Gymnasts and orienteers display better mental rotation performance than nonathletes

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Abstract

The aim of this study was to examine whether athletes differ from nonathletes regarding their mental rotation performance. Furthermore, it investigated whether athletes doing sports requiring distinguishable levels of mental rotation (orienteering, gymnastics, running), as well as varying with respect to having an egocentric (gymnastics) or an allocentric perspective (orienteering), differ from each other. Therefore, the Mental Rotations Test (MRT) was carried out with 20 orienteers, 20 gymnasts, 20 runners and 20 nonathletes. The results indicate large differences in mental rotation performance, with those actively doing sports outperforming the nonathletes. Analyses for the specific groups show that orienteers and gymnasts differed from the nonathletes, whereas endurance runners did not. Contrary to expectations, the mental rotation performance of gymnasts did not differ from that of orienteers. This study also revealed gender differences in favor of men. Implications regarding a differentiated view of the connection between specific sports and mental rotation performance are discussed.

Keywords: cognition, physical exercise, spatial ability, gender differences

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Regular physical exercise is associated with many beneficial effects on physical and mental health, such as better general and health-related quality of life, better functional capacity and better mood states (Penedo & Dahn, 2005). Aside from both these preventive and therapeutic effects, cognitive functions also appear to benefit – throughout life – from acute and chronic sports (Chang, Labban, Gapin, & Etnier, 2012; Hillman, Erickson, & Kramer, 2008). It remains unclear, however, which specific physical activity affects which specific cognitive skill. Physical activities with higher cognitive demands may be assumed to have a stronger influence on cognitive skills than those, which make lower or fewer cognitive demands (Pesce, 2012). For example, Pesce, Crova, Cereatti, Casella and Bellucci (2009) tested the influence of either an aerobic circuit training lesson or a team games lesson on memory performance in preadolescents. The two conditions were characterized by similar exercise intensities but differed in their cognitive complexity (and therefore in their cognitive demands). Memory performance was significantly better after team games than after aerobic circuit training.

One significant cognitive skill, along with others, is mental rotation, i.e. the ability to mentally manipulate two- or three-dimensional objects, whereby these objects may be rotated in any direction or translated in space (Shepard & Metzler, 1971). When the mental rotation paradigm is applied in research, subjects usually have to judge whether a couple of (mostly three-dimensional) objects presented in various orientations are identical to a specific target object. Apart from the classical cube figures used by Shepard and Metzler (1971), alphanumeric characters (e.g. Cooper & Shepard, 1973), images of human faces (e.g. Valentine & Bruce, 1988), body parts (e.g. Petit, Pegna, Mayer, & Hauert, 2003) or even entire bodies (e.g. Jola & Mast, 2005) are used as objects to be rotated. In this context, two types of mental transformations can be differentiated: object-based transformations are mental rotations from an allocentric point of view, in which an object is rotated and the observer's point of view stays fixed. Perspective transformations are mental rotations from an egocentric point of view, in which an object stays fixed and the observer's point of view rotates in relation to the object or the environment (Zacks, Mires, Tversky, & Hazeltine, 2002). Mental rotation, however, is an important and relevant construct for spatial ability and problem-solving strategies (Geary, Saults, Liu, & Hoard, 2000) as well as for specific mathematical and scientific competencies (Hegarty & Kozhevnikov, 1999; Peters, Chisholm, & Laeng, 1995). All studies consistently find gender differences in favor of male subjects (Voyer, Voyer, & Bryden, 1995), which are attributed to biological, but also to socio-cultural differences (Maeda & Yoon, 2012).

The ability to mentally rotate objects and the ability to rotate objects using motor commands or to navigate through one's environment appear to be interrelated. For example, studies in developmental psychology indicating strong associations between motor development and mental rotation performance in children (Frick & Möhring, 2013; Rakison & Woodward, 2008) corroborate studies that show children with impaired motor function displaying impaired mental rotation performance (Jansen, Schmelter, Kasten, & Heil, 2011). Furthermore, several neuroimaging studies have been able to demonstrate that the same areas of the brain are active when carrying out mental rotations as during physical activities involving the rotation of objects (e.g. Draganski et al., 2004; Jordan, Heinze, Lutz, Kanowski, & Jäncke, 2001). However, it appears that the areas that are active during egocentric and allocentric transformations are not the same ones, whereby differences are found particularly at the level of the posterior parietal cortex (Pelgrims, Andres, & Olivier, 2009). These differences suggest that allocentric and egocentric sports may affect mental rotation skills differently. Taken together, considering how important mental rotation skills are to succeeding in numerous activities and professions (Hegarty & Waller, 2005), and consulting empirical evidence both from developmental and neuroimaging studies, it is astonishing that the connection between different sports activities and mental rotation performance has received so little attention until now.

However, the few existing studies that do look at the relation between general physical activity and mental rotation performance indicate promising positive connections (Jansen, Lange, & Heil, 2011; Jansen & Lehmann, 2013; Jansen, Lehmann, & van Doren, 2012; Jansen & Pietsch, 2010; Jansen, Titze, & Heil, 2009; Moreau, Clerc, Mansy-Dannay, & Guerrien, 2012; Moreau, Mansy-Dannay, Clerc, & Guerrien, 2011; Ozel, Larue, & Molinaro, 2002). The sports investigated have included juggling, football, gymnastics and a range of different martial arts, such as fencing, judo and wrestling, as well as physical activities such as running. Acute and chronic physical activity have been found to be positively related to mental rotation performance. In all studies, those who actively performed sports displayed a significantly higher mental rotation performance than subjects who were inactive. The question which types of sport are particularly effective at training mental rotation skills has only been marginally investigated so far, since most studies have only compared a single sport with a group of nonathletes. To the best of our knowledge, only four studies (Jansen, Lange, & Heil, 2011; Jansen & Lehmann, 2013; Moreau et al., 2011, 2012) have compared different types of sport, and these uniformly report that cognitively demanding sports involving mental rotation exert a greater influence. In their intervention studies, Jansen, Lange, and Heil (2011) compared the coordinative sport of juggling with a strength-training program; Moreau et al. (2012) compared wrestlers with endurance athletes.

Only the study by Moreau et al. (2011) and the one by Jansen and Lehmann (2013) have compared two different types of sport and investigated in detail the specific effects of various sports on mental rotation performance. Moreau et al. (2011) showed that elite combat athletes (fencing, judo and wrestling) displayed better mental rotation performance than elite runners. Since the daily practice time did not differ between the two groups, the better mental rotation performance was explained by the repeated use of mental and physical rotation in the practice of combat sports as compared with running, which entails only small degrees of mental and physical rotations. Building upon this, a recent study by Jansen and Lehmann (2013) compared three groups, namely soccer players, gymnasts and nonathletes, in an object-based mental rotation task consisting of human postures and cube figures. They expected athletes whose sport involves mental and physical rotations to display a better object-based mental rotation performance than nonathletes, and the object-based mental rotation performance to differ between the two types of sport. The rationale for these hypotheses was that soccer players are thought to perceive objects mostly from an allocentric point of view, whereas gymnasts mostly train their own body transformations, perceiving the environment from an egocentric point of view. Results showed that the gymnasts displayed a better performance than nonathletes in the object-based mental rotation task. Nevertheless, contrary to the expectations, gymnasts and soccer players did not differ in their mental rotation performance. This well-designed study is limited, however, by the fact that, despite including two different types of sport with varying engagements in mental manipulation of objects (allocentric vs. egocentric transformations), a sports group that trains physically but lacks the systematic involvement of mental rotation in its respective sport activity, e.g. runners, is missing.

With respect to the latter study, one might speculate that there may be some sports that differ more from gymnastics concerning the types of mental transformations and the general mental rotation engagement than soccer does. For example, orienteering is a sport in which the allocentric perspective plays a central role when navigating through one's surroundings. For successful orientation, mostly in the woods, orienteers have to adopt an allocentric perspective to locate themselves as an object on the coordinate system of the map. Therefore, while exercising, they train their mental rotation skills, which in turn should lead to enhanced performance especially in object-based mental rotation tasks – since to solve them one has to adopt an allocentric perspective. To the best of our knowledge, no study has ever compared orienteers with other athletes with or without mental rotation engagement, or even tested whether they differ from nonathletes. However, any differences that might be found would help to determine which specific effects different sports may have on mental rotation skills.

The present study therefore examines whether different sports that make various mental rotation demands differ in terms of the resulting mental rotation performance. Thus, the mental rotation performance of athletes in a sport with a high degree of egocentric transformations (gymnastics), a sport with a high degree of allocentric transformations (orienteering), and an endurance sport without mental rotation demands (running) are compared with each other, and in addition with the performance of a group of nonathletes. The conjecture is that (1) people actively involved in sports will have a better mental rotation performance than nonathletes. That (2) each individual sport will lead to a better mental rotation performance than in nonathletes, irrespective of the mental-spatial demands made by the sport. (3) Furthermore, athletes involved in sports which require mental rotations in order to be carried out successfully (gymnastics and orienteering) will have a better mental rotation performance than athletes doing a sport that does not require mental rotation (running). (4) Finally, it is surmised that orienteers (allocentric transformations) will do better in an object-based mental rotation test focusing on allocentric rotations than gymnasts (egocentric transformations).

Method

Participants

A total of eighty undergraduate students (50 % men in each group, M_{age} = 25.73, *SD* = 4.63), took part in the study, having been recruited with the alleged explanation of wanting to compare mental rotation performance between people studying different subjects at university. The group of *nonathletes* (*n* = 20) consisted of people who had spent less than 30 minutes a day doing at least moderate-intensity physical activity on five or more days of the week in the seven days before the survey (Sproston & Primatesta, 2003). The group of *athletes* (n = 60) consisted of people involved in the three sports orienteering (n = 20), gymnastics (n = 20) and running (n = 20), who had to have been participating in the respective sport for at least two years and who were doing it at least twice a week. The four groups (orienteers, gymnasts, runners, nonathletes) did not differ in terms of their ages ($F(3, 72) = 2.22$, $p = .09$, $\eta^2 = .10$; see Table 1), but did with respect to the number of training sessions per week ($F(3, 72) = 24.60$, $p < .0005$, $\eta^2 = .49$), the minutes spent per training session ($F(3, 72) = 44.62$, $p < .0005$, $\eta^2 = .64$) and the years spent practicing their respective sport ($F(3, 72) = 26.02$, $p < .0005$, $\eta^2 = .51$). As expected, Tukey-HSD post-hoc tests revealed that all three sport groups train more times per week than the nonathletes ($p < .0005$), but that they do not differ between each other ($p > .99$). Tukey-HSD post-hoc tests for the minutes spent per training session showed that, apart from the runners and the orienteers ($p = .18$), all groups differ in the duration of their training session (ps < .004). Tukey-HSD post-hoc tests for the years spent doing the sport showed that all three sports groups spent more years practicing their sport than nonathletes ($p < .0005$), but also that gymnasts started their sports career earlier than runners ($p = .001$). The data contained no missing values, nor were any univariate outliers found using Grubbs' test ($Z = 2.58$, $p > .05$).

Measures

Mental rotation. Set "A" of the Mental Rotations Test (MRT-A) by Peters et al. (1995) was used to assess mental rotation performance. This test was originally developed by Vandenberg and Kuse (1978), using objects made up of cubes, as designed by Shepard and Metzler (1971). Overall, 24 tasks need to be solved in the MRT-A, whereby in each case the object has to be mentally rotated and compared with four other objects made up of cubes. Two of the four stimuli are identical to the target figure. A task is only considered to have been solved if both the correct answers are identified. This means that the maximum possible score is 24 points. The reliability and validity of the test have been demonstrated (Geiser, Lehmann, & Eid, 2006).

Physical activity. Physical activity was examined using the “Sportaktivität” (Sports Activity) subscale of the “Bewegungs- und Sportaktivität” questionnaire (BSA; Fuchs, 2012) in which participants are asked about their regular sports activities over the past four weeks, the frequency with which they carried out these activities, and the duration of each session.

Procedure

First, the MRT-A was carried out to determine the mental rotation performance. Next, participants completed the questionnaire on their current sports behavior, and gave details of their age and sex. The entire procedure lasted 15 minutes and was carried out as an individual test in a quiet room. All subjects gave their informed consent before taking part and were able to discontinue the study at any time.

Statistical analyses

In order to test whether athletes (all three sports groups together) and nonathletes differ from each other with respect to their MRT-A performance, a univariate analysis of variance (ANOVA) was conducted with the dependent variable MRT-A test score and the independent variable activity group (athletes, nonathletes) and gender (male, female). To test all three remaining study hypotheses, a univariate analysis of variance (ANOVA) was performed with the dependent variable MRT-A test score and the independent variables group (orienteers, gymnasts, runners, and nonathletes) and gender (male, female). Gender was considered as a factor because men are known to perform better in object-based mental rotation tests than women (e.g. Voyer et al., 1995). Post-hoc comparisons using Tukey’s HSD test were used to compare specific groups with one another. A significance level of .05 was set for all tests. The effect size was calculated and interpreted using Cohen’s (1988) definition of small, medium, and large effect sizes (η^2 = .01, .06, .14).

Results

Preliminary analyses

The overall ANOVA with the dependent variable MRT-A test score and the independent variables group and gender revealed a significant overall effect, indicating that groups and/or genders differ with respect to their mental rotation performance ($F(7, 72) = 4.07$, $p = .001$, $\eta^2 = .284$). Whereas there was a significant main effect for the factors group ($F(3, 72) = 5.22$, $p = .003$, $\eta^2 = .179$) and gender ($F(1, 72) = 11.39$, $p = .001$, $\eta^2 = .137$), there was no significant interaction between group and gender ($F(3, 72) = .49$, $p = .693$, $\eta^2 = .020$). The mean sum score of the male subjects was $M = 13.75$ ($SD = 4.46$), whereas the mean for the female subjects was $M = 10.68$ ($SD = 4.16$), meaning that this effect can be described as being large. Thus, the uniform distribution of the sexes within the different groups proved to be the central control variable in the present study design.

Primary analyses

[Insert Figure 1 here]

Figure 1 shows the mean scores of the four test groups in the MRT-A test. The first hypothesis postulated a difference between athletes and nonathletes. Athletically active subjects ($M = 13.18$, $SD = 4.40$) displayed significantly higher MRT-A scores ($F(1, 76) = 13.56$, $p < .0005$, $\eta^2 = .151$) than their non-athletic counterparts ($M = 9.35$, $SD = 3.83$). The reported effect size can be described as large. The second hypothesis postulated that each different sport group would display a better mental rotation performance than the group of nonathletes. As already indicated in the preliminary analyses, there is a significant difference between the mean MRT-A scores for the four groups investigated ($F(3, 72) = 5.22$, $p = .003$, $\eta^2 = .179$). The effect size suggests a large effect. The post-hoc comparison using Tukey's HSD test shows that orienteers ($p = .008$) and gymnasts ($p = .011$) have significantly better mental rotation skills than nonathletes. Runners do not differ significantly from nonathletes in terms of their mental rotation performance ($p = .184$). Hypothesis three suggested that those sports involving higher levels of mental rotation (gymnastics and orienteering) would be associated with a better mental rotation performance than sports without mental rotation (running). Although on a descriptive level the gymnasts (p = .661) and orienteers (p = .592) displayed higher means than the runners (see Table 1), this difference is not statistically significant. Contrary to the fourth hypothesis, gymnasts (egocentric transformations) do not differ from orienteers (allocentric transformations) with respect to their mental rotation performance (p > .999).

Since it is not only the level of the mental rotation demands made by a specific sport that could influence mental rotation performance, but also the time spent doing a specific sport and the intensity – in addition to the four hypotheses tested – another ANOVA was conducted including the variables training sessions per week, minutes per training session and years spent doing the sport as additional factors. The results show that none of the variables included exerted a significant main effect on the dependent variable (ps > .134), nor did they interact significantly with one of the other factors (ps > .09). Furthermore, the main effects for the factors group ($F(3, 57) = 2.45$, $p = .033$, $\eta^2 = .167$) and gender ($F(1, 57) = 8.18$, $p = .006$, $\eta^2 = .113$) did not differ notably when these variables were included in the model.

Discussion

The main findings of the present study were that with respect to their mental rotation performance (a) people actively doing sports outperformed nonathletes; (b) orienteers and gymnasts outperformed nonathletes; (c) contrary to expectations, gymnasts did not differ from orienteers; (d) and men outperformed women. Since findings (a) and (d) reflect the existing literature on differences in mental rotation performance between athletes and nonathletes (Jansen et al., 2012; Ozel et al., 2002) and between men and women (Maeda & Yoon, 2012; Voyer et al., 1995) respectively, these results will not be discussed any further.

Sports do not only differ in terms of their physical demands (such as aerobic and anaerobic activity, strength and coordination tasks) though, but also in terms of the demands they make on mental rotation skills (thereby promoting these). It can therefore be assumed that not all sports will affect mental rotation performance in the same way or to the same extent. This is supported by experimental studies demonstrating greater effects on subject's mental rotation performance for sports involving coordination and mental rotation than those with just few cognitive demands (Jansen, Lange, & Heil, 2011; Moreau et al., 2012). However, to date only two cross-sectional studies have compared two sports groups with different mental rotation demands with each other and revealed that elite combat athletes display better mental rotation performance than elite runners (Moreau et al., 2011) or that soccer players do not differ from gymnasts (Jansen & Lehmann, 2013). The present study is therefore the first to compare the three different sports gymnastics (egocentric transformations), orienteering (allocentric transformations), and running (without mental rotations) with a group of nonathletes. Interestingly, besides gymnasts also orienteers display a higher mental rotation performance than nonathletes.

The finding that athletes with lots of experience in allocentric transformations (orienteers) and those with lots of experience in egocentric transformations (gymnasts) did not differ in their mental rotation performance is in line with the results of Jansen and Lehmann (2013). It may indicate that the connection between sports activity and mental rotation performance is primarily explained by the general level of mental rotation demands made by a specific type of sport rather than the different (ego- or allocentric) perspective inherent in the sport. Nevertheless, it also has to be said that in our sample with equal numbers of training sessions per week, the mean training duration is much longer in gymnasts than in orienteers. On the one hand, this reflects the natural setting of the respective sports, on the other hand this could have affected the results of the present study. Further studies aimed at discovering the differential effects of ego- or allocentric sports could ensure that this possible confounding factor does not differ between the groups being compared.

Besides the small sample size, one limitation of the present study is certainly its cross-sectional design, which prevents any causal conclusions from being drawn. Whether people with good mental rotation skills tend to choose sports that make high demands on their mental rotation performance, or whether sports with high levels of object rotations are in fact able to influence mental rotation performance, cannot be answered by this study. However, training and experimental studies do certainly suggest that this is the case (Jansen, Lange, & Heil, 2011; Jansen et al., 2009; Jansen & Pietsch, 2010; Moreau et al., 2011, 2012). More intervention studies are required that compare different sports with one another and with nonathletes. To shed more detailed light on the causal connections between different sports activities and their effects on mental rotation performance, future studies could include the underlying physiological mechanisms involved in different sports activity to a greater extent. Neurophysiological measures, such as functional imaging technologies (fMRT), could directly measure the different neuronal activities and how these change over time (see, for example, Voelcker-Rehage, Godde, & Staudinger, 2011).

Another important limitation is that no additional cognitive ability, for example participant’s overall intelligence or cognitive processing speed, was measured. Considering the study conducted by Jansen and Lehmann (2013), which showed that male and female soccer players differ in their processing speed, one might argue that the differences found in the present study may have been due to differences in precisely this variable. Thus, processing speed is a cognitive ability that deserves more attention in future studies investigating mental rotation differences.

Nevertheless, the present study revealed not only gymnasts, but also orienteers to have better mental rotation performance than nonathletes. This result supports the claim that specific sports may have specific effects on specific cognitive skills.

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Figures and Tables

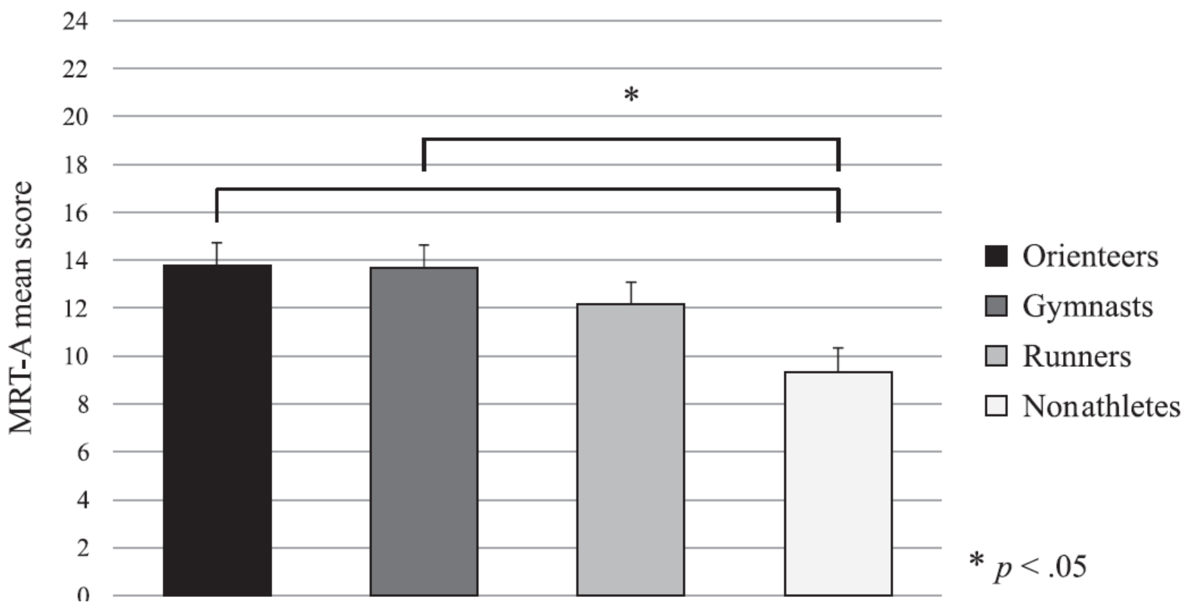

Figure 1. Mean scores of MRT-A for the four groups studied, with standard error of the mean.

Table 1

Mean scores (and standard deviations in parentheses) for all study variables by group.

Variable	Orienteers (n = 20)	Gymnasts (n = 20)	Runners (n = 20)	Nonathletes (n = 20)
MRT score	13.80 (4.35)	13.65 (5.16)	12.10 (3.57)	9.35 (3.83)
Age	26.20 (5.36)	27.15 (6.10)	25.95 (3.12)	23.60 (2.50)
Training sessions per week	2.75 (1.68)	2.65 (.93)	2.85 (.88)	0.35 (0.49)
Minutes per training session	59.5 (8.87)	130 (44.84)	80.75 (26.12)	22.00 (29.49)
Years spent doing sport	10.80 (5.80)	14.20 (4.58)	8.35 (5.06)	1.38 (3.22)