6 to 9.5 years), and the other half ($n = 216$) were fourth graders (mean age: 9.9 years, $SD = 0.49$, range: 8.8 to 12.1 years). They came from schools in Koblenz and received little presents (value: 1€) for participation. Additionally, participating classes were given 4€ per child for class treasury. The sample included children from families with low, middle and high socio-economic status (SES), with high percentages of middle-SES (20%) and high-SES families (45%). Each child was tested in one of the three stimulus conditions (animal pictures, letters, cube figures). In each stimulus condition, 72 second graders and 72 fourth graders (36 boys and 36 girls respectively) were examined.

2.2. Material

The mental-rotation tasks were constructed similar to the "Mental Rotations Test" (MRT, Vandenberg & Kuse, 1978). In the animal-pictures condition, we used colored paintings of animals from the Snodgrass and Vanderwart (1980) sample of familiar stimuli. In the letter condition, children had to mentally rotate upper- and lower-case letters. In the cube-figures condition, we used the three-dimensional figures provided by Shepard and Metzler (1971). Figure 1 shows one sample item from each stimulus condition. In order to parallelize task demands for all three stimulus types and to avoid floor effects in second-grade participants, we only used picture-plane rotations. Each item consisted of one target on the left side and four comparison stimuli on the right. Two of the four comparisons were "correct" (picture-plane rotated versions of the target), and two were "incorrect" (mirror images of the target). Participants had to cross out the two "correct" comparisons. In all three conditions, the mental-rotation task consisted of 16 test items; four items were presented per DIN-A4-sized, landscape-formatted sheet of paper. Six rotation angles were used: 45°, 90°, 135°, 225°, 270° and 315°.

We controlled for general cognitive abilities by administering the subtest "Reasoning" of the "Cognitive-Ability Test" (KFT 1-3, Heller & Geisler, 1983). Information about socioeconomic status was gathered by a questionnaire based on the measure provided by Jöckel et al. (1998).

2.3. Procedure

Children were tested in class rooms during regular school time. Two experimenters administered the tests in class-based groups