EFFECT OF DIFFERING EXERCISE INTENSITIES ON THE RESPONSE TIME OF GYMNASTS AND NON-GYMNASTS IN 3D CUBE MENTAL ROTATION TASK

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Original article *DOI:10.52165/sgj.13.3.301-309*

Abstract
The purpose of the present study was to examine the effect of different levels of exercise intensity on mental rotation performance in gymnasts vs. non-gymnasts'. Forty-one participants (18 females; mean age 20.94±0.89 years, height 1.65±0.03 m, body mass 58.94±5.67 kg, and 23 males; mean age 21.26±0.99 years, height 1.70±0.05 m, body mass 66.87±4.52 kg) divided into two groups (i.e., gymnasts and non-gymnast) voluntarily took part in the present study. The two groups performed a 3D cube mental rotation task at rest, and then performed the same task preceded by short bouts of intense exercise at 60%, 80%, 100% and 120% of their maximum aerobic speed (MAS). The analyses of response times showed that gymnasts performed the mental rotation task faster following bouts of intense exercise than in rest condition, especially in 60% and 80% of MAS, whereas non-gymnasts increased their response times after moderate exercises (i.e., 60 et 80 % of MAS) and stabilized their performance (i.e., equally at the rest) after intense exercises. This finding highlights the specific physical expertise as a variable that can affect the influence of exercise on cognitive processing.

Keys words: *mental rotation, cognitive processing, exercise intensity, gymnastics expertise.*

INTRODUCTION

Mental rotation (RM) is a mental operation in which mental representations of objects are rotated around a three-dimensional (3D) axis space. The concept of mental rotation was introduced by Shepard and Metzler (1971). In their famous experiment, they presented the participants with pairs of misoriented figures of asymmetric 3D cube assemblies and asked them to determine whether they depicted similar or mirror-reversed objects. The authors recorded Response Time (RT) of the participants and found that it increased as a function of the angular disparity between the two objects, revealing an analogy between real and imagined rotations (Shepard & Metzler, 1988).

Mental rotation is one of the most solicited mental abilities in everyday life. One of the domains that particularly involves mental rotation is sport. Sports practice is an ideal context to develop spatial capacities, in particular visualization, orientation, and mental rotation (Bangert, Parlitz, & Altenmüller, 1999; Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Cross, Hamilton, & Grafton, 2006; Ozel, Larue, & Molinaro, 2002; Pietsch & Jansen, 2012). In sports, mental rotation is used in different forms. For example, one could constantly rotate the spatial presentation of her/his own body in order to find it's bearings in space, to make a good reception or to avoid injuries. This strategy relies mainly on egocentric motor processes (Habacha, Lejeune-Poutrain, & Molinaro, 2017). However, team sports would encourage the use of a visual strategy since the athlete is trained to perceive and analyze moving objects, with relation to his partners and opponents. Accordingly, gymnastics seem to encourage the use of an egocentric motor strategy since the athlete trains by moving his frame of reference in space (rotating body) while objects and the environment remain fixed.

Gymnastics include a wide range of motors skills that require developed spatial and mental abilities, which makes gymnasts quite efficient in mental rotation compared to non-gymnasts (Dehghanizadeh, Mohammadzadeh, & Hosseini, 2013; Habacha, Lejeune-Poutrain, & Molinaro, 2017; Jansen & Lehmann, 2013; Schmidt, Egger, Kieliger, Rubeli, & Schüler, 2016; Steggemann, Engbert, & Weigelt, 2011). In addition, several studies reported that gymnasts have shorter RT than non-gymnasts during the mental rotation of a body image and not with 3D objects (Habacha et al., 2017; Jansen & Lehmann, 2013; Jola & Mast, 2005; Steggemann et al., 2011). Further, Guillot, Louis, Thiriet, and Collet (2007) showed no difference between athletes and non-athletes in a mental rotation task. These contradictory results can be due to several factors including the type of task and the stimulus used which would imply different mental strategies (egocentric strategy vs. visual strategy), consequently influencing the performance in mental rotation.

In this regard, one way to better understand the link between sport movement execution and its cognitive processing is to investigate the effect of exercise intensity on cognitive performance. The fact that physical exercise is associated with elevations in mood states and increased psychological well-being (Berger, 1996; Shephard, 1996), and that physical exercise is positively related to several indices of mental health (Morgan, 1984), suggest that physical exercise can enhance cognitive performance. However, no support for this assumption was found in some reviews of the literature (Etnier et al., 1997; McMorris & Graydon, 2000; Tomporowski & Ellis, 1986). This could be explained by the assumption that exercise can affect cognitive performance in an inverted-U shape with better performance corresponding to submaximal exercise intensity and poorer performance corresponding to minimal and maximal exercise (McMorris & Graydon, 2000). Nonetheless, other studies showed that cognitive performance was not always negatively affected by maximal intensity exercise sessions (McMorris & Graydon, 1996a, 1996b) and that it was even improved (Hogervorst, Riedel, Jeukendrup, & Jolles, 1996; Winter et al., 2007). Such discrepancies may be related to the fact that the sport expertise level of the participants have rarely been taken into consideration, especially knowing that physical activity level seems to be an important variable that may affect cognitive performance following intense exercise (Brisswalter, Arcelin, Audiffren, & Delignières, 1997; Zervas, Danis, & Klissouras, 1991).

In the present study we tried to control the expertise level variable by recruiting elite gymnasts and compare their cognitive performances to non-gymnasts after differing exercise intensities. A 3D cube mental rotation task was used to assess cognitive performance (Habacha et al., 2017; Jansen & Lehmann, 2013; Metzler & Shepard, 1974; Shepard & Metzler, 1971; Shepard & Metzler, 1988). We hypothesized that gymnasts will be more capable of maintaining their cognitive skills after bouts of intense exercise than non-gymnasts.

METHODS

Forty-one participants (18 females; mean age 20.94±0.89 years, height 1.65±0.03 m, body mass 58.94±5.67 kg, and 23 males; mean age 21.26±0.99 years, height 1.70±0.05 m, body mass 66.87±4.52 kg) voluntarily took part in the present study. They all have normal or corrected-to-normal vision (i.e., based on their medical records) and were naïve to the purpose of the experiment.

The Gymnasts group was composed of twenty-one participants (8 females; mean age 20.63±0.70 years, height 1.65±0.04 m, body mass 60.00±5.61 kg, VO_{2max} 34.82±5.80 ml/min/kg, MAS 11.06±0.78 km/h, and 13 males; mean age 21.43±1.15 years, height 1.69±0.04 m, body mass 66.85±5.86 kg, VO_{2max} 44.56±3.01 ml/min/kg, MAS 12.69±0.48 km/h). The inclusion criteria for this group were to be a gymnast at a national or international level, to have at least 10 years of experience and to have participated in at least one international competition. The Non-Gymnasts group was composed of twenty participants (10 females; mean age 21.19±0.99 years, height 1.65±0.03 m, body mass 58.10±5.88 kg, VO2max 38.52±6.56 ml/min/kg, MAS 11.75±1.03 km/h, and 10 males; mean age 21.05±0.74 years, height 1.71±0.06 m, body mass 66.90±2.02 kg, VO_{2max} 45.18±2.24 ml/min/kg, MAS 12.75±0.26 km/h). The inclusion criteria for this group were to be non-gymnast, to practice recreational sport for at least 3 years and to have never participated in a national or international competition.

After being informed in advance on the procedures, methods, benefits and possible risks involved in the study, each participant had to review and sign a consent form to participate in the study. The experimental protocol was performed in accordance with the Declaration of Helsinki for human experimentation and was approved by the Ethical Committee. The subjects were assured of the principles of anonymity and volunteering. They were informed that the only use of the data was for scientific research purposes.

After a warm-up of 15 minutes (5 minutes of light running and 10 minutes of specific exercises), participants performed a 20m shuttle run test (Leger, Mercier, Gadoury, & Lambert, 1988). A portable gas analysis system (i.e., Cosmed K4b2) and a heart rate monitor (i.e., Polar time) was used to determine the maximal oxygen uptake (VO_{2max}), the maximal heart rate (HRmax) and the maximum aerobic speed (MAS) for each participant.

The stimuli used in the mental rotation task included pairs of standard and comparison images. The standard image consisted of three-dimensional rotation shapes of "3D cube" (Shepard & Metzler, 1971).

There are 6 models of the cubes (i.e., 3 correct and 3 false) × 8 times × 2 response possibilities (i.e., same and different) = 48 stimuli. The order of stimuli presentation was counterbalanced, and each rotation angle could not appear 2 times successively. Stimuli were displayed and response times were recorded via the free software 3D Imagine® version 1.1.1 2001 (Opensource software for free download at:

https://sourceforge.net/projects/imagine3d/). Participants placed their left and right index fingers on two keyboard buttons that were coloured and labelled as "same" and "different" and were asked to judge whether the two images of a stimulus depicted were the same or different 3D cube assemblies (Figure 1). The mental rotation task lasted about 4 minutes.

After a warm-up of 15 minutes, the participants performed a shuttle run for 2 minutes at one of the intensity levels corresponding to a percentage of their MAS (i.e., 60%, 80%, 100%, and 120%). A heart rate monitor (i.e., Polar time) was used to control the effort level and the percentage of MAS. Immediately afterward, they sat in front of a monitor at about 80 cm distance and performed the 3D cube mental rotation task. The next day, each participant performed the shuttle run at another intensity level followed by the 3D cube mental rotation task. To record a baseline cognitive performance on mental rotation, participant performed the 3D cube mental rotation task at rest on a different day. Which resulted in 5 experimentation days (Rest, 60%, 80%, 100%, and 120% of the MAS). The order of intensity levels was counterbalanced across the experimentation days and the participants.

Data are reported as mean ± standard deviation and confidence intervals at the 95% level (95% CI). Effect size (*dz*) was calculated using GPOWER software (Bonn FRG, Bonn University, Department of Psychology). The following scale was used to interpret *dz*: < 0.2, trivial; 0.2 – 0.6, small; 0.6 – 1.2, moderate; 1.2 – 2.0, large; and > 2.0, very large (Hopkins, 2002). The normality of distribution, estimated by the Shapiro-Wilk test, was acceptable for all variables. Therefore, a 2 (groups: gymnasts, and non-gymnasts) × 5 (exercise intensity level: rest, 60%, 80%, 100%, and 120% of MAS) ANOVA with repeated measures test was computed. For pairwise comparison, a post hoc / Bonferroni was established. The results were considered significantly different (significant) when the probability is less than or equal to 0.05% ($p \leq .05$). The statistical study was performed by SPSS® 20.0 software (SPSS Inc., Chicago, IL, USA).

RESULTS

The ANOVA repeated measure showed a significant difference in the interaction between *Exercise Intensity* and *Groups*, and between *Gymnasts* and *No-gymnasts*, but between *Exercise Intensity* there is no significant difference (Table 1).

In the interaction between *Expertise* and *Exercise Intensity*, as shown in Figures 2, gymnasts had shorter RTs than non-gymnasts in 60% and 80% intensity conditions (i.e., $p < .05$ and $p < .001$ respectively) but not in the Rest, 100% and 120% condition ($p > .05$).

Table 1
ANOVA Statistics.

Source	df	Mean Square	F	Sig.	Effect Size	Observed Power
Exercise Intensity	4	9550.290	0.564	0.689	0.238§	0.185
Groups	1	323704.61	5.576	0.023*	0.756#	0.634
Exercise Intensity*Groups	4	83845.085	4.948	0.001**	0.714#	0.957

(*) significant at p<0.05; (**) significant at p<0.001; (§) small effect size; (#) moderate effect size.

Figure 1. Examples of stimuli used in the 3D cube mental rotation task. A: a correct trial (correct response is “same”). B: a false trial (correct response “different”).

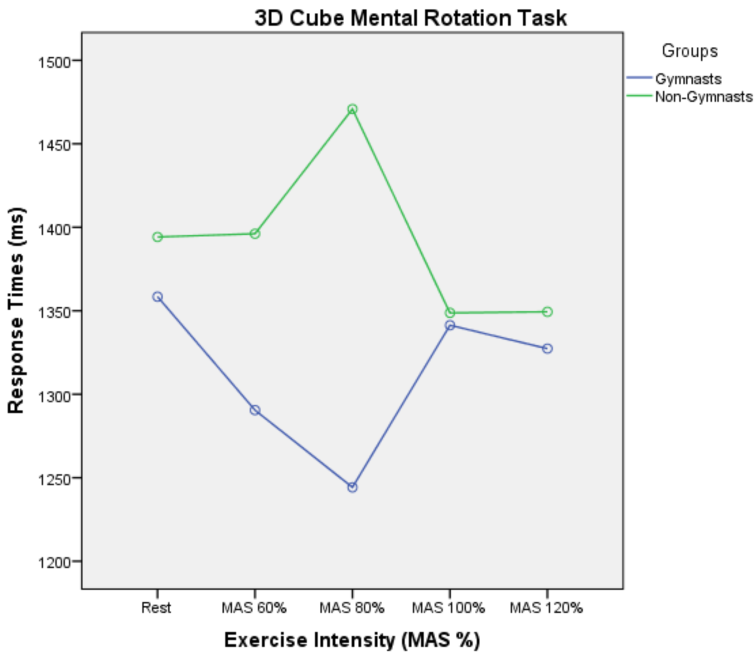

Figure 2. Response times according to different exercise intensities in 3D cube mental rotation task.

DISCUSSION

The present study investigated the effect of exercise intensity on cognitive performance in gymnasts and non-gymnasts. The main aim was to verify whether gymnasts would be capable of maintaining their cognitive processing level and even enhance it after a short period of acute exercise when they perform a cognitive task involving mental rotation of 3D object. For this aim, we designed a 3D cube mental rotation task (Habacha et al., 2017; Jansen & Lehmann, 2013; Metzler & Shepard, 1974; Shepard & Metzler, 1971; Shepard & Metzler, 1988), and we compared the effect of preceding bouts of intense exercise on the mental rotation performances of gymnasts and non-gymnasts.

Our results showed that the gymnasts were able to maintain cognitive ability and even improve it after acute bouts of exercise (i.e., 60%, 80%, 100% and 102% of MAS). In addition, the gymnasts performed mental rotation significantly faster after undergoing a brief exercise at 60% and 80% of their maximal aerobic speed (MAS). This is in accordance with the suggestion that an increase in arousal (i.e., neurophysiological activation) goes along with increasing exercise intensity (McMorris & Graydon, 2000). Likewise, our result agrees with McMorris and Graydon (2000), not only for submaximal exercise, but also for maximum exercise. This increase may be associated with increased cognitive processing in the central nervous system and consequently with an enhanced amount of attentional resources devoted to the cognitive task administered (Kamijo et al., 2004; Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007). However, non-gymnasts performed mental rotation significantly slower after undergoing a brief exercise at 80% of their maximal aerobic speed (MAS). This result is in accordance with the study of Delignières, Brisswalter, and Legros (1994) which showed that when performing a cognitive task at different exercise intensities (i.e., Rest, 20%, 40%, 60% an 80% of MAS), non-athletes, unlike athletes, significantly increase their response times during submaximal effort (i.e., 80% of MAS). In addition, Naito (1994), Pietsch and Jansen (2012) and Ozel et al. (2002) tested athletes and non-athletes in an abstract object mental rotation task and showed shorter response times in athletes than non-athletes. These authors suggested that the regular practice of physical activity could be linked to the spatial abilities of the participants whose subjects present.

However, as demonstrated here, in non-gymnasts, 2 minutes of exercise at 60% of MAS seems to be insufficient to trigger an increase or decrease in cognitive processing. This result may suggest that when designing experiments on the effect of short bouts of exercise on cognitive ability in non-expert athletes, an intensity greater than 60% of the MAS could be necessary to generate an increase in arousal and thus cognitive processing. Alternatively, 2 minutes at 60% of the MAS could have been too short and a longer duration at the same intensity might be necessary. It should be noted that these results take into consideration the level of specific physical expertise.

Interestingly, the interaction between exercise intensity and expertise revealed that only the gymnasts benefited from an enhancement of cognitive processing (i.e., 60% and 80% of MAS). On the one hand, this result corroborates the assumption that cognitive processing is facilitated after bouts of acute exercise (Tomporowski, 2003). On the other hand, this finding specifies the effect of acute exercise by revealing that cognitive facilitation depends on tasks linked to well-learned and automatic skills (McMorris & Graydon, 2000). Additionally and more interestingly, this improvement (i.e., for gymnasts) of mental rotation performance is at 80% of MAS. This is in line with several research studies (Cox, Thomas, Hinton, & Donahue, 2004; Jouini, Mkaouer, & Chamari, 2017a, 2017b) that suggested 80% of MAS as a cut-point for enhancing cognitive performance.

The results of the present study reveal an enhancement of visual mental rotation after brief bouts of intense exercise only in gymnast. However, in a recently accepted study (Khalfallah, Mkaouer, Amara, Habacha, & Souissi, 2021), gymnasts, unlike non-gymnasts, were shown to benefit from the preceding bouts of exercise also with mental rotation based on egocentric motor strategies. Indeed, the same research protocol was carried out, but the mental rotation task included 3D human body images. The results showed that the gymnasts performed mental rotation significantly faster than non-gymnast after undergoing brief bouts of exercise at 80°, 100°, and 120° of their maximal aerobic speed (MAS). The authors suggested that non-gymnasts, faced with upside-down body positions that were not well-learned (as in gymnasts), could not benefit from the increased attention resources devoted to the task. Taken together, these findings may suggest that preceding bouts of intense exercise enhance mental rotation performances in gymnasts and not in non-gymnasts, both in motor-based and visual-based mental rotation tasks. In fact, the mental emulations of a 3D rotated cube are quite familiar to the internal logic of artistic gymnastics, so gymnasts were able to fully benefit from the increase in arousal and enhanced amount of attentional resources to solve the task (Kamijo et al., 2004, 2007). This finding corroborates the selective physical expertise of gymnasts in mental rotations task (Habacha et al., 2017; Khalfallah et al., 2021; Steggemann et al., 2011).

CONCLUSION

Our study is the first to show a decrease in response times in a 3D cube mental rotation task after acute bouts of exercise, but it could hardly explain the discrepancies in the literature about the influence of exercise on cognitive processing. The level of physical activity/expertise seems to be an important variable that may affect cognitive performance following intense exercise. Our study, based on egocentric motor strategy, highlights another variable: the task parameters linked to selective physical expertise of the participants. Further studies should take into account these two variables to better understand the influence of exercise on cognition and to avoid unwarranted generalizations.

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Article received: 4.5.2021
Article accepted: 18.8.2021