Gender differences in math and mental rotation accuracy

but not in mental rotation speed in 8 years old children

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Abstract

Gender differences in a psychometrical and in a chronometrical mental rotation test and in a standardized math test were investigated with a sample size of 109 boys and girls aged 7 or 8 years. The results revealed gender differences in all accuracy-based measures, i.e., in the paper-pencil mental rotation test, in the math test, and in the error rate of the chronometrical test. In line with the literature for adults, however, no gender difference was found in the speed of mental rotation itself. Moreover, no evidence for a speed-accuracy tradeoff was found. Thus, gender differences in tasks of math and visual-spatial cognition are present well before puberty but they seem to be restricted to accuracy-based measures.

Key words: gender differences; math performance; visual-spatial cognition; mental rotation

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Whereas females outperform males on e.g., measures of verbal fluency, males outperform females on certain tests of math performance and of spatial ability (e.g., Halpern, 1992). This male advantage is largest on mental rotation tasks (Voyer, Voyer & Bryden, 1995) where, generally, participants are required to determine if two or more figures are either identical but rotated versions of each other or mirror images. The cause(s) for the gender differences, however, are still far from being understood. The explanations being offered include more "psycho-social" ones (like stereotype threat, Shih, Pittinsky & Ambady, 1999; sex role identification, Signorella & Jamison, 1986; or differential experience and socialization, Baenninger & Newcombe, 1989), and also more "biological-neuronal" ones (like sex hormone level, Imperato-McGinley, Pichardo, Gautier, Voyer & Bryden, 1991; rate of maturation, Sanders & Soares, 1986; or cerebral lateralization, McGlone, 1980).

These explanations often run the risk of over-generalization and thus, it might help to (re)turn to the empirical facts that have to be explained. With adults, the situation is relatively clear-cut, i.e. gender differences are observed in accuracy based math tests (e.g., Mau & Lynn, 2001) and in accuracy based mental rotation tests (Voyer et al., 1995; Linn & Petersen, 1985) even when there is no speed component involved at all (Masters, 1998; Peters, 2005), but they are small or even absent when the speed of the mental rotation process itself is measured under the terms of an information-processing approach (e.g., Peters, 2005; Jansen-Osmann & Heil, in press).

Unfortunately, with respect to primary school-age children, the empirical situation is less homogenous, both with respect to the age at which gender differences emerge (or, more generally, whether they emerge before or only with puberty, see e.g., Newcombe, Bandura & Taylor, 1983; Vederhus & Krekling, 1996; Levine, Huttenlocher, Taylor & Langrock, 1999) and with respect to the specific measures that do or do not reveal them. Therefore, it is the

goal of the present study to address three questions that still remain open: First, are gender differences already observable at the age of 7 or 8 years, i.e., well before puberty, as suggested by, e.g., Kerns and Berenbaum (1991)? Second, is the pattern observed with adults - i.e., gender differences are present in accuracy-based but absent in speed-based measures - already observed with children? If so, then the difference between accuracy- and speed-based measures should be identified as one factor that contributes to the inconsistency of the results regarding gender differences before puberty. Or do gender differences in the speed of mental rotation itself exist with children but not (anymore) with adults? In that case, one would speculate that a speed difference might have turned into an accuracy difference during cognitive development. And finally, we are interested as to whether an inherent link exists between math performance and mental rotation ability, as suggested by the work of e.g. Casey, Nuttall and Pezaris (1997; see also Lehmann & Jüling, 2002)

<div align="center">Methods</div>

Participants

109 children volunteered in the study (47 girls, 62 boys, aged 7 or 8 years, $M = 7.7$ years, $SD = 0.53$). Children were recruited through three different primary schools in the area of Duesseldorf, Germany. Prior to testing, all parents gave their informed written consent.

Material and Procedure

Three tests were used to measure math and mental rotation performance. Children received the math and the paper-pencil mental rotation test in one classroom session as group tests. One week later children individually solved the chronometrical task in a quite room of the school. The chronometrical task was presented on a laptop and lasted approximately 30 minutes. The three tests used were:

1)   Objective math performance test SBL 2 (German: Schulleistungsbatterie SBL2 Rechnen Leistungsstufe II, Form A; Kautter, Storz & Munz, 2002). The SBL 2 is a speeded paper-pencil test consisting of 30 arithmetic (addition, subtraction and multiplication) and 20

word problems. An example of a word problem reads as follows: "Susi and Nina received 6 nuts. Both girls got the same number of nuts. How many nuts did each girl receive?" The arithmetic problems were presented in groups of 6 problems per sheet, with 90 s allowed per sheet. Each of the word problems was read aloud by one of the experimenters, and the children were asked to read them along silently. There were 30 s given for solving each of the word problems. The maximum overall score (arithmetic plus word problems) was 50 points. [1]

2)   Paper-pencil mental rotation test (Lohaus, Schumann-Hengstler & Kessler, 1998), an un-speeded test presenting 8 pairs of 3-D cube figures rotated in depth. Children had to decide if the two figures were the same or not. The maximum score was 8 points.

3)   Chronometrical mental rotation task (Wiedenbauer & Jansen-Osmann, in press). In this computer-based task, children were asked to decide as fast as possible whether two presented stimuli were identical or mirror images (50%) of each other while keeping errors to a minimum. The stimuli (see Figure 1) consisted of colored drawings of six different animals (elephant, fox, crocodile, cow, leopard, horse). The pictures were taken from Rossion and Pourtois (2004) and were presented in front of a black background. An upright drawing was presented on the left and a comparison one rotated in the picture plane by either 22.5°, 67.5°, 112.5°, or 157.5° clockwise or counter-clockwise on the right. Half of the animals were when presented upright facing to the left, the other half facing to the right. In each of the 8 angular disparities, each pair of drawings was presented twice (same and different) resulting in a total of 96 trials, preceded by 16 unrecorded practice trials with new animal drawings (frog and monkey). Each trial started with a 500 ms fixation square followed by the drawings prompting to answer by pressing either the left ('same') or the right mouse button ('different').

Statistical analysis

        In the SBL 2 and in the mental rotation test, the number of correctly solved items was used as dependent variable. In the chronometrical task dependent variables were (a) the error rate as a function of angular disparity (number of incorrect responses divided by number of

trials, i.e., 24) and (b) the speed of the mental rotation process. Regression lines (least squares method) between angular disparities and RT were computed separately for each child. Mental rotation speed was calculated in °/s by using the inverse of the slope.

Analyses of variance were calculated for the SBS 2 score, for the mental rotation test score, and for mental rotation speed with the factor "gender". An analysis of variance was computed for the error rate in the chronometrical mental rotation task with "angular disparity" (22.5°, 67.5°, 112.5°, and 157.5°) defined as within-subject factor and "gender" defined as a between-subject factor. Probability of Type-I errors was controlled on the basis of the method suggested by Holms (1979).

Results and Discussion

Gender differences were significant in all three accuracy scores (see Table 1): In the SLB 2 math performance, boys ($M = 34.6$, $SE = 1.21$) outperformed girls ($M = 30.8$, $SE = 1.46$), $F(1, 107) = 4.13$, $p < .05$. The effect size amounted to $d = 0.39$. In the paper-pencil mental rotation test, boys ($M = 5.19$, $SE = 0.20$) outperformed girls ($M = 4.40$, $SE = 0.22$), $F(1, 107) = 6.73$, $p < .05$. The effect size amounted to $d = 0.50$. The analysis of variance for the error rate in the chronometrical mental rotation task revealed in addition to a significant main effect of factor angular disparity, $F(3, 221) = 54.29$, $p < .001$, a significant effect of the factor „gender", $F(1, 107) = 4.19$, $p < .05$, as well as a significant interaction between angular disparity and gender, $F(1, 107) = 5.75$, $p < .05$. Boys outperformed girls, but only for the two larger angular disparities (means and standard errors for girls: 22.5° = 1.27 and 0.26; 67.5° = 1.61, and 0.29; 112.5° = 3.11 and 0.39; 157.5° = 5.29 and 0.56. Values for boys: 22.5° = 1.29 and 0.22; 67.5° = 1.36 and 0.25; 112.5° = 2.02 and 0.33; 157.5° = 3.32 and 0.48). The gender-effect size in the overall error rate amounted to $d = 0.40$. Moreover, the SLB 2 math score showed small although significant correlations with both the paper-pencil mental rotation test score ($r = .26$) and the error rate in the chronometric task ($r = -.29$; both $p < .01$). The two mental rotation accuracy scores, however, were not correlated ($r = -.11$, ns), replicating our

earlier results regarding the stimulus-specificity of the mental rotation process (Jansen-Osmann & Heil, in press).

In contrast, however, no gender difference was present in the speed of the mental rotation process itself ($F(1, 107)=0.56$, *ns*, $d = 0.14$), which amounted to 116 °/s on average, well in line with the literature (e.g., Kail, Pellegrino & Carter, 1980). We found no correlation between the speed of mental rotation and any of the accuracy-based measures (all $r < .1$, *ns*). Most importantly, mental rotation speed and error rate in the chronometric task were not correlated ($r = .06$, *ns*), indicating the absence of a speed-accuracy tradeoff.

Thus, the results are pretty straight forward, and although they are new from the developmental science perspective, they are in fact in line with the recent literature with adults (Peters, 2005; Jansen-Osmann & Heil, in press): Gender differences favoring males are present with a medium effect size in both math performance and in mental rotation abilities already in 8 year old girls and boys, i.e., well before puberty. Moreover, math performance and mental rotation ability seem to be correlated, as already suggested by, e.g., Lehmann and Jüling (2002).

Gender differences, however, were *only* present in accuracy-based measures but were absent when the speed of the cognitive process of mental rotation itself was measured. In line with research with adults, this pattern of results cannot be traced back to a speed-accuracy tradeoff (Peters, 2005; Jansen-Osmann & Heil, in press). Thus, our data do not support the idea that gender differences for children are manifested in speed differences but turn into accuracy differences for adults. All the accuracy-based measures revealed gender differences although the measures itself were pretty heterogeneous according to a number of aspects: The math and the mental rotation test were paper-pencil tests and they were administered in groups while the (error rate of the) mental rotation task was computer-based and was determined individually. An explicit time-pressure was introduced for the SLB 2, an implicit one (the instruction to respond as fast as possible while keeping errors to a minimum) for the

computer task, while explicitly no time pressure at all was introduced for the mental rotation paper-pencil test. The latter one used 3D objects rotated in depth while the computer task used 2D stimuli rotated in the picture plane. More experiments are needed to orthogonally manipulate these aspects in detail to validate that indeed the accuracy versus speed distinction is crucial as suggested by the present results. More specifically, we predict that comparable to the situation with mental rotation in adults (see, e.g., Peters, 2005), for the math performance the speed component of the SLB 2 should not be critical as long as floor effects are avoided, but here, empirical data are still lacking.

Irrespective of all these differences between the different variables used, however, the results revealed gender differences for accuracy measures but not so for speed measures, well in line with the results for adults (Peters, 2005; Jansen-Osmann & Heil, in press). Because evidence exists that mental rotation might differ qualitatively between primary school age children and adults (see, e.g., Jansen-Osmann & Heil, 2006; 2007), this is by no means trivial. Thus, speed of the cognitive process might not be a candidate mechanism for explaining gender differences in accuracy, and at the same time, these two variables obviously measure two rather independent aspects (see also Peters, 2005).

The history of developmental sciences can be characterized by intensive, sometimes even acrimoniously conducted discussions and debates regarding the relative impact of nature versus nuture in causing individual or group differences, and gender differences by no means are an exception. These debates sometimes run the risk of losing track of the empirical realities they aspire to explain. In the case of gender differences in mental rotation (and math) performance, these empirical realities include the presence of gender differences in accuracy based measures well before puberty but the (almost complete, see Jansen-Osmann & Heil, in press) absence of such gender differences in child- as well as in adulthood when the speed of the cognitive process itself is examined. From our point of view, none of the presently existing theories regarding gender differences in math performance and spatial ability allows

for this dissociation between accuracy- and speed-based measures, a situation that has to be revised.

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Author Note

Footnotes

[1] Because the gender difference did not differ between the two subtests, only the overall test performance is reported.

Table 1

Means (M) and standard errors (SE) of the dependent variables as a function of subjects'

gender and the effect-size (d) of the gender difference. Significant effect sizes are highlighted.

Dependent variable	Boys		Girls		Effect size of gender difference
	M	SE	M	SE	d
Math test (SLB 2)	34.6	1.21	30.8	1.46	0.39
Mental rotation paper-pencil test:	5.19	0.20	4.40	0.22	0.50
Mental rotation task: error rate	1.99	0.29	2.82	0.32	0.40
Mental rotation task: speed (° / s)	114.2	7.32	119.4	4.93	0.15

Figure Captions

Figure 1.   An example of a stimulus ("same" trial with a 112.5° disparity) in the

chronometrical mental rotation task. Original stimuli were colored.

Figure 1: