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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)

5.1.2. Materials and procedure

5.1.2.1. First session. Participants were tested collectively in a large classroom, letting at least a seat free between them, to avoid cheating. After asking for verbal consent for participation, they were read the instructions on how to perform the mental rotation test, which they could also read printed on a sheet, and required to solve three example items. On completion, and after having confirmed that they understood the task, they were allowed 3 min to solve the first 12-item MRT-A (Peters et al., 1995), followed by a 3-min break and finally a further 3 min to solve the last 12 items. Participants received the test face down by two female experimenters and were instructed to turn it over and to begin to fill it in at the experimenters' start signal. At the stop signal they had to place the pen on the table even if they had not finished the test (which is usual, given the short time provided). Before collecting the sheets, participants were asked to report their matriculation number in order to be able to match the data of the three sessions. Finally, the experimenters communicated the group membership, time and room for the next session.

5.1.2.2. Second session. The subsequent week, the single groups were met the same day in different times by the same two experimenters in a smaller classroom. The repeated testing group ($n = 24$) was only tested with the same procedure of the first day using the parallel version MRT-B, then thanked and reminded to come back the following week. The three training groups were first presented two slides showing what the mental rotation test is, and outlining the importance of mental rotation. Subsequently, instructions differed among groups. The strategic group ($n = 26$) was presented a slide showing that successful performance depends on using holistic rather analytic strategies whose effectiveness was stressed with a graph showing increasing slopes (scanned from Terlecki, Newcombe, & Little, 2008). Then, participants were shown a slide with a green box including three holistic strategies (to rotate the target until it matches with the stimuli, to rotate the stimuli to see if they match the target, to rotate the stimuli globally) and a red box with two analytic strategies (to count the cubes, to rotate the stimuli piece by piece). Finally, the participants were invited to practice the holistic strategies with 20 mental rotation items from Vandenberg and Kuse (1978), which they received printed on a sheet. For each item, one of the experimenter pointed at each stimulus once a time and 'rotated' it eventually with the hands and the body to see if it matched with each of the proposed rotations. Then, she showed the correct rotations and the wrong ones explaining why they were or not rotated versions of the target. The motivational group ($n = 26$), after being shown the two common slides, was presented a slide outlining that successful performance depends on 'believing in succeeding' and 'perceiving to be able to do it', with a couple of graphs from previous studies (Moè, 2012; Moè & Pazzaglia, 2010) which were described. Then they were presented a list of 7 typical masculine (e.g., finding the quickest way to reach a place, building or repairing something), 5 feminine (e.g., learning a foreign language, feeling others' emotions), and 3 gender-neutral (e.g., paying attention during a lecture, being curious about learning new things) activities. One of the experimenter read each activity once a time and asked the participants, involved in turn, if, in their opinion, there are gender differences in that activity and if they think that the underlying ability can be improved. This way, in the group there was always someone declaring there are substantial differences or no gender difference, no improvement or every improvement possible, so that to ensure the occurrence of contrasting beliefs and opinions. Finally, the experimenter (who was their Psychology of Personality teacher) reassumed the results of the discussion and provided experimental evidences that everybody can succeed and that gender differences (if any) depend on practice with the task, attributional beliefs and perceived ability which are controllable factors that can be changed resulting in performance improvements. The motivational and strategic training group ($n = 24$) was presented with the same two common slides, and the two slides of the strategic and motivational training groups with the graphs showing that both effective strategies and adaptive motivations contribute toward explaining successful performance. Subsequently, they were presented a slide with 4 masculine, 3 feminine and 1 gender-neutral abilities, and invited to believe that everybody could succeed, and to be aware of the importance of perceiving themselves as able. Finally, they were shown a last slide which depicted that holistic strategies are the most effective, and they were guided – in the same way as the strategic group - to practice with 10 items of the MRT (Vandenberg & Kuse, 1978). All three training sessions lasted 1 h, see Appendix for the whole set of slides used to support teaching. Finally, the three training groups were asked to perform the MRT-B as the repeated testing group, thanked for participating and reminded to come back for the last session, the following week.

5.1.2.3. Third session. All the participants were called again and administered the MRT (Peters et al., 1995) as in the first session. Given that there is no further parallel or equally difficult version, participants received either items1–12 of MRT-A and items13–24 of MRT-B, or items 1–12 MRT-B and items 13–24 MRT-A. Finally, they were thanked again, debriefed and greeted.

5.1.3. Scoring

The mental rotation score – for each of the three submissions - was the number of correctly solved items, namely those in which both of the two correct alternatives were chosen: maximum score 24.

5.2. Analyses and results

A preliminary analysis showed no difference in mean scores between participants receiving first half MRT-A, second half MRT-B or the opposite (third session). A MANOVA 4 (groups: strategic, motivational, motivational and strategic, repeated testing) × 2 (gender) × 3 (sessions: pre-training, post-training, one week follow-up) run on mean mental rotation scores revealed the following effects: gender $F(1, 92) = 8.06$, $p = 0.006$, $\eta_p^2 = 0.08$ (men $M = 14.31$, $SE = 1.14$, 95% CI 12.05–16.57, women $M = 10.70$, $SE = 0.57$, 95% CI 9.56–11.83, Cohen d 0.56), groups $F(3, 92) = 9.96$, $p < 0.001$, $\eta_p^2 = 0.24$ [mean values (SE and 95% CI in brackets) were 13.66 (1.18; 11.33–16.00), 14.52 (1.12; 12.30–16.74), 15.05 (1.56; 11.95–18.15), and 6.78 (1.19; 4.41–9.14) respectively for strategic, motivational, motivational and strategic, and repeated testing groups], sessions $F(1, 92) = 37.98$, $p < 0.001$, $\eta_p^2 = 0.29$ [mean values (SE and 95% CI in brackets) were 8.72(0.56; 7.61–9.84), 14.14 (0.75; 12.65–15.63), and 14.65 (0.77; 13.12–16.17) respectively pre-training, post-training, and in the one week follow-up], and interaction groups by sessions, $F(3, 92) = 10.25$, $p < 0.001$, $\eta_p^2 = 0.25$.

Given that no interaction involving gender was found, and due to the small number of men in each group, only women's performances were then analyzed through a MANOVA 4 (groups: strategic, motivational, motivational and strategic, repeated testing) × 3 (sessions: pre-training, post-training, one week follow-up) leading to the following effects: groups $F(3, 74) = 7.95$, $p < 0.001$, $\eta_p^2 = 0.24$ [mean values (SE and 95% CI in brackets) were 11.88 (1.12; 9.64–14.12), 11.19 (1.15; 8.90–13.49), 13.65 (1.10; 11.47–15.83), and 6.06 (1.18; 3.70–8.41) respectively for strategic, motivational, motivational and strategic, and repeated testing groups], sessions $F(1, 74) = 38.06$, $p < 0.001$, $\eta_p^2 = 0.34$ [mean values (SE and 95% CI in brackets) were 7.06 (0.48; 6.10–8.02), 12.05 (0.67; 10.71–13.39), and 12.98 (0.69; 11.59–14.36) respectively pre-training, post-training, and one week follow-up], and a 2-way interaction, $F(3, 74) = 8.67$, $p < 0.001$, $\eta_p^2 = 0.26$, see Fig. 1.

Post-hoc comparisons showed that a) for the three training groups, scores at pre-training differed from scores at post-training and one-week follow-up (all $ps < 0.005$), while scores at post-training did not differ from scores at the one-week follow-up; b) for the repeated testing group, scores at the one-week follow-up session differed from scores at both pre- and post-training, all $ps < 0.001$, while scores at pre- and post-

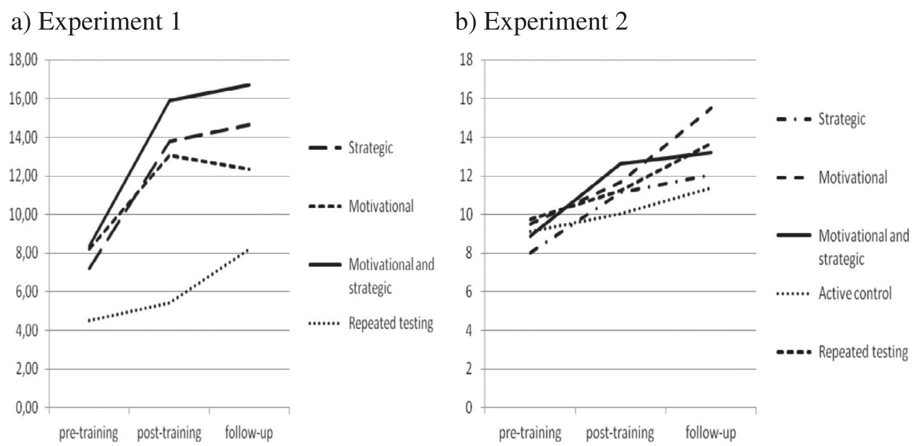

Fig. 1. Mean scores pre-training, post-training, and in the one-week follow-up. Women sub-sample. Note that mean men score pre-training is 10.68 in Experiment 1 and 13.50 in experiment 2.

training did not differ. Cohen *d* for comparison pre- vs post-training for the three strategic, motivational and motivational and strategic training groups were respectively 1.23, 0.86, and 1.61, all large effects. The mean scores obtained by trained women ($n = 60$) in the post-training ($M = 14.30$, $SE = 0.84$) and in the follow-up ($M = 14.63$, $SE = 0.86$) sessions were higher than that achieved by men in the pre-training session ($M = 10.68$, $SE = 1.25$): $t(80) = 2.28$, $p = 0.025$, and $t(80) = 2.45$, $p = 0.017$.

5.3. Interim discussion

As predicted, the three training groups improved performance as an effect of training. Training motivation was as helpful as training strategies. Additionally, it was found that women after training reached a performance higher than that of men. The repeated testing group increased performance from the second to the third administration of the MRT probably as an effect of repeated practice, as in previous studies (e.g., Peters et al., 1995; Terlecki et al., 2008).

It is important to note that the repeated testing group had low mental rotation scores since the pre-training session. Only in the follow-up session did it reach a mean value close to that of the three training groups in the pre-training session, maybe due to practice with mental rotation items or to regression to the mean. In addition, it was a passive control group that was not involved in anything, but nonetheless repeatedly performed the MRT without receiving any particular instruction, and who met the experimenters less time than the other training groups. To solve these issues and for replicability of the results a second experiment was set up by adding a different control group (active) involved in practicing with verbal materials. This latter group was given information about the MRT, as was done with the other groups, and practiced with verbal tasks in a 1 h training session. It was predicted that this group without strategic, or motivational training would not improve mental rotation performance or else improve slightly as a result of repeated practice or even of knowing the importance of mental rotation in a range of tasks, which is a motivational factor, favoring performance if perceived as a challenge, or impairing it if perceived as a threat (Putwain & Symes, 2014).

6. Experiment 2

6.1. Method

6.1.1. Participants

One hundred-five undergraduate psychology students (77 women), $M_{age} = 20.39$, $SD = 1.01$, participated to obtain course credits and were randomly assigned to one of five groups (repeated testing, active control, strategic, motivational or motivational and strategic, see Materials and procedure description) on the basis of their matriculation number, see Table 1.

6.1.2. Materials and procedure

These were the same as those used in Experiment 1, but with a new active control group. In the second session, after having presented the two common slides, participants were involved in verbal tasks, such as 'Define the following four words (4 min): to label, friendly, to interact, new-born', 'write at least 7 words containing "mbr" (2 min)'. The cover story (third slide, see Appendix) was that 'cognitive' exercises favor cognitive processes on which mental rotation is based. Subsequently, this group was tested in the same way as the others.

Finally, in a follow-up collective session, the participants were debriefed, and it was stressed that both strategic and motivational factors matter, whereas practicing with verbal tasks did not favor performance. The mean pre-training and post-training scores of the five groups were shown so that the participants - mainly those assigned to the repeated testing or active control groups - left the experimental situation with the correct information on ways of scoring at best in mental rotation.

6.2. Analyses and results

A MANOVA 5 (groups: strategic, motivational, motivational and strategic, active control, repeated testing) × 2 (gender) × 3 (sessions: pre-training, post-training, one week follow-up) run on mean mental rotation scores, revealed the following effects: gender $F(1, 95) = 13.43$, $p < 0.001$, $\eta_p^2 = 0.12$ (men $M = 15.28$, $SE = 0.97$, 95% CI 13.36–17.20, women $M = 11.18$, $SE = 0.56$, 95%, CI 10.08–12.29, Cohen *d* 0.92), groups, $F(4, 95) = 3.23$, $p = 0.016$, $\eta_p^2 = 0.12$ (strategic $n = 19$, $M = 12.70$, $SE = 1.52$, 95% CI 9.68–15.72, motivational $n = 19$, $M = 15.59$, $SE = 1.15$, 95% CI 13.30–17.87, motivational and strategic $n = 22$, $M = 15.31$, $SE = 1.07$, 95% CI 13.18–17.43, active control $n = 24$, $M = 11.29$, $SE = 1.21$, 95% CI 8.87–13.70, repeated testing $n = 21$, $M = 11.28$, $SE = 1.24$, 95% CI 8.82–13.74), and sessions, $F(1, 95) = 76.59$, $p < 0.001$, $\eta_p^2 = 0.45$ [mean values (SE and 95% CI in brackets) were 10.88 (0.54; 9.81–11.95), 13.52 (0.59; 12.34–14.69), and 15.30 (0.69; 13.93–16.67) respectively pre-training, post-training, and in the one week follow-up].

As in Experiment 1, given that no interaction involving gender was found, and due to the small number of men in each group, only women performances were then analyzed revealing significant main effect sessions $F(1, 72) = 62.79$, $p < 0.001$, $\eta_p^2 = 0.47$ [mean values (SE and 95% CI in brackets) were 9.04 (0.53; 7.99–10.09), 11.35 (0.60; 10.15–12.54), and 13.17 (0.70; 11.77–14.56) respectively pre-training, post-training, and one week follow-up sessions], and a 2-way interaction groups by sessions $F(4, 72) = 2.98$, $p = 0.025$, $\eta_p^2 = 0.14$, see Fig. 1.

Post-hoc comparisons showed that for the motivational and strategic and strategic training groups, the pre-training score was lower ($ps < 0.003$) than the post-training and follow-up ones, which did not differ from each other, suggesting improvements since the beginning, as in Experiment 1. The motivational training group showed substantial improvements in the one-week follow-up session, gaining a mean score (15.50) higher than those of the other sessions, $p = 0.001$, but the difference between pre- and post-training was not significant. For the active control group no difference between scores was significant, after Bonferroni correction. For the repeated testing group just the mean score in the follow-up session differed from those at the pre-test ($p = 0.005$) and post-test ($p = 0.010$), which did not significantly differ from one other after the Bonferroni correction. Cohen d for comparison pre- vs post-training for the three strategic, motivational and motivational and strategic training groups were respectively 0.63, 0.57, and 0.79, all large effects. Interestingly, mean scores obtained by trained women (no active control) in the post-training session ($M = 11.25$, $SE = 0.65$), and in the follow-up ($M = 12.79$, $SE = 0.76$) did not differ from those achieved by men pre-training ($M = 13.50$, $SE = 1.07$), $t(87) < 1.89$, ns.

7. Discussion

The two experiments confirmed the effectiveness of the trainings in improving mental rotation scores. In Experiment 1, the effect was clear and straightforward: women in the motivational and strategic and strategic training roughly doubled their scores. In Experiment 2, the trained women increased their performance significantly, but to a lower extent. In fact, in Experiment 1 after training, women scored higher than men pre-training, while in Experiment 2 they scored the same as men. The repeated testing group also increased performance, but this occurred later on, confirming that repeated testing favors performance (see Uttal & Cohen, 2012 for a meta-analysis). Interestingly, the active control group, who met the experimenters the same amount of time as the other training groups, but who was taught neither holistic strategies nor motivation did not significantly improve the mental rotation scores. This occurred, even if participants underwent multiple tests, thereby suggesting that simply meeting the experimenters did not foster performance.

7.1. Effectiveness of training motivation

The strategic and the motivational and strategic training were equally effective with significant increase in performance from the pre- to the post-training, while the motivational training generated a significant improvement from the pre- to the post-training in Experiment 1, but not in Experiment 2. Despite not reaching a statistical significant effect, the scores increased by about half a standard deviation, as observed in previous spatial trainings. Nevertheless, caution is needed in interpreting the efficacy of this motivational training. In particular, future studies could assess the role played by some potential underlying mechanisms, one of which could refer to motivational aspects, which could be assessed. In addition, it demonstrates that women benefit from both practice with effective strategies and reflecting on adaptive motivations, as shown by the comparison between the motivational and the motivational and strategic groups.

The effect sizes comparing scores before and after the training session ranged from 0.86 to 1.61 in Experiment 1 and from 0.57 to 0.79 in Experiment 2 with an overall composite effect size for the strategic, motivational, and motivational and strategic groups of 1.23 and 0.68, respectively in Experiment 1 and 2. The effect sizes reported in previous meta-analyses and research studies (Jaušovec & Jaušovec, 2012; Miller & Halpern, 2013; Uttal et al., 2013) are of about half a standard deviation, namely 0.50. Here, the effect is larger, mainly in Experiment 1 meaning that focusing on specific strategies and/or motivations is highly effective. In fact women can succeed in solving the mental rotation items using different strategies than men (Jordan et al., 2002), suggesting that there are different routes to effective mental rotation performance and that motivational factors can contribute to explain successful performance.

It is important to note that the improvement in mental rotation scores was achieved in just a single 1-h training session. While most of the previous training studies were run along several sessions, there is at least one study that shows that one session training could suffice with university students (Stransky et al., 2010). However, it may be that more training sessions will improve the mental rotation scores further. In particular, given that women appear to benefit from longer training (Terlecki et al., 2008) and improve later, while men seem take advantage from the beginning, it is possible that the gender gap will reduce or close if more training sessions are included.

In both experiments the repeated testing group increased performance from session 1 to 3, suggesting improvements due to familiarity with the test. While this result echoes studies showing that students who do daily school subjects that focus on spatial skills underscore in mental rotation (e.g., Hausmann, 2014) to the point of nullifying the gender gap (Moè, 2016), caution is required because no effect was obtained for the active control group introduced in Experiment 2 involved in practicing with verbal tasks. Future studies should be performed to confirm it (it was obtained with a sample of 19 women) and also to verify if the practice with verbal tasks affects not only performance, but also the subsequent use of analytic strategies and/or motivation toward spatial and masculine tasks. It is possible that the active control group improved less than the other groups because it was primed to employ verbal/analytic strategies. Including in future studies also measures of spatial abilities which rely less on holistic processing of the stimuli could help to understand to which extent the strategies taught and employed affect performance.

7.2. Reducing the gender gap in mental rotation

The three kinds of training were equally effective, but women's advantage was clear if their scores were compared with those of men at pre-training. This suggests that women can improve following a strategic and/or a motivational training until they reach or go beyond the typical men's performance. Notably, the gender difference was significant and the effect size was large as those found by Geiser et al. (2008), Linn and Petersen (1985), and Voyer, Voyer, and Bryden (1995) of up to half a standard deviation.

As reviewed by Hyde (2005), who supports the gender similarity hypothesis, there are just a few abilities such as mental rotation in which the gender difference is so frequently observed and could be ascribed to precocious biological factors, even to organizational factors, so that males appear to be at an advantage from the first months of life (Frick, Möhring, & Newcombe, 2014). This said, this study shows that trained women can reach the level of men's performance. It is true that even men, when trained, increase their performance, but if not, trained women can close the gender gap with untrained men. Therefore, the results here obtained confirm that men outscore women by 0.56 and 0.92 in the two experiments, but also that women increase their scores after the strategic and/or motivational training (Cohen's d 1.23 and 0.68).

This shows that being trained in motivational issues and/or in using the holistic strategies can actually cover even this highly critical gender difference in mental rotation. It is possible that, if this kind of training operates with mental rotation abilities, which are considered masculine, the more it will be expected to work with other cognitive abilities for which smaller gender differences have been observed.

7.3. Limitations

Since this is the first time the effects of including motivational aspects in training devised to improve mental rotation abilities are assessed, some limitations must be acknowledged. First of all, no measure of either strategies used or motivation was taken. This prevent to draw any firm conclusion about the underlying mechanisms. It cannot be ruled out that (a) there was no significant increase in holistic strategies use and/or motivation, (b) the strategic training was effective not only because holistic strategies were taught, but also because motivation improved, (c) some participants continued to use the preferred strategies after training, and (d) even the repeated testing and active control groups increased motivation and/or use of holistic strategies due to increased familiarity with the mental rotation items or to higher perceived competence and confidence. Secondly, to assess the mental rotation abilities the same items were used in the three sessions. Even if in previous training studies the same procedure was adopted of using the same measure twice (Jaušovec & Jaušovec, 2012; Sorby et al., 2013) or more (Stransky et al., 2010), even as much as 12 times (Terlecki et al., 2008), it maybe that participants improved because they became more familiar with the items. However, the repeated testing and the active control did not improve their mental rotation scores from the pre-training to the second session, suggesting that simply solving the same items reshuffled in a different order is not enough. Even more critical is the test used in session 3, which could have favored performance even more being made up of items from MRT-A and from MRT-B. However, of the six training groups in the two experiments only one increased performance further from the second session. This does not rule out the fact that further improvements were difficult to achieve due to the high score already obtained at the second session. Thirdly, only undergraduate psychology students participated so that any generalization is limited, in particular regarding students majoring in STEM or no STEM fields. Finally, the number of men was low and uneven among groups (22% and 27%, ranges 12–27 and 16–37, respectively in the two experiments), so that no firm conclusion can be drawn about the differential effects of the training among genders and the possibility that training reduces the gender gap.

7.4. Future avenues

Future studies could encompass these limitations by including a measure of strategies used through a self-report, and a chronometric mental rotation test which will enable not only speed but accuracy data to be collected (speed being an index of the use of holistic strategies: Heil & Jansen-Osmann, 2008), as well as some motivational measures. Among them, perception of competence, incremental theory, confidence, and the stereotyped view of spatial and masculine abilities should be considered, because previous studies have proved to be critical in explaining at least women's performance (Estes & Felker, 2012; Moè, 2009). To exclude effects due to familiarity with the items, it is advisable in future studies to use new mental rotation items to assess at least the maintenance effects. One possibility is to use MRT-A and MRT-B in a balanced order in sessions 1 and 2 and a new mental rotation test with different items in session 3, so as to avoid using a more difficult version such as the MRT-C developed by Peters et al. (1995) which requires in-depth rotations and which gives rise to a larger gender gap. In addition, in future studies more men should be included in order to verify if the gender gap is maintained or narrowed after the training sessions, an issue that recent studies have addressed, leading to contrasting results (for instance gender differences were narrowed in Miller and Miller & Halpern, 2013, but not in Stransky et al., 2010). Finally, the inclusion of students from STEM or no STEM degrees could help to understand to what extent the kind of training could favor men and women having different attitudes and even abilities in spatial tasks. Note that in this study there were only psychology students men whose scores, mainly in Experiment 1, were rather poor compared to the men mean score 12.1 reported by Peters et al. (1995) for arts students. In future studies, this suggests analyzing the differential trends for low and high scorers, men and women, as performed by Terlecki et al. (2008). A further issue which is worth studying is maintenance. Previous research has found either that the advantages are maintained or that they disappear altogether after 8 months (Miller & Halpern, 2013). Some mediators could explain these contrasting results and it is feasible that motivation is the factor which sustains the adoption of the most effective/holistic strategies and hence performance. Assessing mental rotation abilities at a delayed interval after the end of training and measuring motivational aspects will allow to verify this prediction.

7.5. Theoretical and practical implications

The main theoretical implication is that motivational aspects matter. Not only instructions that focus on motivational factors favor performance (e.g., Martens et al., 2006; Moè, 2012), but also effective motivational attitudes can be taught resulting in improved mental rotation scores. Whereas the underlying mechanisms can be either motivational or based on use of more effective holistic strategies, the results achieved on mental rotation performance outline that teaching motivation favor women mental rotation performance to the extent to reach the men's performance or going beyond. It is worth to note that this result was achieved testing women in a threatening environment (Inzlicht & Ben-Zeev, 2000, 2003), that is in mixed-gender groups, and that they could have improved even more if tested in same-gender groups.

The results of this study are very interesting also within the actual debate about cognitive gender differences (Miller & Halpern, 2014). Scholars have outlined that gender differences in cognition - if any - are not as high as previously believed (Halpern, 2012), do not apply for all the category members, sometimes referring only to the right tails (Wai, Cacchio, Putallaz, & Makel, 2010), also because they are driven and maintained by beliefs (Halpern et al., 2011), stereotypes and role models (Reilly & Neumann, 2013). The results of this study outline that motivational aspects can definitively explain women underscoring: when motivation is taught women score as high or even higher than men.

From a practical point of view the main and important suggestion is to include motivational aspects in trainings aimed at improving mental rotation scores. Research has until now neglected this point, showing that practice with spatial tasks and/or the use of the most effective strategies favor performance, while the effects of teaching motivation and on motivation, per se or in conjunction with the teaching of strategies, have never been considered before. This issue is particular interesting within the actual debate about women under-representation in STEM fields. Many factors play a role, among them attitudes and gender roles (Ceci, Williams, & Barnett, 2009), which are motivational aspects. The results of this research outline that they can be taught resulting in improved mental rotation performance. This suggests that changing the motivations toward STEM disciplines is a new underexplored approach which could potentially affect the likelihood of choosing STEM fields. Previous research showed that improving mental rotation abilities favor STEM enrollment and success (Newcombe & Frick, 2010; Stieff & Uttal, 2015; Uttal et al., 2013), but there is currently little discussion around changing attitudes toward STEM as another and potentially just as useful approach. The current study definitely adds to the literature and outlines that motivational aspects of spatial reasoning might be just as important as actual skills.

Compliance with ethical standards

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

Conflict of interest

The author declares that she has no conflict of interest.

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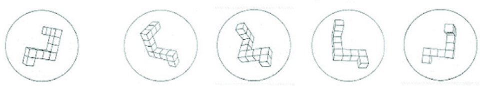
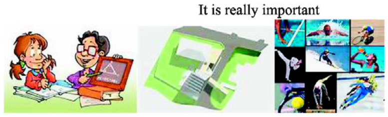
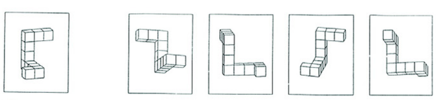
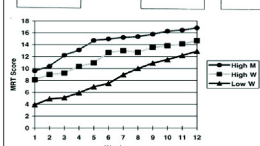
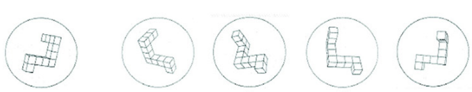
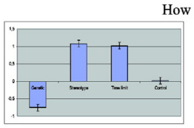
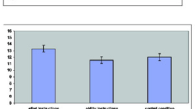
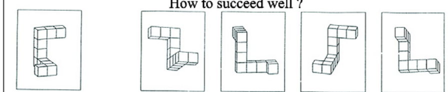
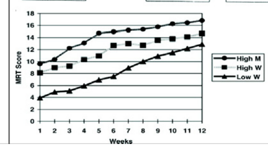
Appendix A. The slides used in the second session of the training

Slide	Contents
First (all groups but repeated testing)	Mental Rotation Test (MRT)  It assesses mental rotation abilities
Second (all groups but repeated testing)	It is really important  learning everyday tasks movements
Third (strategic group), fifth (motivational and strategic group)	How to succeed well ?   X X Effective strategies Practice
Forth (strategic group), sixth (motivational and strategic group)	 To perform this test it is possible to use **Effective holistic strategies** **to rotate the target** until it matches with the stimuli **to rotate the stimuli** to see if they match the target **to rotate the stimuli globally** **Not effective analytic strategies** **to count the cubes** **to rotate** the stimuli **piece by piece**
Third (motivational and motivational and strategic groups)	How to succeed well ?  Perceiving to be able to do it  Believing in succeeding
Forth (motivational group)	How much is each of these abilities modifiable? How much able do you perceive? Learning a foreign language Feeling others' emotions Drawing Recalling people's names Solving math problems Engaging in a new sport, Finding a route on a map Finding the quickest way to reach a place Building or repairing something Doing a puzzle Making calculations in mind Paying attention at a lesson or at a conference Willing to know new things Reasoning in a logical and sequential manner
Forth (motivational and strategic group)	How much is each of these abilities modifiable? How much able do you perceive? Learning a foreign language Feeling others' emotions Recalling people's names Solving math problems Finding the quickest way to reach a place Building or repairing something Making calculations in mind Paying attention at a lesson or at a conference
Third (active control group)	How to succeed well ?   X X Concentration Mental training

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