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Does experience with spatial school subjects favour girls' mental rotation performance?

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ABSTRACT

Most men outperform women in mental rotation and this can explain their overrepresentation in STEM fields where spatial abilities are required. Beyond genetics, a wide range of often interacting factors can account for the gender gap in mental rotation: experiential, strategic, cultural, and motivational. This study considered type of school and explanations about gender differences. A sample of 221 adolescent students (mean age 14.86, 162 girls) attending either a Low Spatial Thinking (LST, $n = 120$) or a High Spatial Thinking (HST, $n = 101$) type of school performed a mental rotation task, and received instructions suggesting three different explanations (genetic, common-held stereotype, women anxiety) for boys outscoring. Girls' mental rotation scores were higher in the HST than in the LST type of school. Boys scored higher than girls in the LST but not in the HST type of school. The common-held stereotype instructions, suggesting a controllable attribution for gender differences, increased performance only for girls in the HST type of school. Results are discussed within a bio-psycho-social view of gender individual differences in mental rotation.

1. Introduction

Common sense, anecdotes, gender beliefs and gender roles assign to men or women, boys or girls different abilities and attitudes, but do men and women really perform differently in cognitive tasks? Scientists have tried to solve this debate by concluding that women and men or girls and boys are more alike than different, at the same time showing that a few cognitive differences do exist (Halpern, 2012; Halpern et al., 2007). Even assuming the most extreme position of the gender similarity hypothesis (Hyde, 2005), there is an ability in which men consistently outperform women (Voyer, Voyer, & Bryden, 1995): mental rotation, i.e. the capacity to operate mental rotations with 3-D or 2-D objects (e.g., Hausmann, Schoofs, Rosenthal, & Jordan, 2009). This is fundamental in performing many everyday tasks ranging from driving, finding a route on a map (e.g. Pazzaglia & Moè, 2013), finding one's direction, to learn, especially when this relates to representing and understanding subjects like geology, biology, chemistry, physics, geometry, mathematics: those involved in STEM career choice and success (Wai, Lubinski, & Benbow, 2009).

1.1. The gender gap in mental rotation: explanations

Women underperform men in mental rotation by .52 to 1.49 standard deviations (Geiser, Lehman, & Eid, 2008): a large effect. This gap, which can be observed from the age of 4–5 months (Moore & Johnson, 2008), increases with age (Geiser et al., 2008), and can help to explain why women are so underrepresented in STEM fields (National Science Foundation, 2011). Research has focused on explanations for this gender gap and on ways of helping women to increase their mental rotation performance.

Given that men and boys consistently score higher than women and girls, neural and hormonal differences have been suggested as being the cause of this stable gender gap. Gender differences in activation have been found in performing a mental rotation task (Alivisatos & Petrides, 1997; Richter, Ugurbil, Georgopoulus, & Kim, 1997). Women show bilateral activation, while men activate mainly the right areas resulting in higher efficiency and greater performance (Jordan, Wuestenberg, Heinze, Peters, & Jaencke, 2002; Hugdahl, Thomsen, & Ersland, 2006). These structural differences could reflect prenatal and early postnatal testosterone exposure which has been found to produce stable organizational effects, in particular a greater development of the right hemisphere on which spatial tasks rely more (Halpern, 2012), as well as to favour sex-typed preferences and hence greater experience with spatial toys, activities or games. In addition, activational effects due to circulating testosterone have been found in normal (e.g., Hausmann, Slabbekoorn, Van Goozen, Cohen-Kettenis, & Güntürkün, 2000), as well as in clinical populations (Puts, McDaniel, Jordan, & Breedlove, 2008) and interestingly in girls having a male twin who were exposed to high levels of androgens in utero (Tapp, Maybery, & Whitehouse, 2011).

Although these results support a biological explanation, evidence is mixed, suggesting that circulating testosterone did not necessarily relate to spatial performance, where moderate and not high levels of

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androgens appear to favour performance in spatial tasks, and where women and men can achieve the same cognitive results using different brain regions (for a review see Miller & Halpern, 2014). This suggests that other interactive factors also play an important role. For instance, Hausmann et al. (2009) found that the activation of gender stereotypes leads to an increase in testosterone levels in men, which, in turn, favour mental rotation performance. Among the most studied factors are experience with spatial tasks (Ginn & Pickens, 2005), the number of masculine activities performed (Flaberty, 2005), role models (Neuburger, Ruthsatz, Jansen, Heil, & Quaiser-Pohl, 2013), testing situation (Hirnstein, Andrews, & Hausmann, 2014), response strategies (Hirnstein, Bayer, & Hausmann, 2009), and stereotypes activation (Wraga, Helt, Jacobs, & Sullivan, 2007). Due to the common-held stereotype of poor spatial abilities, women experience a stereotype threat during the testing situation that causes reduced performance (Hausmann et al., 2009; Moè & Pazzaglia, 2006), independently of their ability: women majoring in science underperformed men and non-stereotyped women when primed about their academic programme (Hausmann, 2014).

1.2. Effects of training and sustained exposure to spatial tasks

Mental rotation abilities can be improved by training (Uttal et al., 2013; Uttal, Miller, & Newcombe, 2013), practising spatial tests (Wright, Thompson, Ganis, Newcombe, & Kosslyn, 2008), and sketching 3-D objects (Sorby, 2009), resulting in improved STEM learning (Uttal, Miller & Newcombe, 2013). These improvements can be long lasting and transfer to other tasks (Stransky, Wilcox, & Dubrowski, 2010) provided that sustained exposure is guaranteed. For instance, Miller and Halpern (2013) found that 12 h of spatial training improved mental rotation ability and scores in physics and reduced the gender gap, but these effects disappeared in an 8-month follow-up.

Moreover, it is possible that positive beliefs play a role, mediating the effects of training. Both points, namely sustained exposure and positive beliefs, will be developed further in this study.

1.3. Beliefs and mental rotation performance

Among the positive beliefs, previous studies have considered those based on identity (to attend a selective private college: McGlone & Aronson, 2006), positive stereotypes (women or girls were told they perform better than men or boys: Heil, Jansen, Quaiser-Pohl, & Neuburger, 2012; Moè & Pazzaglia, 2006; Moè, 2009), effort attribution (Moè & Pazzaglia, 2010), self-affirmation (Martens, Johns, Greenberg, & Schimel, 2006), incremental view of spatial abilities (Moe, Meneghetti, & Cadinu, 2009), and externalizing the reason for underperforming (Moè, 2012). In all of these enhancing situations, an increase in women's or girls' performance has been found, sometimes reaching the level of men's or boys' performance (Campbell & Collaer, 2009; Moè, 2009; Wraga, Duncan, Jacobs, Helt, & Church, 2006).

1.4. Academic programme and mental rotation

Some school subjects such as design, geometry, physics, and chemistry require great mental rotation abilities and spatial thinking. These subjects are tackled on a frequent or even daily basis in some schools and to a lesser degree in others. This could result in increased or decreased perception of competence and identification with the domain, as well as increased confidence and reduced anxiety, which have been shown to be related with mental rotation performance (e.g., Estes & Felker, 2012; Ramirez, Gunderson, Levine, & Beilock, 2012). In fact, students majoring in the physical sciences have been found to score higher in mental rotation than those majoring in arts or social sciences (Peters et al., 1995; Hausmann, 2014), with greater effects for men who use more effective strategies (Li & O' Boyle, 2008). Due to experience with spatial materials and tasks, science rather than art students improve mental rotation ability in their first year of university (Moreau, Mansy-Dannay, Clerc, & Guerrien, 2010). In addition, beliefs also play a crucial role, and sometimes cause, maintain or increase the gender gap, as shown by Hausmann (2014): priming participants' academic programme activates gender stereotypes and causes reduced performance in women, regardless of whether they are majoring in the arts or sciences.

Differences due to academic programme have been found in both genders in four cultures (Peters, Lehmann, Takahira, Takeuchi, & Jordan, 2006), but the gender gap is nonetheless maintained, except for women majoring in math-science fields with a genetic predisposition and high spatial experience (Casey & Brabeck, 1990), in music students compared to those majoring in sports and education (Pietsh & Jansen, 2012), and for non-stereotyped science students (Hausmann, 2014).

Whether or not the gender gap is maintained, reduced or disappears completely, these studies, when conducted on young adult participants rather than on adolescent students, suggest that effects due to type of school exist and can account for (gender) individual differences in mental rotation. It is true that to date, only university students aged 19–25 were considered, while high school, adolescent students were not examined at all. This is surprising because it is precisely during adolescence that students develop their preferences and choose their university degrees in line with previous experiences and skills developed at high school (Eccles, 2005), and with the skills and abilities they already possess (Wai et al., 2009).

1.5. The current study: aims and hypotheses

Due to the importance of both beliefs and experience with spatial tasks in helping women and girls improve their spatial abilities, this research studied the effects of induced beliefs in two groups of adolescent students attending either a school with many spatial subjects on its curriculum, or a school with few. Given that the focus is to study girls' mental rotation performance, two schools attended mainly by girls were selected. The first deals largely with spatial school subjects, such as geometric and plastic design and art, while in the second the main subjects are classical and modern languages and literature, which require mainly verbal processes.

The first aim was to compare mental rotation abilities in girls and boys attending the two high schools where subjects implying mental rotation or spatial processing (e.g. design, graphic arts) are offered to a greater extent or to a lesser degree. Considering that experience with spatial tasks and training raise performance, and that differences due to academic programme have been detected in university students majoring in social sciences or physical sciences, hypothesis 1 was that a difference in mental rotation performance would arise between students attending the two types of school. More specifically, girls are expected to score higher in mental rotation in the school offering more spatial subjects compared to girls attending the other school and to boys.

The second aim was to study the effects of beliefs on performance. A previous study conducted in a mixed gender context showed increased performance for both genders after instructions stressed that women underperform due to external reasons (stereotypes or time limits) rather than to more stable genetic reasons, compared with a control condition in which participants were told there was a gender difference favouring men, but without any explanation provided (Moè, 2012).

Hypothesis 2 was that girls improve mental rotation performance following instructions that liberate them from the fear of being incapable, due to supposed genetic differences. These girls should benefit from instructions that stress that a common-held stereotype, and not an inability to afford the task, is the real reason for underperforming mainly in the HST school where girls have greater experience with spatial tasks. It is expected that girls improve performance more after the stereotype instruction than after the genetic instruction, which is expected to