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Mental rotation and mathematics: Gender-stereotyped beliefs and relationships in primary school children

Angelica Moè

Department of General Psychology, University of Padova, Italy
via Venezia, 8, 35131 Padova, Italy

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ABSTRACT

This study aimed to examine gender differences in mental rotation and in gender-stereotyped beliefs and to assess relationships among mental rotation performance, mathematics ability, and gender-stereotyped beliefs in primary school children. Sixty-three 2nd graders (mean age 7.83) and sixty 4th graders (mean age 9.82) were administered a 2-D animal and a 3-D cube mental rotation test, a mathematics ability test, together with a self-report questionnaire devised to measure gender-stereotyped beliefs in both typical masculine, and feminine fields. Results indicated that boys scored higher than girls in mental rotation, but not in mathematics. They also highlighted that both sexes hold gender-stereotyped beliefs, and that mental rotation ability was significantly related with mathematics ability of fourth graders; however, there was no significant relationship with mathematics ability of second graders and mental rotation ability. The discussion focuses on sex differences in mental rotation, mathematics, gender-stereotyped beliefs and their relationships in childhood.

1. Introduction

Mental rotation is a type of spatial ability which requires an individual to mentally rotate spatial objects to verify how they would look from a different angle or perspective (see Reilly, Neumann, & Andrews, 2017 for a recent review). It is a very important ability related to many everyday tasks (Newcombe & Frick, 2010; Pazzaglia & Moè, 2013), and with learning (e.g., Newcombe, Levine, & Mix, 2015; Nuttall, Casey, & Pezaris, 2005), particularly in STEM fields such as engineering, physics, mathematics, chemistry, and surgery.

A large amount of research has demonstrated that men and boys outscore women and girls in mental rotation, with effects as high as up 1 *SD* (for a meta-analysis see Geiser, Lehman, & Eid, 2008). This gender gap is one of the highest ever observed in cognitive tasks. It can explain women underrepresentation in STEM fields, as shown by Wai, Lubinski, and Benbow (2009): spatial ability (spatial visualization, mechanical and abstract reasoning) at high school predict subsequent STEM entry. Consequently, it is important to ascertain when this gender gap emerges and begins to relate with achievement in fields such as mathematics, and the underlying factors. One potential factor could be the endorsement of the common-held gender stereotype that men are more talented than women in spatial and mathematical fields, which could cause stereotype threat, that is the fear of underperforming due to a negative and endorsed stereotype (Steele, 1997). Children have not always developed the typical gender-stereotyped beliefs of both masculine or feminine tasks (e.g., Neuburger, Ruthsatz, Jansen, Heil, & Quaiser-Pohl, 2013; Neuburger, Ruthsatz, Jansen, & Quaiser-Pohl, 2015), which can be observed in adults (e.g. Hirnstein, Andrews, & Hausmann, 2014). As a consequence, in this study also gender stereotypes toward a typical feminine field will be assessed, to have a measure of the children's tendency to see abilities (both masculine and feminine) in a stereotyped way: first language was chosen being verbal abilities the principal complement to spatial ones (Newcombe & Frick, 2010).

The knowledge of the age at which sex differences in performance begin to occur and the gender-stereotypes are endorsed could increase the understanding of this gender gap in cognition and its implications, including ways to combat stereotype threat effects (Johns, Schmader, & Martens, 2005; Martens, Johns, Greenberg, & Schimel, 2006). In addition, it could help to devise intervention programs to foster girls' development of mental rotation abilities, which, in turn, could either favour math performance and reduce the gender-stereotyped beliefs.

This study aimed to verify the occurrence of a gender gap favoring boys in mental rotation in eight and ten years old children, to examine the extent to which children hold gender-stereotyped beliefs in both typical masculine (mental rotation, mathematics), and feminine fields (first language), and to assess relationships among mental rotation ability, mathematics, and gender-stereotyped beliefs.

E-mail address: angelica.moe@unipd.it.

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1.1. The gender gap in mental rotation in childhood

Men consistently outperform women in mentally rotating 2-D or 3-D objects, giving rise to one of the largest six differences ever observed in cognitive tasks (e.g., Maeda & Yoon, 2013; Voyer, Voyer, & Bryden, 1995; Zell, Krizan, & Teeter, 2015). As for as children, some studies found that even five months old infants (Moore & Johnson, 2008), 4 to 5 years old children (Levine, Huttenlocher, Taylor, & Langrock, 1999), and second graders (for a review see Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005) males outperform females, while others showed that the sex difference is not significant before the age of 10 (e.g., Hoyek, Collet, Fargier, & Guillot, 2012; Titze, Jansen, & Heil, 2010a).

In sum, while it is well demonstrated that men and boys outperform women and girls in mental rotation, there is not enough research to draw conclusions about the age at which this gender gap begins to occur. Discrepant results have been found, which could depend on the kind of mental rotation task used (Voyer et al., 1995), and rotation required: in-depth, or in the picture plane, with 2-D or 3-D stimuli (e.g., Frick, Moëhring, & Newcombe, 2014). For instance, Hahn, Jansen, and Heil (2010) found that using a 'same-different' task in which children were asked if the two objects (animals) are the same, but rotated or not, female pre-schoolers aged 4.8 to 6.1 years made more errors than males with rotated, but not with upright stimuli. Using the same task with rotated animals, letters or cubes, Jansen, Schmelter, Quaiser-Pohl, Neuburger, and Heil (2013) found that 8 and 10 years old boys were more accurate than girls with letters or with animals as stimuli, only at the highest angular disparity, but not with cubes, and that overall boys were faster than girls. Neuburger, Jansen, Heil, and Quaiser-Pohl (2011) demonstrated that while overall 10 year-old children outperformed 8 year-old, no age-related difference occurred for girls in the cube-stimuli condition, which is more difficult requiring rotating 3-D stimuli in depth. Finally, further confirmation of the importance of the stimuli characteristics and difficulty for the sex effect to occur with children came from the study of Ruthsatz, Neuburger, Jansen, and Quaiser-Pohl (2015) who found that the cubes were perceived as more masculine than feminine by children aged 8.83 to 11.83, and that the sex difference in performance occurred only with cubes rotated in-depth. Consequently, in this study, to assess the occurrence of sex differences in mental rotation with primary school children, both a 2-D animals and a 3-D cubes version were used.

1.2. Mathematics and mental rotation relationships

Higher-level mathematical skills relate with mental rotation abilities in college students (for reviews see Halpern, 2000; Wai et al., 2009), while there is a paucity of studies with primary school children (Bruce & Hawes, 2015). Interestingly, with college students, Thompson, Nuerk, Moeller, and Kadosh (2013) found that mental rotation relates also with basic processing of numbers (e.g., processing of decade and unit digits, and number magnitude comparison). This suggests that the relation between mathematics and mental rotation can begin early, from primary school, when the basic knowledge of mathematics is acquired. However, to the best of our knowledge, there is no study assessing this relationship between mental rotation and mathematics in a cross sectional study in primary school children.

Various spatial abilities, such as assembly skills assessed at age 3 (Verdine et al., 2014), block design and mental rotation in first grader girls (Casey et al., 2015), block building (Kersh, Casey, & Young, 2008), mental transformation abilities in first and second graders (Gunderson, Ramirez, Beilock, & Levine, 2012) relate with subsequent math abilities. These results from longitudinal studies suggest that performance in a particular spatial ability which is mental rotation could relate with mathematics ability. However the results from training studies, based on the assumption that improving spatial skills favours achievement in STEM domains (Uttal, Miller, & Newcombe, 2013), were not conclusive. In 7 year-old children mathematics was favoured immediately after mental rotation training (Cheng & Mix, 2014), but not when tested a few days later (Hawes, Moss, Caswell, & Poliszczuk, 2015). This suggests that the link between mental rotation and mathematics in primary school children is not so clear and that further research is needed to better understand if it occurs and at which ages. This knowledge could be important in explaining sex differences in attitudes toward mathematical and spatial tasks.

1.3. Gender-stereotyped beliefs and performance

The magnitude of the sex difference in mathematics achievement is overall very small (Cohen's d = 0.15: boys higher scores), when measured with standardized test and in favour of girls when assessed through marks (Voyer & Voyer, 2014). However, even if small, it differs among countries (Else-Quest, Hyde, & Linn, 2010). For Italy, where this study was undertaken, averaging math, algebra, data, geometry, measurement, and number (TIMSS), for 14–16 year-old students it is 0.08 (only in data and measurement it is 0.15). The PISA results show a Cohen's d equal to 0.15 for math confirming the very small effect. Therefore, the prediction in this study is to also find no sex difference in mathematics with primary school students.

Even if the sex difference in math performance is small to null, boys are more self-confident than girls in math (Hyde, Fennema, Ryan, Frost, & Hopp, 1990) and report more positive math attitudes and affect than girls (Cohen's ds ranging from 0.10 to 0.33) (Else-Quest et al., 2010). Considering the Italian context, boys score slightly higher than girls in math self-confidence (Cohen's d = 0.18), but the difference is higher for value assigned to math (Cohen's d = 0.27) and math self-efficacy (Cohen's d = 0.36) suggesting that at ages 14–16 there is a stereotype favoring boys who in fact deem math more important than girls. This gender stereotype about math abilities and that regarding spatial abilities have been directly studied in a few studies yielding to inconclusive results about the age they emerge. Cvencek, Meltzoff, and Greenwald (2011) found, using either explicit and implicit measures, that children believe that math is for boys starting from age 8, and that boys identify with math more strongly than girls do. Differently, Neuburger et al. (2015) showed that only 10 year-old boys consider themselves more able than girls in math, and that children aged 10 believe with no sex distinction that boys are better than girls in mental rotation; although Neuburger et al. (2013) found that only boys hold this stereotype. Interestingly, Vander Heyden, van Atteveldt, Huizinga, and Jolles (2016) confirmed with 10 and 12 year-old students that both sexes considered spatial abilities as masculine, using an explicit measure, while with an implicit measure (the Implicit Association Test for children) only boys held the stereotype, while girls were gender-neutral. In the Italian context, Passolunghi, Rueda Ferreira, and Tomasetto (2014) found that only 14 year-old students hold the explicit stereotype of males as being more talented in math, while 9 year-old children considered their sex as more talented and only 11 years old boys believed males to be more talented.

These beliefs could cause less confidence in women (Estes & Felker, 2012), less practice with spatial tasks (e.g., Feng, Spence, & Pratt, 2007), higher anxiety levels (Ferguson, Maloney, Fugelsang, & Risko, 2015) and, as a consequence, reduced performance (Levine, Foley, Lourenco, Ehrlich, & Ratliff, 2016), to the point of confirming the stereotype, through stereotype threat effects (Steele, 1997). However, this is not always the case. In fact, recent meta-analyses showed that overall effects of induced stereotypes are small to null and that some important mediators can make the difference. Doyle and Voyer (2016) confirmed that only women's math performance, but not spatial performance, was affected negatively in the threatening condition, while men were unaffected. This suggests that the awareness of the stereotype matters. In fact women are usually more aware of the stereotype about their poor abilities in math, while the same awareness does not apply for mental rotation. Similarly men could not endorse the math stereotype given