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Can girls think spatially? Influence of implicit gender stereotype activation and rotational axis on fourth graders' mental-rotation performance

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ABSTRACT

Mental-rotation tasks usually induce large gender differences in favor of males. The influence of task features and stereotype activation on the mental-rotation performance of elementary-school children has rarely been investigated. This study examined the performance of 272 fourth-grade boys and girls in a psychometric mental-rotation task varying implicit gender-stereotype activation (threatening vs. non-threatening task framing) and rotational axis (picture-plane vs. in-depth rotations). Children's gender stereotypes were assessed by a questionnaire. Both genders showed a male stereotype for mental rotation. Implicit gender stereotype activation influenced the gender difference only in picture-plane mental-rotation tasks. Boys outperformed girls in the threatening condition, but not in the non-threatening condition, here. However, in-depth rotation tasks induced a significant male advantage in both the threatening and the non-threatening conditions. Findings suggest that a task framing relating mental rotation to arts induces a stereotype-lift effect and that the rotational axis moderates the effect of implicit gender-stereotype activation.

1. Introduction

Stereotypes are "expectations or beliefs about characteristics associated with different groups" (Swim & Hyers, 2009, p. 411). They influence achievement not only by inducing long-term effects on self-concept and skill development (Appel & Kronberger, 2012; Bussey & Bandura, 1999), but also by interrupting – or, in the case of positive in-group stereotypes, promoting – cognitive, perceptual and motor performance in the test situation (Aronson & McGlone, 2009). The detrimental effect of negative stereotypes is called *Stereotype Threat* (Steele, 1997; Steele & Aronson, 1995), the beneficial effect of positive stereotypes is called *Stereotype Lift* (Walton & Cohen, 2003). The present study examined the situational influence of implicitly activated gender stereotypes on mental-rotation performance, a domain for which large gender differences in favor of male participants are usually found in adults (Lippa, Collaer, & Peters, 2010; Voyer, 2011; Voyer, Voyer, & Bryden, 1995). Furthermore, the influence of rotational axis on boys' and girls' mental-rotation performance was investigated, because previous studies indicate a larger male advantage for in-depth rotations than for picture-plane rotations (Voyer et al., 1995).

1.1. The gender effect in mental-rotation performance and the influence of rotational axis

Mental-rotation tests, which assess the ability to rotate two- and three-dimensional objects in the mind (Shepard & Metzler, 1971), induce one of the largest cognitive gender differences (Halpern, 2012), which emerge already before adolescence (e.g. Johnson & Meade, 1987; Neuburger, Jansen, Heil, & Quaiser-Pohl, 2011).

In addition to age, task characteristics influence the gender effect in mental rotation, with the "Mental Rotations Test" (MRT, Vandenberg & Kuse, 1978; Peters et al., 1995) inducing the largest male advantage. Objects similar to the cube figures of the MRT, like blocks, dominoes, cube puzzles, and LEGO material, are more frequently part of boys' environments (Kersh, Casey, & Mercer Young, 2008). Because of the gender difference in stimulus familiarity, boys are more likely to process such stimuli holistically (Bethell-Fox & Shepard, 1988), which might in turn support efficient mental rotation. Furthermore, cube figures might activate gender stereotypes of male superiority because they remind of male-stereotyped objects and thus lead to stereotype-threat effects. Results of a recent study with fourth graders suggest that gender-stereotyped stimuli indeed influence the gender difference in children's mental-rotation performance (Neuburger, Heuser, Jansen, & Quaiser-Pohl, 2012a). In addition to stimulus characteristics, dimensionality (picture-plane vs. in-depth rotations) might also contribute to the large male advantage in the MRT (cf. Neuburger et al., 2012a;

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Neuburger et al., 2011; Titze, Jansen, & Heil, 2010a; Voyer et al., 1995). However, there are only a few systematic studies concerning this issue, and therefore, it is not yet clear if the large male advantage in three-dimensional rotation tasks like the MRT is really due to rotational axis or if it simply reflects the higher difficulty (e.g. working memory demands) of such tasks. The present study investigated the effect of the rotational axis on fourth-grade boys' and girls' mental-rotation performance by comparing two mental-rotation tasks which required either picture-plane rotations or in-depth rotations of the Shepard and Metzler (1971) cube figures.

With regard to the underlying causes of the male advantage, there is some evidence for genetic and hormonal influences (e. g. Grimshaw, Sitarenios, & Finegan, 1995; Heil, Kavšek, Rolke, Beste, & Jansen, 2011) but pure biological explanations are not unequivocally supported by the data (Halari et al., 2005; Hines et al., 2003; Rahman, Wilson, & Abrahams, 2004). Moreover, socio-psychological and experiential factors have been demonstrated to influence mental-rotation performance: Task instructions that promote effort attributions or outline the role of stereotypes in explaining the gender difference can enhance mental-rotation performance (Moè, 2012; Moè & Pazzaglia, 2010), and self-confidence has been found to affect mental-rotation performance and to mediate the gender difference (Estes & Felker, 2012). In line with Nash's (1979) gender-role mediation hypothesis, a recent meta-analysis confirmed a positive relationship between masculinity and mental-rotation performance (Reilly & Neumann, 2013). Additionally, various spatial trainings have substantial effects on mental rotation (Uttal et al., 2013), and gender-related differences in spatial experience (e. g. Quaiser-Pohl, Geiser, & Lehmann, 2006; Cherney & London, 2006) are considered as a causal factor contributing to the male advantage. As outlined in current causal models, the multiple factors leading to the male advantage are best conceptualized in a psycho-bio-social framework integrating social, biological, and psychological influences, considering the complex interactions and covariations among the different variables (Halpern et al., 2007; Hausmann, Schoofs, Rosenthal, & Jordan, 2009).

1.2. Stereotype-threat and stereotype-lift effects on mental-rotation performance

Stereotype threat and stereotype lift comprise all of the three causal dimensions, i.e. they include social, biological, and psychological processes: Stereotypes are social phenomena, representing probabilistic beliefs about characteristics of males and females or "paired associations between gender categories and attributes" (Ruble & Martin, 1998, p. 940). Stereotype threat induces a physiological stress response and dysfunctional cognitive and affective processes (Schmader, Johns, & Forbes, 2008), while stereotype lift "may alleviate the self-doubt, anxiety, and fear of rejection that could otherwise hamper performance on important intellectual tests" (Walton & Cohen, 2003, p. 457). The psycho-bio-social nature of the effects of stereotype activation is also supported by the findings of Hausmann et al. (2009), suggesting that sex hormones mediate stereotype threat effects. The activation of stereotypes in a test situation can be implicit, e.g. by priming the stereotyped group identity or by emphasizing the evaluative or diagnostic nature of the test, or explicit, e.g. by indicating a group's inferiority in the test (Nguyen & Ryan, 2008).

Since working memory has been identified as an important mediator and moderator of stereotype threat (Beilock, Rydell, & McConnell, 2007; Schmader et al., 2008) and mental rotation strongly relies on working memory (Kaufman, 2007), it seems plausible to assume that stereotype threat influences girls' and women's mental-rotation performance — given that gender stereotypes in the domain of spatial ability actually exist.

Several studies demonstrate the influence of gender stereotype activation on *adults' and adolescents'* mental-rotation performance (Dunst, Benedek, Bergner, Athenstaedt, & Neubauer, 2013; Hausmann et al., 2009; Heil, Jansen, Quaiser-Pohl, & Neuburger, 2012; Miller, 2012; Moè, 2009; Moè & Pazzaglia, 2006; Sharps, Welton, & Price, 1993). And this effect of stereotypes was found in the results of MRT tests with children, too (cf. Nash, 1979; Neuburger, Ruthsatz, Jansen, Heil, & Quaiser-Pohl, 2013; Rammstedt & Rammsayer, 2001).

Although the male advantage is well documented to emerge before adolescence (e.g. Johnson & Meade, 1987; Titze et al., 2010a; Neuburger et al., 2011), stereotype threat and lift effects on *children's* mental-rotation performance have rarely been examined, with the few existing studies reporting somewhat heterogeneous results: While Titze, Jansen, and Heil (2010b), who investigated fourth-graders, did not find any effects of gender-stereotype activation on the mental-rotation performance of boys and girls, Neuburger, Jansen, Heil, and Quaiser-Pohl (2012b) found that the gender difference in fourth-graders disappeared when task instruction explicitly outlined either a positive female stereotype or the equal ability of boys and girls. Similarly, in an implicit stereotype-threat paradigm, Huguet and Régner (2007) found that the performance of girls aged 11–13 years in a spatial memory task was impaired when the task was described as "geometry task" in contrast to "memory game"; interestingly, this stereotype-threat effect even occurred despite girls' counter-stereotypic beliefs (Huguet & Régner, 2009). Thus, there is evidence that both explicit and implicit stereotype activation can influence children's spatial performance. The present study aimed at complementing previous research by investigating the effect of implicit stereotype activation on the mental-rotation performance of fourth-graders. Similarly to Huguet and Régner (2007, 2009), gender stereotypes were activated by the task framing, which either outlined that the mental-rotation task measured spatial abilities or that it measured artistic abilities.

1.3. Design and hypotheses

The study examined the effects of implicit stereotype activation and rotational axis on the mental-rotation performance of fourth-grade girls and boys in a 2 (genders: boys vs. girls) × 2 (task framing: threatening vs. non-threatening) × 2 (rotational axis: in-depth vs. picture-plain rotations) between-subjects design. Gender stereotypes were activated by varying the information about the diagnostic purpose of the mental-rotation task (threatening condition: assessing spatial ability, non-threatening condition: assessing artistic ability). Rotational axis was varied by administering either a picture-plane version or an in-depth version of the mental-rotation task. In addition to children's mental-rotation performance, gender stereotypes with regard to mental rotation, spatial imagination, mathematics, and art were examined. On the basis of the results of Neuburger et al. (2013), it was expected that mental rotation would be male-stereotyped only by boys (Hypothesis 1) and that spatial imagery and mathematics would be female-stereotyped by both boys and girls (Hypotheses 2 and 3). With regard to art, no specific hypothesis was formulated because of the lack of previous research regarding children's gender stereotypes about art. Concerning mental-rotation performance, it was expected that both gender-stereotype activation and rotational axis would influence the gender effect: In contrast to the non-threatening task framing, the threatening framing should induce stereotype-threat effects in girls and stereotype-lift effects in boys; therefore, the threatening framing was expected to result in a larger male advantage than the non-threatening framing (Hypothesis 4). Furthermore, in-depth rotations were expected to result in a larger male advantage than picture-plane rotations (Hypothesis 5).

2. Material and methods

2.1. Participants

Participants were recruited from German public schools and randomly assigned to the four experimental conditions by the experimenter. 272

fourth graders (34 boys and 34 girls in each of the four conditions) participated in the study. Parents gave their informed consent. The sample included children aged 9–11 years (*mean age* = 9.81 years, *SD* = 0.44) from families with low (8.8%), middle (21.0%) and high (35.3%) socio-economic status (SES). No reward was given to the participants, because supervisory school authority did not permit rewarding in order to ensure voluntary participation.

2.2. Material

2.2.1. Mental-rotation tests

Task format was the same as in the “Mental Rotations Test” of Vandenberg and Kuse (1978). The paper–pencil tasks consisted of twelve test items with one target on the left side and four comparison stimuli on the right (see Fig. 1).

Children were instructed to solve as many items as possible within 5 min. Two of the four comparisons were rotated versions of the target and had to be crossed out by the participants; the other two comparisons were rotated mirror images of the target. The following rotational angles were used: 45°, 90°, 135°, 180°, 225°, 270°, and 315°. As rotation stimuli, the cube figures originally designed by Shepard and Metzler (1971) were used. There were two versions of the MRT, one with picture-plain rotations (Fig. 1: top) and another with in-depth rotations (Fig. 1: bottom). Test items had already been used in previous studies by Neuburger et al. (2011), Neuburger et al. (2012a, b); on the basis of those previous results, the items with the highest discriminatory power were chosen for the shortened test versions used in the present study. Reliability analysis confirmed good internal consistencies (picture-plane version: Cronbach's $\alpha = .81$; in-depth version: $\alpha = .80$).

2.2.2. Gender-stereotypes questionnaire

Children's gender stereotypes were measured by four questions: (1) “Who is good at solving mental-rotation tasks?” (2) “Who is good at imagining something spatially?” (3) “Who is good at mathematics?” (4) “Who is good at art (drawing, painting)?” Answers were given on a five-point scale (only girls — more girls than boys — as many girls as boys — more boys than girls — only boys).

2.2.3. General cognitive ability

As an indicator of general cognitive abilities, the “Connecting Numbers Test” (Zahlenverbindungstest, ZVT, Oswald & Roth, 1987) was used, which is equivalent to the Trail Making Test (Reitan, 1956) and highly correlates with standard IQ tests ($r = .60$ to $r = .80$, Vernon, 1993). The ZVT contains four matrices of numbers. Each matrix consists of 90 randomly arranged numbers, which have to be connected by lines according to their size. Before solving the test matrices, children are given two example matrices. Then, for each matrix, they are instructed to connect as many numbers as possible within 30 s.

2.2.4. Questionnaire for parents

Information about socio-economic status (SES) was gathered by a questionnaire based on the Index of Education Level (IEL) by Jöckel et al. (1998). Participants' parents were asked to indicate their highest school and professional degree. This index was assessed because of Levine, Vasilyeva, Lourenco, Newcombe, and Huttenlocher's (2005) findings on the influence of SES on gender differences in spatial ability. In former studies we found this relationship, too (see Ruthsatz, Neuburger, & Quaiser-Pohl, 2013).

2.3. Procedure

Mixed-gender groups of 10–20 children were tested by a female experimenter in school classrooms. In a short introduction, children were informed that they would get their individual performance results after the experiment. This was done in order to encourage children to do their best in the performance tests and to create a threatening situation, which is necessary for stereotype threat/lift effects. After this general introduction, the respective mental-rotation task framing was given. In the diagnostic threatening condition, the experimenter said: “First, we will test your spatial imagery. Spatial imagery is important for mathematic, physics, and technics, and when you build something, for example with LEGO or LEGO technics.” In the non-threatening condition, the experimenter said: “First, we will test your artistic abilities. Such abilities you need, for example, when you paint a picture, draw figures, or do handicrafts.” Next, the mental-rotation task was introduced by rotating a pair of scissors in front of the children, outlining that the turn-around of an object does not change its features. Then, the paper–pencil task was explained on the basis of two example items. After task understanding had been ensured, children were instructed to work both fast and accurately on the test and solve as many items as possible within 5 min. After the mental-rotation task was finished, the gender-stereotype questionnaire was administered. The experimenter outlined that children should spontaneously answer according to their personal experiences and opinions and that there were no right or wrong answers. Afterwards, the ZVT was administered. Then, for each matrix, children were instructed to connect as many numbers as possible within 30 s. In the end, the children were thanked for their participation and dismissed. When the experiment was finished, the children received their individual test results, accompanied by a letter emphasizing that spatial abilities can be strongly improved by training.

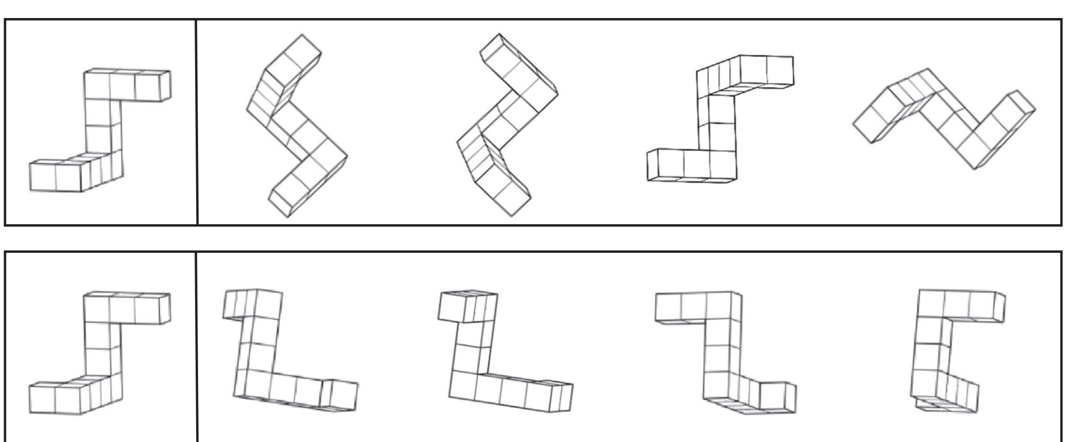

Fig. 1. Example items from the MRT with picture-plane rotations (top) and the MRT with in-depth rotations (bottom).

3. Results

3.1. General cognitive ability

Raw scores in the ZVT were transformed into age-corrected T-values. Children's general cognitive ability ranged from $T = 28$ to $T = 80$ ($M = 59.53$; $SD = 13.97$). In order to examine if the four groups differed with regard to general cognitive ability, a 2 (gender) × 2 (task framing) × 2 (rotational axis)-ANOVA was computed, which revealed the following effects: a main effect of gender, $F(1,264) \times 5.35$; $p = .02$; partial $\eta^2 = .02$ (Note: All further reported η^2 also refer to the partial η^2.), and an interaction of task framing and rotational axis, $F(1,264) = 10.05$; $p = .002$; $\eta^2 = .04$; none of the remaining effects reached significance, all $p \geq .10$. Overall, girls ($M = 61.43$; $SD = 14.29$) outperformed boys ($M = 57.63$; $SD = 13.42$). In the threatening condition, performance was higher in the in-depth task ($M = 61.75$; $SD = 16.06$) than in the picture-plane task ($M = 58.88$; $SD = 12.96$); in the non-threatening condition, performance was higher in the picture-plane task ($M = 62.53$; $SD = 54.97$) than in the in-depth task ($M = 54.97$; $SD = 12.21$). Because of these group differences, general cognitive ability was included as a covariate in the analyses of children's mental-rotation performance.

3.2. Gender stereotypes

Boys' and girls' answers to the four gender-stereotype questions were coded from −2 (only girls) to +2 (only boys); descriptive results are shown in Fig. 2. In order to examine if children's answers significantly differed from the neutral point of the scale (= 0), one-sample t-tests were computed. As expected, boys' answers significantly differed from 0 towards the male pole of the scale for mental rotation, $t(133) = 11.36$; $p < .001$, for spatial imagery, $t(133) = 4.30$; $p < .001$, and for math, $t(132) = 5.46$; $p < .001$. Unexpectedly, girls' answers also indicated a significant male stereotype for mental rotation, $t(134) = 9.31$; $p < .001$, but neither for spatial imagery, $t(135) = 1.09$; $p = .28$, nor for math, $t(135) = 1.25$; $p = .21$. With regard to art, both boys and girls favored their own gender: Boys' answers significantly differed from 0 towards the male pole, $t(133) = 3.30$; $p = .001$, girls' answers significantly differed from 0 towards the female pole, $t(135) = 5.25$; $p < .001$. Thus, Hypotheses 1–3 were partially confirmed.

In order to analyze the relationship between perceived gender stereotypes and performance we computed correlations between the score of the item “Who is good at solving mental rotation tasks?” and MRT performance. For boys the correlation was almost zero, for girls we found a positive correlation of $r = 0.235$ ($p < .01$), i.e. the more typically male the girls estimated mental rotation tasks the better was their performance. Because of the rather low and gender specific correlations and therefore complex relationships we did not include the gender stereotype score into further data analyses.

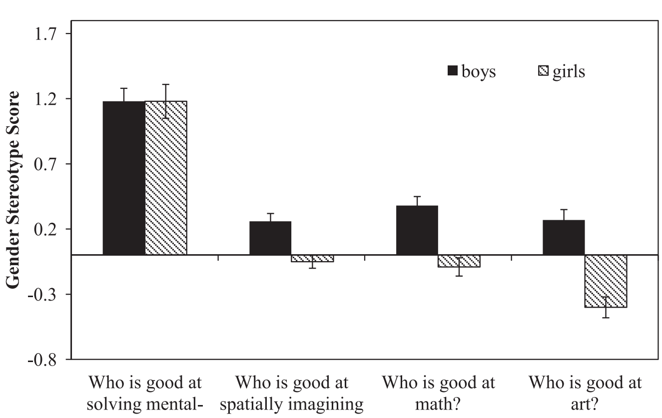

Fig. 2. Boys' and girls' gender stereotypes (means and standard errors of the mean). Scores range from −2 (only girls) to +2 (only boys).

3.3. Mental-rotation performance

Mental-rotation performance was defined as number of correctly solved items, i.e. items, in which both rotated versions of the target and none of the mirrored versions had been crossed out; thus, a maximum score of 12 could be achieved. One-sample t-tests confirmed that average performance accuracy (number of correct items divided by the number of attempted items) was above chance level (= 1/6) for both boys and girls in all conditions, all $p < .01$.

A 2 (gender) × 2 (task framing) × 2 (rotational axis)-ANCOVA with general cognitive ability as covariate (see Section 3.1.) revealed the following effects: a marginally significant effect of the covariate general cognitive ability, $F(1,263) = 3.47$; $p = .06$; $\eta^2 = .07$, a main effect of gender, indicating that overall, boys ($M = 5.61$; $SD = 3.37$) outperformed girls ($M = 4.00$; $SD = 3.04$), $F(1,263) = 20.53$; $p < .001$; $\eta^2 = .07$, a main effect of rotational axis, indicating that overall, performance in the picture-plane condition ($M = 5.46$; $SD = 3.39$) was higher than in the in-depth condition ($M = 4.15$; $SD = 3.09$), $F(1,263) = 10.95$; $p = .001$; $\eta^2 = .04$, an interaction of gender and rotational axis, $F(1,263) = 4.09$; $p = .04$; $\eta^2 = .02$, and a three-way interaction of gender, task framing, and rotational axis, $F(1,263) = 4.36$; $p = .04$; $\eta^2 = .02$; none of the remaining effects reached significance, all $p > .10$; all $\eta^2 \leq .01$.

To further analyze the interactions, separate 2 (gender) × 2 (task framing)-ANCOVAs were computed for the two rotational-axis conditions. For the picture-plane condition, the ANCOVA revealed no significant main effects, all $p > .05$; all $\eta^2 \leq .02$, but, as expected, an interaction of gender and task framing, $F(1,131) = 6.11$; $p = .02$; $\eta^2 = .05$: Simple main effects showed that boys outperformed girls in the picture-plane/threatening condition, $F(1,65) = 9.22$; $p = .003$; $\eta^2 = .12$, but there was no significant effect of gender in the picture-plane/non-threatening condition, $F(1,65) = 0.21$, $p = .65$; $\eta^2 = .003$; Fig. 3 shows that the gender effect disappeared because boys performed better in the threatening than in the non-threatening condition and girls performed better in the non-threatening than in the threatening condition.

In contrast to the ANCOVA for the picture-plane condition, the ANCOVA for the in-depth condition did not reveal an interaction of gender and task framing, $F(1,131) = 0.08$; $p = .78$; $\eta^2 = .001$, but a main effect of gender, indicating an overall higher performance of boys, $F(1,131) = 25.31$; $p < .001$; $\eta^2 = .16$, and a main effect of task framing, indicating an overall higher performance in the non-threatening framing condition, $F(1,131) = 4.01$; $p = .047$; $\eta^2 = .03$. Thus, Hypothesis 4 was confirmed for the picture-plane condition, but not for the in-

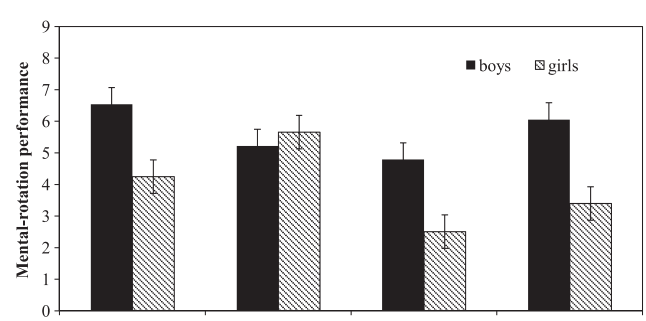

Fig. 3. Boys' and girls' mental-rotation performance in the four conditions (means and standard errors of the mean).

depth condition. Hypothesis 5 was confirmed, because a significant main effect of gender in favor of boys was only found for the in-depth condition, but not for the picture-plane condition. In order to compare the present results to those of previous studies, effect sizes (Cohen's *d*) were computed for the gender effects in the four conditions. The largest male advantage was found in the two in-depth conditions (threatening condition: $d = 0.82$; non-threatening condition: $d = 0.89$); in the picture-plane/threatening condition, the size of the male advantage was $d = 0.67$, and in the picture-plane/non-threatening condition, no male advantage was found ($d = -0.13$).

Analyzing the effects of the task framing condition and the rotational axis more properly with separate two-way ANCOVAs for boys and girls, Bonferroni-corrected p-values revealed significant effects of task framing ($F(1,131) = 5.81$; $p = .017$; $\eta^2 = .042$) and rotational axis only for girls ($F(1,131) = 16.633$; $p < .001$; $\eta^2 = .113$) but not for boys. For boys there was a significant interaction between task framing and rotational axis ($F(1,131) = 4.362$; $p = .047$; $\eta^2 = .032$). Cohen's *d* of the performance difference between the task framing conditions, separately for gender and rotational axis, showed that girls performed better in the non-threatening condition (art) with both rotational axes (girls/picture-plane: $d = -0.44$; girls/in-depth: $d = -0.38$). Also the boys showed a slightly better performance in the art condition with in-depth rotations (boys/picture-plane: $d = 0.37$; boys/in-depth: $d = -0.29$), although with picture-plane rotations they performed worse in the non-threatening (art) condition.

4. Discussion

Spatial skills are major determinants for educational and professional success in mathematical, technical, and scientific domains, where there is still a considerable gender gap (Wai, Lubinski, & Benbow, 2009). Therefore, the present study aimed at shedding some more light on the conditions under which girls underperform. Results suggest that both task framing and rotational axis influence the gender effect in fourth graders' mental-rotation performance: No male advantage was found in the picture-plane rotation task, when the task was described as a measure for artistic ability, while boys outperformed girls in the picture-plane rotation task, when the task was described as a measure for math, physics and technics. However, in the in-depth rotation task, boys significantly outperformed girls in both the threatening and the non-threatening conditions. Thus, the results reported by Huguet and Régner (2007, 2009), who found that task framing influenced the gender effect in the spatial memory performance of 11–13 year-old children, were only partially confirmed for the mental-rotation performance of 9–11 year-old children. This finding provides for a better understanding of the inconsistencies in previous results concerning stereotype threat and lift effects in children's spatial performance, because it points to a possible moderating variable: Both Huguet and Régner (2007, 2009) and Neuburger et al. (2012b), who found that the gender effect in spatial performance disappeared under non-threatening conditions, used picture-plane tasks, whereas Titze et al. (2010b), who found no stereotype threat/lift effects, used in-depth tasks. In contrast to stereotype threat/lift effects in *adults and adolescents*, which have also been reported for in-depth spatial tasks (e.g. Hausmann et al., 2009; McGlone & Aronson, 2006; Moè, 2009), the effect of gender stereotype activation on *children's* spatial performance possibly depends on dimensionality. Since overall, performance was higher in the picture-plane condition than in the in-depth condition, this might point to task difficulty as a more general moderator for stereotype threat effects. According to Nguyen and Ryan (2008), it is not yet clear if stereotype threat effects are more likely to occur in more challenging tasks. In contrast to the present results, some studies suggest that a higher task difficulty should rather increase than reduce stereotype threat effects in girls (e.g. Neuville & Croizet, 2007). Following this line of evidence, the effects of dimensionality on the gender effect and on stereotype threat/lift effects in spatial performance might be due to the *type* of task, i.e. to the specific mental operations involved in in-depth rotations of perspective drawings, instead of being a simple result of task *difficulty*.

The male advantage in in-depth rotations of perspective drawings seems to be especially persistent, which suggests that "the female disadvantage might not lie in the process of mental rotation per se but in the derivation of a 3-dimensional representation from a 2-dimensional image" (Neubauer, Bergner, & Schatz, 2010, p.529). This assumption is supported by studies showing that the male advantage disappears when rotation stimuli are shown as true three-dimensional models (McWilliams, Hamilton, & Muncer, 1997) or virtual reality presentations (Dunst et al., 2013; Neubauer et al., 2010). Gender differences regarding the degree to which foreshortened objects are part of everyday activities, e.g. in computer games (Quaiser-Pohl et al., 2006; Terlecki & Newcombe, 2005) and construction activities (Kersh et al., 2008; Neuburger et al., 2013), probably play an important role in explaining the influence of dimensionality on girls' spatial performance.

Besides the inclusion of both picture-plane and in-depth spatial tasks, the present study adds to previous research in the field of stereotype-threat/-lift effects in children's mental-rotation performance by examining the influence of *implicit* stereotype activation. While Neuburger et al. (2012b) and Titze et al. (2010b) activated gender stereotypes by explicitly stating that boys (or girls) outperformed girls (or boys), the present study used a more subtle stereotype activation method, which helps in disentangling stereotype threat/lift effects from the broader category of self-fulfilling prophecies (Rosenthal & Fode, 1963; Rosenthal & Jacobson, 1968). Results in the picture-plane condition strongly suggest that such "true" stereotype threat/lift effects indeed influence children's mental-rotation performance, because the male advantage disappeared in the non-threatening condition. However, two aspects of the present results somewhat contradict the stereotype threat/lift assumption: First, children's answers in the stereotype questionnaire did not fully confirm the hypotheses; especially, girls did not show a male stereotype for spatial imagery and math. This discrepancy between the stereotype threat/lift effects in the picture-plane condition and girls' answers in the questionnaire might be due to the phenomenon that "individuals, particularly women, [are] more likely to endorse gender stereotypes implicitly than explicitly" (Swim & Hyers, 2009, p. 412).

Thus, children's implicit gender stereotypes concerning spatial ability deserve more attention in future research. Another unexpected finding in the present study was that in the in-depth rotation task, both boys and girls performed higher in the non-threatening condition. Thus, the non-threatening task framing apparently had a gender-independent stress-releasing effect in the in-depth condition. With regard to boys' performance pattern, this might indicate that, like stereotype threat effects, stereotype lift effects are also influenced by task difficulty, such that performance is promoted more strongly by the activation of a positive in-group stereotype when the task is easy. In difficult tasks, members of the positively stereotyped group might experience a cognitive imbalance between the concepts of group, self, and ability, similar to the conflict induced by stereotype threat, but in the reversed direction, which might impair performance.

The findings on the relationship between the estimation of gender stereotypes of the tasks and task performance (positive correlation and only with girls) give further insights into the underlying mechanisms of the phenomena of stereotype lift or stereotype threat. We found a coexistence of a more male stereotype with high performance in mental rotation only in girls. This might be due to the fact that the gender stereotype questionnaire was administered after the children had solved the MRT items. Especially high performing girls might underestimate their performance in difficult gender stereotyped tasks, and in order to legitimize their own test results (which they expect to be bad) strengthen their gender stereotypes in order to reduce cognitive dissonance. Another explanation might be that a person although he or she is aware of a specific gender stereotype needn't be convinced of it. In general, results show that experimental activations of stereotypes are never targeted to a "tabula rasa" person and the effects of such instructions will be filtered by already existing beliefs and self-representations. In addition to further examining the role of dimensionality (or, more generally, the role of task difficulty) and automatic gender associations, future studies on stereotype threat/lift effects on children's spatial performance should also meet the following limitations of the present study. First, since the study had a between-subjects design, the mental-rotation performance was not assessed before stereotype activation. Thus, differences between the conditions are between-groups differences that, strictly speaking, cannot be labeled as "performance improvements" or "impairments". However, retesting designs lead to other methodological problems, like training effects or influence of task difficulty if different tasks are administered (see Neuburger et al., 2012b). Second, in the threatening condition, several ability domains were mentioned (spatial ability, math, physics, technics, and building/constructing), so it is not clear, which of the domains induced the stereotype threat effect in girls' performance. However, although "pure" spatial ability framings might improve internal validity, elementary-school children might not have an idea of what is meant by the construct "spatial ability". Therefore, the threatening framing in the present study also referred to some contexts in which spatial ability is needed in order to make the construct more descriptive and concrete.

In sum, we can say that 9 to 11 year old girls can spatially think, but that their spatial-test performance can be improved or distorted by a task framing (art vs. math, physics and technics) as well as by the rotational axis (picture-plane vs. in depth rotations). Girls at this age perform best in picture-plane rotation tasks together with the non-threatening task framing that mental rotation is related to art.

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