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Teaching motivation and strategies to improve mental rotation abilities

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ABSTRACT

Mental rotation is a critical ability for succeeding in Science, Technology, Engineering, and Mathematics (STEM) fields. It has been widely demonstrated that men outperform women in mental rotation. However, women can improve their performance if trained to use effective strategies and if they practice using spatial tasks. This study tested the hypothesis that training motivation is an effective tool to increase women's mental rotation scores. Two experiments showed that women trained to believe they can succeed and instructed to use holistic strategies increased their mental rotation scores as much as 1 SD, to the point of reaching or going beyond men's scores before training. The results were achieved in a 1 h training session and by comparing both repeated testing and active control groups. The discussion focuses on the importance of motivational factors in explaining the gender gap in mental rotation and in STEM careers.

Gender differences in cognition, behavior, and attitudes are commonly held beliefs, but to what extent are they reality, or merely false stereotypes? Referring to gender as the result of socio-cultural and experiential factors, even scientists hold contrasting views, ranging from the gender similarity hypothesis (Hyde, 2005) to demonstrating that differences are even higher than believed (Halpern, Straight, & Stephenson, 2011), particularly in some domains. Among them there is mental rotation, that is the ability to mentally maintain, manipulate, and rotate 2-D or 3-D objects in the space accurately and rapidly (Shepard & Metzler, 1971). Mental rotation is a component of intelligence (Kaufman, 2007), is crucial for carrying out many everyday tasks, such as orienting (Pazzaglia & Moè, 2013), or performing motor actions (Moreau, Clerc, Mansy-Dannay, & Guerrien, 2012), and to learn school subjects such as biology, chemistry, physics, or geometry (Peters, Lehmann, Takahira, Takeuchi, & Jordan, 2006). Mental rotation skills also predict entry in STEM fields (Wai, Lubinski, & Benbow, 2009), so that women under-representation in STEM careers could be partially explained by their low mental rotation ability.

Men score higher than women in mental rotation tests (Peters, Laeng, Latham, & Jackson, 1995; Vandenberg & Kuse, 1978): the Cohen's d ranging from 0.52 to 1.49 (Geiser, Lehman, & Eid, 2008). Research showed that many factors explain this gender gap, ranging from biological to social, motivational and experiential (Halpern, 2012). Moreover, spatial ability is malleable and it can be changed through spatial training sessions which are effective, with a mean effect size of Hedges' $g = 0.47$ (Uttal, Miller, & Newcombe, 2013). However, surprisingly due to their importance, the role played by motivational aspects in favoring training effectiveness has never been explored. This study will test for the first time the effectiveness of including motivational aspects in trainings aimed at improving mental rotation ability.

1. Motivational factors affecting mental rotation performance

A range of motivational factors such as an incremental theory of masculine abilities (Moè, Meneghetti, & Cadinu, 2009), defined as the belief that abilities are not fixed, but they can change over time, confidence (Estes & Felker, 2012), effort attribution (Moè & Pazzaglia, 2010), and the stereotyped view of mental rotation as an innate male ability (Moè, 2012) have been proven to affect mental rotation performance.

Women adopt a more conservative strategy when solving mental rotation items compared to men (Hirnstein, Bayer, & Hausmann, 2009). This could depend on their level of anxiety (Ramirez, Gunderson, Levine, & Beilock, 2012), which in turn can arise from the testing situation (Hirnstein, Andrews, & Hausmann, 2014), gender role beliefs (Massa, Mayer, & Bohon, 2005; Ortner & Sieverding, 2008), or stereotypes (Moè, 2012; Wraga, Helt, Jacobs, & Sullivan, 2007).

Women tend to underperform when the testing situation (mixed-gender) or instructions prime the common-held stereotype of their poor spatial abilities (Moè, 2009). However, their mental rotation scores increase when invited to self-affirm (Martens, Johns, Greenberg, & Schimel, 2006), to think about positive identities (McGlone & Aronson, 2006), to believe that women score higher than men (Moè & Pazzaglia, 2006; Wraga, Duncan, Jacobs, Helt, & Church, 2006), to be more confident (Estes & Felker, 2012), to attribute good performance to effort (Moè & Pazzaglia, 2010), to recognize that the source of gender individual differences is not 'innate ability' but false stereotypes or anxiety arousing from the time limit set (Moè, 2012). In addition, it has been shown that the more women believe they are able to improve

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when carrying out stereotypical masculine tasks (e.g., solving math problems, building or repairing something) the higher their mental rotation scores and their use of the most useful strategies based on processing the stimuli holistically (Moè, 2009).

2. Strategic factors affecting mental rotation performance

There are notable gender differences in strategies used to approach the mental rotation tasks. On average, men seem to prefer using holistic strategies based on processing the stimuli globally, which are more effective, while women adopt more piecemeal strategies, based on rotating a single arm of the configuration or counting the cubes (e.g., Heil & Jansen-Osmann, 2008), which are less effective (Janssen & Geiser, 2010; Schultz, 1991). Studies using fMRI found that in performing mental rotation tasks men show right parietal activation, women inferior frontal activation (e.g., Hugdahl, Thomsen, & Ersland, 2006; Thomsen et al., 2000; Weiss et al., 2003). This suggests that women rely mainly on effortful control (Hjelmervik, Westerhausen, Hirnstein, Specht, & Hausmann, 2015), analytical (Jordan, Wüstenberg, Heinze, Peters, & Jäncke, 2002), and reasoning strategies (Thomsen et al., 2000), based on a serial, categorical approach (Hugdahl et al., 2006). Differently men use more holistic-gestalt strategies (Jordan et al., 2002), which are automatic and effective "bottom-up" modalities (Butler et al., 2006), based on a coordinate processing approach (Hugdahl et al., 2006). These asymmetries can be observed even in preschoolers (Hahn, Jansen, & Heil, 2010) and do not disappear even when men and women are paired for mental rotation ability (Jordan et al., 2002).

This result suggests that many interacting factors matter and contribute to explain the gender gap. Following a bio-psycho-social view, the genetic predisposition, assessed in women through familial handedness patterns (right-handers with at least one non right-handed relative: Casey, 1996), does not favor performance per se, but it helps because it fosters in both genders experience with spatial tasks and activities (Cherney & London, 2006; Ginn & Pickens, 2005), and use of holistic strategies (Geiser, Lehmann, & Eid, 2006), resulting in higher confidence in succeeding (Hirnstein et al., 2009), and spatial ability self-perceptions (Halpern, 2012), which are critical experiential and motivational factors.

3. Improving mental rotation abilities

As shown in two meta-analyses (Baenninger & Newcombe, 1989; Uttal et al., 2013), mental rotation abilities can be improved by training sessions that focus on practicing with spatial tasks and materials: not only the training sessions are effective, but also the advantages maintain, and transfer to other spatial tasks. The improvement in mental rotation scores as a result of training could be due to the use of holistic strategies, to increased motivation or both: performing spatial tasks and appraising to be able to solve them should favor the subsequent use of holistic strategies as well as sustain confidence and ability perception. This speculation could be tested directly by teaching those strategies and motivations and allowing exercising with mental rotation tasks. However, none of the studies quoted (over 200 in Uttal et al., 2013) explicitly considered motivational factors and only a few directly taught holistic strategies.

Studies which followed or were not considered in these meta-analyses confirmed that teaching strategies based on processing the stimuli holistically (Sorby, 2009), and practicing with spatial tasks (Sorby, Casey, Veurink, & Dulaney, 2013) or mental rotation items improve mental rotation scores, and reduce the gender gap (Miller & Halpern, 2013; Stieff, Dixon, Ryu, Kumi, & Hegarty, 2014). These effects maintain in the long term (Meneghetti, Borella, & Pazzaglia, 2016), and apply to a range of populations (Newcombe & Frick, 2010). Furthermore, teaching effective strategies to solve the mental rotation items also cause changes in brain activation (Jaušovec & Jaušovec, 2012; Neubauer, Bergner, & Schatz, 2010), gray matter density (Draganski et al., 2004), and increase learning in geology (Sanchez, 2012). The effect sizes reported in these recent studies are about half of a standard deviation (e.g. Jaušovec & Jaušovec, 2012; Miller & Halpern, 2013), confirming the results of Uttal et al. (2013).

4. The current study

Given the importance of motivational factors in favoring mental rotation performance, this study represented a first-time attempt at comparing the effects of a 'classic' training program which focused on teaching strategies and allowing practice with spatial tasks, with a 'new' motivational training aimed at fostering competence perception, effort attribution, and counter-stereotypical beliefs. In addition, a third kind of training approach, which considered both motivational and strategic aspects, has been included. It is predicted that a training focused on having practice with using holistic strategies will result in improvements linked with the adoption of more effective modalities to solve the mental rotation items, as demonstrated in previous studies even in a brief single-session intervention (Stransky, Wilcox, & Dubrowski, 2010). Training motivation will favor performance because participants will be more confident, perceive more able and capable to increase their performance, and previous studies showed the importance of these motivational aspects. Training motivation and teaching effective strategies will favor because both strategic and motivational aspects are sustained. Repeated testing (control condition) is expected not to favor performance or to favor only slightly, because no motivation is fostered and no strategy is taught, but only practice with mental rotation items is allowed.

5. Experiment 1

5.1. Method

5.1.1. Participants

One-hundred undergraduate psychology students, 78 women ($M_{age} = 19.32$, $SD = 0.84$) participated on a voluntary basis or for course credits and were randomly assigned to one of four groups (repeated testing, strategic, motivational or motivational and strategic, see Second Section description) on the basis of their matriculation number, see Table 1.

Table 1
Number of participants and mean age in the four/five groups.

Groups	Experiment 1			Experiment 2		
	Men	Women	Mean age (SD)	Men	Women	Mean age (SD)
Strategic	6	20	19.33 (0.92)	3	16	20.50 (1.51)
Motivational	7	19	19.13 (0.61)	7	12	20.38 (0.81)
Motivational and strategic	3	21	19.30 (0.80)	8	14	20.18 (1.05)
Repeated testing	6	18	19.50 (0.98)	5	16	20.58 (1.12)
Active control				5	19	20.35 (0.49)