Original Article

Enhancing Spatial Ability Through Sport Practice

Evidence for an Effect of Motor Training on Mental Rotation Performance

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Abstract. This experiment investigated the relationship between mental rotation and sport training. Undergraduate university students (n = 62) completed the Mental Rotation Test (Vandenberg & Kuse, 1978), before and after a 10-month training in two different sports, which either involved extensive mental rotation ability (wrestling group) or did not (running group). Both groups showed comparable results in the pretest, but the wrestling group outperformed the running group in the posttest. As expected from previous studies, males outperformed women in the pretest and the posttest. Besides, self-reported data gathered after both sessions indicated an increase in adaptive strategies following training in wrestling, but not subsequent to training in running. These findings demonstrate the significant effect of training in particular sports on mental rotation performance, thus showing consistency with the notion of cognitive plasticity induced from motor training involving manipulation of spatial representations. They are discussed within an embodied cognition framework.

Keywords: mental rotation, spatial ability, individual differences, training effect, embodied strategies

Introduction

Explaining directions, remembering the location of an object, or performing a motor action are just a few examples of common cognitive tasks that require spatial coding and representations. An extensive amount of literature concerning these processes has led to even further differentiation, corresponding to differences in cognitive demands and neural pathways recruited (see Carroll, 1993, for a review). In fact, two meta-analyses (Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995) distinguished three categories of spatial abilities: spatial perception, spatial visualization, and mental rotation, from differences in the psychometric rationale as well as in the cognitive processes involved in various spatial ability tasks.

One of these categories, mental rotation, is a subcomponent of spatial ability, which involves maintenance and manipulation of two- or three-dimensional objects. It is known to be an important cognitive process not only for apprehending surroundings and moving oneself around in the environment, but also for performing a wide range of cognitive tasks that require visualizing potential transformations of items (Carroll, 1993). Mental rotation has been studied extensively throughout different kind of tasks, often based on three-dimensional Shepard-Metzler figures (Shepard & Metzler, 1971). These tasks commonly yield the largest effect sizes on gender differences, which can explain researchers' constant interest in them when studying individual differences in spatial cognition.

Interestingly, mental rotation has proved to be decisive in numerous activities or professions. In fact, many professional occupations such as surgeons, pilots, dentists, engineers, and others seem to positively affect mental rotation ability (see Hegarty & Waller, 2005, for a review). Following this line of research, other researchers highlighted different experiential factors that can potentially improve mental rotation performance. Studying science (Moreau, Mansy-Dannay, Clerc, & Guerrien, 2010; Peters, Lehmann, Takahira, Takeuchi, & Jordan, 2006), playing videogames (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; De Lisi & Wolford, 2002; Feng, Spence, & Pratt, 2007; Quaiser-Pohl, Geiser, & Lehmann, 2006), or training motor skills (Jansen, Titze, & Heil, 2009; Moreau, Clerc, Mansy-Dannay, & Guerrien, 2010), for example, were all correlated to higher performance in mental-rotation ability assessments.

With respect to the latter findings, the relationship between motor processes and mental rotation ability has been explored in a quite consequent body of literature, from psychometric to neuropsychological data. Thus,

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studies consistently showed activation of motor cortical areas when performing a three-dimensional mental rotation tasks (Cohen et al., 1996; Richter et al., 2000; Williams, Rippon, Stone, & Annett, 1995), in addition to the neural activation corresponding to the response motor action. Moreover, a decrease in performance was found in a related study when a concurrent motor task was being performed simultaneously, in the case of both tasks being incompatible (Wexler, Kosslyn, & Berthoz, 1998). Consistent with these results, mental rotation performance was impaired in pathological subjects showing motor deficits in a prior experiment (Lee, Harris, & Calvert, 1997).

From that line of research, we can presume close ties between mental rotation ability and motor processes. The latter include different actions based on common neural mechanisms that tap into mutual motor representations. Therefore, considering that mental rotation can rely on motor representations, motor training in an activity that engages mental manipulation of objects in three-dimensional space should lead to an enhanced ability to rotate stimuli. However, such changes should not be noticeable after a training program focused on a motor activity that requires very little object manipulation. More generally, these effects should not occur if mental rotation ability is specific to the particular stimuli type used during training – and thus not transferable from one object type to another.

To confirm this hypothesis, we set up an experiment involving athletes practicing either an activity that does require mental rotation of bodies (wrestling) or an activity that does not (running). Runners also constituted the control group, as running does not seem to involve the manipulation of complex mental representations in order to solve activity challenges. This group was meant to control for effects that would be due to physiological changes related to the physical activity alone. We assessed mental rotation performance before and after a 10-month training period and expected a significant effect of motor training in wrestling – but not in running – on mental rotation performance.

Method

Participants and Training Sessions

A group of 62 undergraduate students at the University of Lille volunteered for this study. They were divided randomly into two equal groups: those who practice wrestling (i.e., Olympic wrestling – FILA – and not professional show wrestling) (group 1: 18 males and 13 females, *M* = 20.6 years, *SD* = 3.05, range: 18–25) and those who run (group 2: 18 males and 13 females, *M* = 20.9 years, *SD* = 2.88, range: 18–24). There were 2-h sessions scheduled once a week for the entire academic year (10 months). None of the participants were experts in one of these activities, nor in any other sport related to wrestling or running. The training they followed consisted of regular practice sessions in one of these two sports.

In wrestling, this would typically include a full warm-up, using wrestling drills (30–40 min), a technical part (demonstration of new moves, correction of previous techniques, 45 min to 1 h), a few matches (15–20 min), and relevant stretching moves (10–15 min). In road running, all sessions started with a warm-up (about 30 min of light jog, at a comfortable pace), followed by interval workouts (run/jog, or run/walk) or long runs (about 45 min to 1 h 15 min), mainly aerobic but sometimes reaching individual anaerobic thresholds on various distances, depending on the initial level and the goals set with the athletes, and finally stretching (10–15 min). No particular training sessions were explicitly intended for the development of mental imagery skills.

Athletes were first tested at the beginning of the academic year, and again 10 months later at the end of the academic year. During this period, none of the courses the students followed was purposely intended to develop or improve spatial abilities. Further, no feedback was given to the students after the first session, since this could have artificially affected the next one. Also, none of the participants took the MRT prior to the experiment, and none of them was explicitly aware of the present research hypothesis.

Testing Material and Procedure

All participants took the MRT-A redrawn from Vandenberg and Kuse (1978), as provided by Peters et al. (1995). It includes 24 problems to solve, involving three-dimensional geometric shapes based on Shepard and Metzler stimuli (1971). For each problem, there are two correct and two incorrect answers (rotated figures and mirror-imaged figures, respectively). The test requires mentally maintaining and manipulating the presented figures with accuracy and speed; this is the most commonly used test in the literature to assess mental rotation ability among large populations. As recommended by Peters et al. (1995), we allowed 3 minutes for each part, separated by a 4-minute break.

Participants took the test in a quiet room, and all received similar instructions about the task. Therefore, to the best of the experimenter's knowledge, conditions were standardized throughout the entire experiment.

We used the same procedure as Peters et al. (1995) for scoring, giving one point for each item only if both answers were correct. Thus, scores could range from 0 to 24.

After taking the test, participants were asked to explain the strategy they used to solve MRT problems. This was meant to further our understanding of individual differences yielded by the test. For statistical readability, we then categorized their answers into four conditions. This is discussed in detail in the Results section.

Table 1. Mean MRT scores (out of 24) by sport and sex, for the pretest and the posttest

	Pretest							
	Wrestling				Running			
	N	Mean	*SD*	Range	*N*	Mean	*SD*	Range
Males	18	12.28	3.12	8–19	18	12.00	2.91	8–18
Females	13	9.23	1.69	6–12	13	9.76	1.69	7–13
Total	31	11.00	3.00	6–19	31	11.06	2.68	7–18
	Posttest							
	Wrestling				Running			
	N	Mean	*SD*	Range	*N*	Mean	*SD*	Range
Males	18	14.17*	2.50	10–19	18	13.05*	2.75	8–18
Females	13	11.38*	1.32	9–14	13	10.77*	1.69	8–14
Total	31	13.00*	2.49	9–19	31	12.10*	2.60	8–18

Note. *$p < .05$ (difference between repeated measures).

Results

MRT Data

Descriptive statistics for each testing session are shown in Table 1. A 2 (Sport; wrestling vs. running) × 2 (Gender) factorial analysis of variance (ANOVA) revealed no significant differences between participants from wrestling and running groups before training (*ns* and η^2 *ns*). Results showed gender differences in the whole sample, favoring males ($F(1, 58) = 16.12$, $p < .001$, $\eta^2 = .22$). During a factorial ANOVA on posttraining data, gender differences remained significant ($F(1, 58) = 19.33$, $p < .001$, $\eta^2 = .25$).

A 2 (Sport; wrestling vs. running) × 2 (Gender) × 2 (Time of testing; pre vs. post) ANOVA with a repeated measure on the last variable yielded significant main effects of gender ($F(1, 58) = 19.47$, $p < .001$, $\eta^2 = .25$) and of time of testing ($F(1, 58) = 60.56$, $p < .001$, $\eta^2 = .51$). The analysis also revealed a significant interaction between sport and time of testing ($F(1, 58) = 6.43$, $p < .05$, $\eta^2 = .10$). This means that the wrestling group and the running group did not benefit similarly from their training, that is, the former showed greater enhancement in mental rotation ability. However, the interaction involving gender and time of testing was not significant. Hence, both males and females seem to have benefited somehow equally from their training – at least with respect to the specific cognitive processes assessed.

Solving Strategies

From the self-reported answers of participants concerning strategies, we distinguished four different categories: adjustment, rotation, analytic, and unidentified. *Adjustment* means that athletes adapted their strategy to the particular problem encountered. *Rotation* refers to a strategy based on rotating the item presented (object-based mental rotation), or rotating the environmental frame (perspective-taking strategy), but not a combination of both (which would be included in the adjustment condition). *Analytic* included all strategies that consist of counting or analyzing parts of the figures to make a decision, whereas participants who were not explicitly aware of their own strategy appear under the label *Unidentified*.

The MRT is explicitly described as a rotation test. Thereby, the fact that most participants, regardless of their group, chose to mentally rotate the MRT items was expected (see Peters et al., 1995). Indeed, the Rotation strategy was the preferred choice for most participants, before or after training (see Figure 1), and remained stable across participants ($\chi^2(3, N = 124) = 2.44$, *ns*). Analytic and unidentified con-

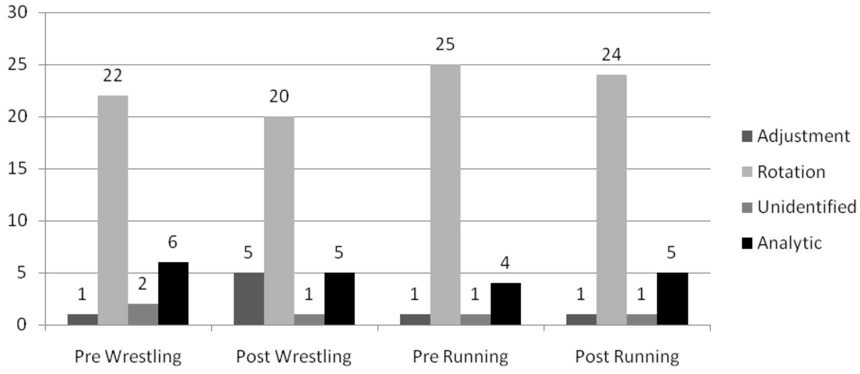

Figure 1. Strategies for wrestling and running groups after the pretest session and the posttest session (number of athletes in each category).

ditions were constant over time ($\chi^2(3, N = 124) = .48$, *ns*; and $\chi^2(3, N = 124) = .62$, *ns*, respectively). However, there was a slight increase in the adjustment condition for wrestlers ($\chi^2(1, N = 62) = 2.95, p < .10$, when comparing it with other categories altogether), consistent with a broadening of strategic possibilities. Besides, the mean MRT score was the highest for the adjustment condition, regardless of training and sport ($M = 18.75$). As a whole, these results underline the efficiency of adaptive strategies to solve MRT problems.

Discussion

The experiment reported reveals the effect of specific motor training on mental rotation ability. Practicing wrestling, an activity that involves mental manipulation of motor representations, induced cognitive changes that benefited performance in a mental rotation task made up of geometric shapes. A training program in running, on the other hand, did not affect mental rotation scores, at least over a 10-month period. In fact, their score improvements were within normal range for test-retest MRT paradigms (see Peters et al., 1995, for a discussion). This finding adds to an extensive amount of research pointing to the plasticity of cognitive processes through adequate training sessions, including those that are not primarily aimed at developing mental rotation ability. It also shows that mental rotation is a rather general process that can be performed on different types of stimuli, while involving shared components. Another interesting feature of this experiment is that it underlines, in a single study, the evolution of mental rotation ability over time. The pretest/posttest design allowed the identification of causal relations that previous cross-sectional studies could not clearly highlight (Moreau et al., 2010). The data displayed above confirm the importance of motor processes when considering training particular skills or abilities involved in spatial reasoning, and the strong relation between motor and spatial components.

Beyond the mere description of the significant effects of the present study, there is a need to identify what mechanisms could be responsible for mental rotation abilities enhancement and how they influence one another. Although many different factors might be interacting to yield these results, we can narrow them down via a thorough analysis of the data (combined with a discussion of the relevant literature in different related fields).

We observed a significant interaction between testing time and sport on MRT performance. The athletes' specific training program had substantial consequences on mental rotation scores. A closer look at this interaction revealed that, in fact, only wrestlers showed improvements from one session to another. Participants seem to have benefited more from practicing an activity that involves body rotations in three-dimensional space (wrestling) than from one that does not (running). This is interesting since it clearly shows the impact of the particular motor training features involved in wrestling, such as motor rotations in a three-dimensional environment. In this case, the specific cognitive processes involved in motor practice were transferred to another task, different in nature, the MRT. Furthermore, *SD*s in the wrestling group were reduced over time (but not in the running group), highlighting the cognitive benefits to most of the athletes involved in the experiment. We should note that motor practice should be understood globally to include both motion as well as observation and implicit imagery, since these aspects cannot be dissociated from one another in a practice session. Because of the functional equivalence of these actions, sharing as they do common representations and neural mechanisms (see Decety, 2002, Grèzes & Decety, 2001; Jeannerod, 1995, 1999), it seems likely that they participate jointly in the process of improving mental rotation performance.

A compelling body of literature supported by neuroimaging data might help to refine our understanding of these results. Mental rotation is a rather general cognitive process, involving multiple brain structures, one that can be carried out on a wide range of objects. In the experimental field, most studies have used geometric figures (such as the Shepard-Metzler stimuli) or body parts (e.g., hands), hence often displaying brain activation discrepancies depending on the stimuli type. Following that observation, Kosslyn and colleagues suggested that there are at least two different ways to perform mental rotation, one that involves cognitive structures shared with motor execution and one that does not (Kosslyn, Digirolamo, Thompson, & Alpert, 1998). The particular items presented would implicitly trigger one of these strategies. However, this phenomenon becomes more complex because the use of these strategies is flexible and determined partly by previous exposure. In a study by Wraga, Thompson, Alpert, and Kosslyn (2003), activation of premotor (BA 6) and primary motor (M1) areas was determined in a rotation task involving geometric shapes subsequent to a hand rotation task. The results showed that motor strategies are likely to be used when rotating nonbody figures if a previous rotation task concerned body parts. Thus, engaging motor processes is not automatic in mental rotation, but rather triggered by stimulus type or previous experience. In the present study, considering the intense training they had undergone, it is therefore plausible that athletes practicing wrestling recoded nonbody objects into body shapes. Because of the large number of motor representations that are available to them, wrestlers would be primed to engage in specific cognitive procedures when facing mental rotation problems, even without immediate prior exposure to a motor task.

Furthermore, this hypothesis is consistent with current work on embodied cognition. Recent studies showed that providing Shepard-Metzler figures with body characteristics dramatically improves item matching (Alexander & Evardone, 2008; Amorim, Isableu, & Jarraya, 2006), in accordance with the pioneer work by Parsons (1987). Moreover, in an fMRI study, Zacks, Ollinger, Sheridan, and

Tversky (2002) found activation of the premotor cortex in the spatial transformation of body objects and emphasized that multiple neural systems support different mental transformations (Zacks et al., 2002). Accordingly, our data provide support for the idea that embodied strategies in trained wrestlers led to cost-efficient procedures because of the manipulation of objects familiar to them. On the other hand, trained runners did not have this possibility of recoding figures into body shapes, either because their motor training did not emphasize the spatial manipulations of bodies or because embodied strategies were too demanding and thus not efficient and adequate to the task to perform.

Embodied cognition in the MRT also provides a heuristic insight into strategic choices for each problem encountered. The ability to adjust one's strategy to the particular problem encountered was correlated to high MRT performance, regardless of sport or sex. Interestingly, flexibility in the use of strategies proved to be a feature displayed mainly by trained wrestlers. After practicing a sport involving mental rotation processes on a daily basis, they were more likely to use flexible behaviors than trained athletes who practiced running or than athletes in any of these two sports before training. Recoding neutral figures into body shapes probably led to strategies more adapted to the particular problems with which athletes have to cope. Dealing with bodies instead of geometrical figures allows one to rule out incompatible matches more quickly (analytic strategies) and to rotate shapes more efficiently while maintaining initial configurations (rotation strategies). It is easier to notice that objects differ from one another or to retain spatial properties when considering body shapes in contrast with neutral figures. Thus, individuals using embodied strategies are more likely to adapt their procedure to the problem at hand.

This consideration is also in line with prior experiments showing that trained individuals tend to display more adaptable behaviors than untrained ones in tasks for which they can use processes developed through practice (Coyle & Bjorklund, 1997; Schwenck, Bjorklund, & Schneider, 2007). Although the strategies factor displays a limited effect size in this study, the short timespan between the two sessions (10 months) does not allow for an extensive modification of strategic behaviors or for expertise acquisition.

Training effects aside, gender differences were found before and after practice in both sports, consistent with a large body of literature on individual differences (see Halpern & Collaer, 2005, and Hegarty & Waller, 2005 for reviews). This means that both males and females benefited somehow equally from their training period. Although the present study does not allow for unequivocal conclusions regarding that particular issue, probably because of the rather short training span, it seems likely from previous literature that gender differences could be cut down with a longer training period (Feng, Spence, & Pratt, 2007; Vasta, Knott, & Gaze, 1996), in line with the notion that environmental factors play a decisive role in yielding gender differences in spatial ability.

Finally, other factors are likely to explain part of the individual differences displayed in this study. Working memory processes, including capacity and attention features, could play an important part in mental rotation ability. Research on that particular issue has been conducted, displaying significant effects and underlining the role of working memory and executive functioning to mediate differences in mental rotation and spatial ability performances (Kaufmann, 2007; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001) as well as the close ties between visuospatial abilities and fluid intelligence. Also, one should bear in mind that the effects observed in the present study cannot necessarily be generalized to all types of stimuli. In fact, there is evidence that individuals perceive two- and three-dimensional objects differently (Elman et al., 2008), each with its own distinct neural correlate (Kawamichi, Kikuchi, Noriuchi, Senoo, & Ueno, 2007). Embodied strategies would likely be of limited relevance with two-dimensional figures.

We conclude by pointing out that more work involving longitudinal designs needs to be conducted in order to gather data that leave no doubt about the directional interpretations drawn from them. These particular experimental designs should allow researchers not only to observe, but also to explain individual differences in human cognition, while confirming the implication of working memory and executive processes among them.

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