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Effects of the axis of rotation and primordially solicited limb of high level athletes in a mental rotation task

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ABSTRACT

A recent set of studies has investigated the selective effects of particular physical activities that require full-body rotations, such as gymnastics and wrestling (Moreau, Clerc, Mansy-Dannay, & Guerrien, 2012; Steggemann, Engbert, & Weigelt, 2011), and demonstrated that practicing these activities imparts a clear advantage in in-plane body rotation performance. Other athletes, such as handball and soccer players, whose activities do require body rotations may have more experience with in-depth rotations. The present study examined the effect of two components that are differently solicited in sport practices on the mental rotation ability: the rotation axis (in-plane, in-depth) and the predominantly used limb (arms, legs). Handball players, soccer players, and gymnasts were asked to rotate handball and soccer strike images mentally, which were presented in different in-plane and in-depth orientations. The results revealed that handball and soccer players performed the in-depth rotations faster than in-plane rotations; however, the two rotation axes did not differ in gymnasts. In addition, soccer players performed the mental rotations of handball strike images slower. Our findings suggest that the development of mental rotation tasks that involve the major components of a physical activity allows and is necessary for specifying the links between this activity and the mental rotation performance.

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1. Introduction

Mental rotation is an important cognitive ability that permits the mental rotation of representations of two- or three-dimensional objects. In a well-known study, Shepard and Metzler (1971) asked participants to judge whether two rotated 3D cube figures depicted identical or different objects and observed that the response time (RT) was linearly proportional to the angle of rotation from the original position. This result suggested that participants mentally rotated one item in reference to the other and that the degree of rotation of an object from the original directly correlates with the length of time required for a participant to judge if the two items are identical or different. This mental rotation of abstract objects induces an object-based transformation, for which the relationship between the environment and the egocentric frame of the observer remains fixed, while each of their relations to the object reference frame are updated (Amorim, Isableu, & Jarraya, 2006; Steggemann et al., 2011). This type of mental transformation classically generates a linear increase in the RTs as the angular disparity increases (Cooper, 1975; Shepard & Metzler, 1971; Steggemann et al., 2011). Other mental rotation tasks require egocentric perspective transformations, for which the relationship between the environment and the object reference frames remains fixed, while each of their relations to the egocentric reference frame of the observer are updated (Amorim et al., 2006; Jola & Mast, 2005; Steggemann et al., 2011). In these mental body rotation tasks, participants are asked to judge the laterality of full human body postures with one arm outstretched. In contrast to the mental rotation of abstracts objects, RTs are generally independent of rotation angle (Wraga, 2003; Wraga, Creem, & Proffitt, 2000; Wraga, Creem-Regehr, & Proffitt, 2004; Zacks, Mires, Tversky, & Hazeltine, 2002). Some studies of mental body rotations showed constant RTs at low angles but a sudden increase with greater angles (Graf, 1994; Keehner, Guerin, Miller, Turk, & Hegarty, 2006; Kozhevnikov & Hegarty, 2001; Michelon & Zacks, 2006). These findings show that the classical linear increase in the RTs with increasing rotation angles is not inevitable in mental body rotation tasks; even if some studies showed a linear increase in the RTs with increasing rotation angles, the slopes were less steep than those reported for abstract objects rotation (Easton & Sholl, 1995; Parsons, 1987; Rieser, 1989).

The above-mentioned differences in RT patterns depend on the spatial frames of reference involved in the mental rotation processes, i.e., object-related vs. egocentric frames of reference (Preuss, Harris, & Mast, 2013; Zacks et al., 2002). Using human body postures, Parsons (1987) showed a correlation between the time required for participants to imagine themselves in the position of the human-body stimulus and the time required to make a handedness judgment of the same figure during a mental body rotation task. He proposed that the participants performed the task by imagining themselves in the position of the body figure (i.e., egocentric perspective transformation). Therefore, this egocentric mental transformation would require embodied transformations and more specifically, the mapping of body axes (head–feet, front–back, and left–right) onto the stimuli defined as a spatial embodiment prior to performing the mental perspective transformation, which is defined as motoric embodiment (Amorim et al., 2006; Jola & Mast, 2005; Parsons, 1987; Steggemann et al., 2011). Thus, this embodied process relies on one's long-term knowledge of body structure (Amorim et al., 2006) and can be modulated by the motor processes because mental rotation rates are slower for impossible body postures compared to possible ones (Petit & Harris, 2005).

The influence of motor processes on the mental rotation performance is another noteworthy issue. The first study to investigate the relationship between motor processes and mental rotation was proposed by Wexler, Kosslyn, and Berthoz (1998), who asked participants to simultaneously perform manual and mental rotations of a joystick and observed the slower rotation times when manual and mental rotations were performed in opposite directions compared to when the rotation directions were identical. In accordance with the authors' hypothesis, this result suggests that mental rotation processes represent covert motor rotation. Similarly, Wohlschläger and Wohlschläger's research (1998) demonstrated that concordant directions in simultaneous manual and mental rotations facilitated mental rotation; conversely, discordant rotation directions inhibited mental rotation. These results suggest a common process that controls both overt and covert object reorientation dynamics.

The influence of motor tasks on mental rotation encouraged some authors to investigate the effect of a wider motor activity (i.e., physical activity) on mental rotation performance. A recent study by Pietsch and Jansen (2012) reported that students who study sports and athletics exhibit better mental rotation abilities than students in science education. In addition, physical activity, such as juggling, was found to enhance performances in a mental object rotation task (Jansen, Titze, & Heil, 2009). Undergraduate students performed better in a mental object rotation task after 10 months of training that included highly coordinated and rotational movements, such as wrestling, than after a period of training of the same duration that did not include these movements, such as running (Moreau et al., 2012). Taken together, these studies revealed that training or the practice of physical activities influences mental rotation performance.

Further studies focused on the effect of an extended practice of physical activities that involve full body rotations by investigating the mental body rotation performances among rotational experts. Ozel, Larue, and Molinaro (2002) first compared the mental rotation performances of experts in physical body rotations (i.e., gymnasts) and athletes who rarely execute physical body rotations in their activity to those of non-athletes. The results showed that the athletes performed better than the non-athletes, but no difference was observed between the two groups of athletes. This study showed a general effect of physical practice, but failed to highlight an effect of the frequent execution of physical body rotations on the mental rotation performances. This shortcoming may be due to the nature of the task used in their study (i.e., mental object rotation), which required object-based transformations. The object-based transformation is not an embodied process and does not allow the implementation of one's motor expertise during a mental rotation task (Jola & Mast, 2005; Steggemann et al., 2011). Steggemann et al. (2011) highlighted that the selective effect of motor expertise can be observed in a mental body rotation task that requires egocentric perspective transformations. In their study, gymnasts, which were defined as full body rotation experts, outperformed other athletes in a left–right judgment task (i.e., perspective transformation task) that involved body images that were presented in 135° and 180° in-plane orientations. This selective effect would illustrate the specific expertise of gymnasts with extreme in-plane body orientations (Steggemann et al., 2011). However, different results were obtained in Jola and Mast's study (2005) for another type of motor experts (i.e., dancers). In their study, Jola and Mast asked expert dancers and non-experts to solve a mental body rotation task using body postures rotated in-plane. The RTs and error rates did not significantly differ between experts and non-experts. The authors suggested that the test stimuli (i.e., line drawings of the human body rotated in picture plane) would not encourage the use of dancers' specific expertise, which is the movement around a different rotational axis (e.g., the longitudinal body axis during pirouettes).

Various physical activities appear to differentially affect the mental rotation abilities. One way to better understand the interplay between motor expertise and mental rotation is to investigate the effects of specific components of the physical activity in a mental body rotation task. In the current study, we focused on the rotation axis and the primordially solicited limb during practice in soccer and handball players.

In their study, Steggemann et al. (2011) considered handball and soccer players to be non-experts of rotational movements because their activities do not require in-plane body rotations. While in-plane orientations beyond 90° are indeed rare in handball and soccer practice, orientations below 90° are quite frequent. In addition, soccer and handball players constantly experience in-depth rotations because their activities involve various twists in the air that require rotations around the longitudinal body axis. To our knowledge, only one recent study compared the mental rotation task performance between soccer players and non-athletes in a task that involved cubes and human body figures as stimuli (Jansen, Lehmann, & Van Doren, 2012). The results revealed that soccer players performed faster than non-athletes in mental rotation tasks that involved embodiment (i.e., human body figures). This finding seems to support the idea that egocentric skills are developed in this physical activity, even if the activity is classically known as an activity with a high exocentric component (Jansen et al., 2012).

Because practicing movements around one axis may create difficulties in performing the same movements around another axis (Jola & Mast, 2005) and in-plane rotations and in-depth rotations partly involve different cognitive processes (ter Horst, van Lier, & Steenbergen, 2010), we hypothesized that the sensorimotor experience related to the rotation axes that are largely engaged in a physical activity could influence the mental rotation performance. Consequently, we investigated the effect of the rotation axis by comparing performances in a mental rotation task using images of handball and soccer movements that involved the rotation of two body axes (in-depth and in-plane) between high level handball players, soccer players and gymnasts.

Another specific feature of soccer and handball that may potentially influence mental rotation is the extensive use of two different limbs. This feature is often neglected in mental rotation tasks. Because the mental representation of the body is continuously updated with regard to its position or movements of body parts (Ionta & Blanke, 2009), handball players are expected to develop an increased perceptual sensitivity to the movements of their arms, and the same can be expected in soccer players for movements of their legs. Gymnasts are expected to develop a similar perceptual sensitivity in their arms and legs because gymnastics involves both of these body parts. As most mental rotation studies use hand laterality judgments, which is a task that does not take into account the limbs that are mainly involved in certain physical activities (i.e., as a more exclusive use of the legs in soccer), we investigated whether the predominant use of the arms or legs influences the mental rotation performance in a laterality judgment task.

We hypothesized that differences in the performance between different groups of athletes will suggest that these components influence mental rotational processes via sensorimotor experience related to the physical activity if the mental rotation tasks include components that are specific to the studied physical activities. More precisely, we expected that handball and soccer players, who are frequently exposed to in-depth rotations, would judge the in-depth rotated images more quickly than in-plane rotated images in the present study. We also expected that the amount of time required for gymnasts to judge in-depth or in-plane rotated images would not significantly differ. In addition, different RT patterns that depend on the solicited limb during each physical activity will yield information regarding the importance of this component in mental rotation.

2. Methods

2.1. Participants

A total of 55 males (M_{age} = 22.8 years, SD = 2.9 years) voluntarily participated in the experiment. All participants had normal or corrected-to-normal vision. Each participant was unaware of the purpose of the experiment and provided informed consent before being tested.

Three groups of athletes were formed: 19 soccer players, 21 handball players and 15 gymnasts. Table 1 depicts the mean age and training experience of the three groups. The inclusion criteria for each group required that participants were currently practicing their activity and that they trained regularly over the last six years (for at least 8 h per week). In addition, each participant reported having no practical experience in the other groups' activity or at the most, only minimal experience from school lessons. The three groups did not significantly differ in age, $F(2,52) = 0.959$, $p = .390$ or mean training experience, $F(2,52) = 1.347$, $p = .269$.

2.2. Stimuli

The stimuli used in the current study included images of handball and soccer strike moves being executed with either the left or right arms or legs. The images were rotated in eight orientations (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°) about two axes: in picture plane and in-depth.

Table 1
Mean age and training experience of the three groups of athletes.

	Age		Training experience	
	Mean (Years)	SD (Years)	Mean (Years)	SD (Years)
Soccer players	23.6	2.9	12.8	2.7
Handball players	22.3	3.2	12.1	2.8
Gymnasts	22.6	2.6	13.6	2.3

Images of left and right strike moves were produced using mirror images of each other such that each left–right pair of stimuli was identical except for the change in position. Accordingly, 64 different stimuli (2 sports × 2 laterality × 2 rotation axes × 8 orientations) were generated (Fig. 1). The images were 15 cm in size and presented on the center of a black background. The stimuli were displayed on a personal computer via proprietary software developed by our laboratory. This software program was developed to record the accuracy of each response as well as the response time (i.e., from stimulus onset to button-press).

2.3. Procedure and task

The participants were seated in front of a computer at a distance of 60 cm in darkened and separate rooms of a gymnasium. For the 20 training trials, the experimenter remained in the room to ensure that participants followed the instructions and to provide task instructions as necessary. After training, the experimenter left the room and was absent for the duration of the test period.

Participants were asked to judge as quickly and accurately as possible whether the left or right arm was performing the strike move that was presented using their index finger to press either the left or a right button on the keyboard. The left and right buttons were color-coded and labeled as "left strike" and "right strike". The order of the test trials was randomized using the proprietary software. Moreover, each orientation was displayed three times but not more than twice successively, such that no image of the same sport (handball or soccer strike) was presented in more than three consecutive trials. This approach resulted in a total of 192 trials (64 stimuli × three representations of each orientation). The trials were divided into two test blocks of 96 trials each.

Each trial began with a blank screen presented for 2000 ms, after which a black fixation cross appeared for 500 ms. After fixation, the test image was presented for a maximum of 5000 ms, and the next trial began if a response was given.

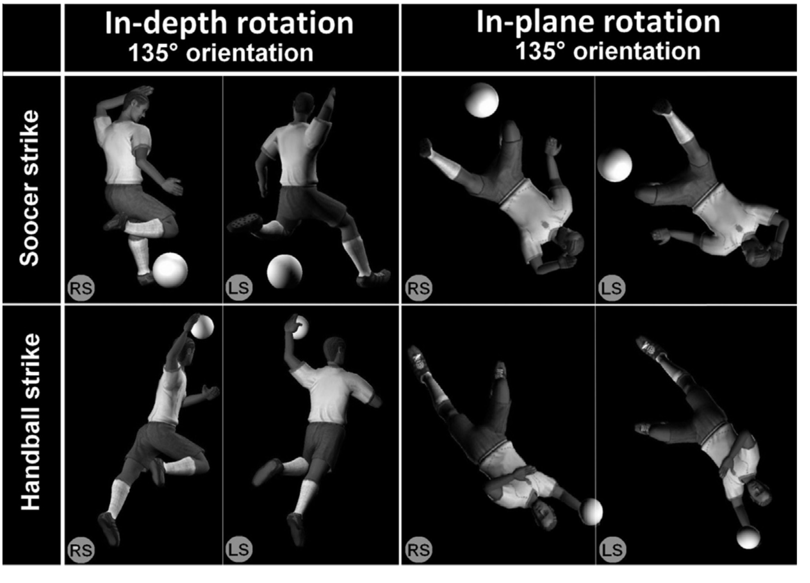

Fig. 1. Examples of stimuli corresponding to a handball strike and soccer strike rotated over 135° in-plane and in-depth: RS) Right Strike (right hand outstretched); LS) Left Strike (left hand outstretched).

2.4. Data analysis

Only data from correct responses were included in the analyses, and RT outliers were excluded (faster than 300 ms and slower than 3000 ms) according to previous studies of mental rotation using human body figures (Amorim et al., 2006; Steggemann et al., 2011).

Two ANOVAs were conducted on the reaction time (RTs) and error rates data using the rotation axis (in-plane, in-depth), sport move (handball strike, soccer strike), and orientation (0°, 45°, 90°, 135°, 180°) as within-subject factors and sport (handball, soccer, gymnastics) as a between-subject factor. We computed descriptive data, Bonferroni post hoc tests and deviation contrasts of RTs to test for linear trends.

3. Results

3.1. Response times (RTs)

The results revealed a significant main effect of orientation on the mental rotation performance, $F(4,208) = 13.816$, $p < .001$, $\eta^2 = .21$. A contrast analysis showed a linear increase in the RTs as the rotation angle increased, $F(1,52) = 17.403$, $p < .001$, $\eta^2 = .25$. The two-way interaction between orientation and rotation axis reached significance, $F(4,208) = 14.700$, $p < .001$, $\eta^2 = .22$. Separate contrasts revealed a significant linear increase in the RTs as the in-plane rotations increased, $F(1,52) = 19.239$, $p < .001$, $\eta^2 = .27$. Such a linear trend was absent when the stimuli were rotated in-depth, $F(1,52) = 0.730$, $p = .397$, $\eta^2 = .01$ (Fig. 2).

The sport (i.e., soccer, handball, gymnastic) did not exert a significant effect, $F(2,52) = 2.111$, $p = .131$, $\eta^2 = .07$. As expected, the rotation axis influenced the mental rotation performances, $F(1,52) = 16.868$, $p < .001$, $\eta^2 = .25$, such that shorter RTs were observed for in-depth rotations ($M = 930$ ms, $SD = 28$) than for in-plane rotations ($M = 1008$ ms, $SD = 35$). More interestingly, a significant two-way interaction between the rotation axis and sport was found, $F(2,52) = 4.899$, $p < .05$, $\eta^2 = .16$, which revealed that soccer players and handball players performed faster for in-depth rotations than for in-plane rotations, $p < .01$ and $p < .001$. The same interaction was not significant for gymnasts (Fig. 3).

In addition, the sport movement exerted a significant main effect, $F(1,52) = 21.057$, $p < .001$, $\eta^2 = .29$. The RTs for soccer strikes ($M = 944$ ms, $SD = 28$) were shorter than for handball strikes ($M = 994$ ms, $SD = 34$). The two-way interaction between the factors "sport move" and "sport" was significant, $F(2,52) = 14.574$, $p < .001$, $\eta^2 = .36$. Soccer players performed faster for soccer strike images

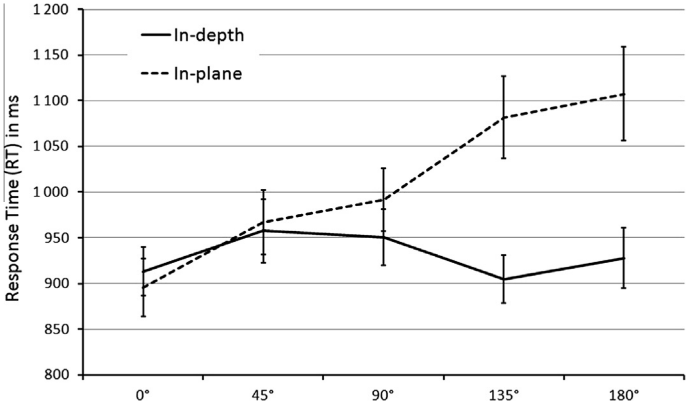

Fig. 2. Response time according to the two-way interaction between orientation and rotation axis.

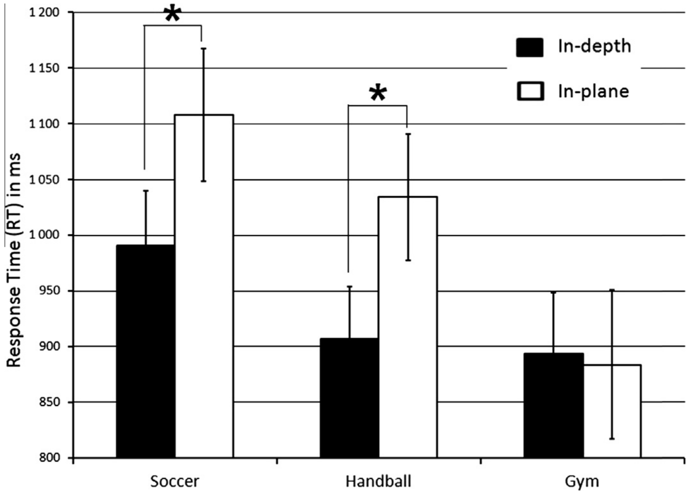

Fig. 3. Response time according to the two-way interaction between rotation axis and sport.

than for handball strike images, $p < .001$. However, this difference was not significant in gymnasts and handball players (Fig. 4). Moreover, the two-way interaction between "sport move" and the rotation axis reached significance, $F(1,52) = 4.737$, $p < .05$, $\eta^2 = .08$. Post hoc tests revealed that the significant difference in the RTs between soccer strikes and handball strikes was greater for in-plane rotations than for in-depth rotations.

The two-way interaction between the sport movement and orientation reached significance, $F(4,208) = 10.183$, $p < .001$, $\eta^2 = .16$. Separate contrasts revealed a linear increase in the RTs as the rotation angles of the soccer strike stimuli, $F(1,52) = 9.730$, $p = .01$, $\eta^2 = .16$, and the handball strike stimuli, $F(1,52) = 20.445$, $p < .001$, $\eta^2 = .28$, increased. However, the handball strike stimuli showed steeper increases in the RTs for increasing rotation angles than soccer strike stimuli, $t(54) = 3.744$, $p < .001$.

3.2. Error rates

The error rates were included in the analyses to quantify the response accuracy. A significant effect of the orientation was observed, $F(4,204) = 7.432$, $p < .001$, $\eta^2 = .13$. A contrast analysis

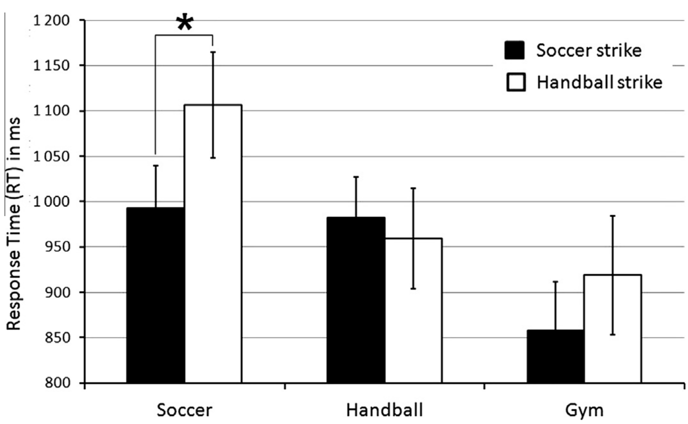

Fig. 4. Response time according to the two-way interaction between sport move and sport.

showed a linear increase in the error rates as the rotation angle increased, $F(1,52) = 9.844$, $p < .01$, $\eta^2 = .16$. The interaction between the orientation and rotation axis reached significance, $F(4,204) = 9.529$, $p < .001$, $\eta^2 = .16$. Separate contrasts revealed a significant linear increase in the error rates as the in-plane rotations increased, $F(1,52) = 20.564$, $p < .001$, $\eta^2 = .28$. Such a linear increase was not observed when the stimuli were rotated in-depth, $F(1,52) = 1.256$, $p = .268$, $\eta^2 = .024$ (Fig. 5).

The main effect of the rotation axis reached significance, $F(1,52) = 21.510$, $p < .001$, $\eta^2 = .30$. In-plane rotations were significantly more error prone ($M = 4.63\%$) compared to in-depth rotations ($M = 2.74\%$). More interestingly, the interaction between the rotation axis and sport was significant, $F(2,51) = 5.213$, $p < .01$, $\eta^2 = .17$. Post hoc tests revealed that handball and soccer players committed significantly more errors for in-plane rotations than for in-depth rotations, $p < .01$, while the error rates of gymnasts were equal for in-plane and in-depth rotations (Fig. 6). In addition, handball players committed more errors than gymnasts for in-plane rotations, $p < .05$, and soccer players also committed more errors than gymnasts for in-plane rotations but the difference was not significant, $p = .063$.

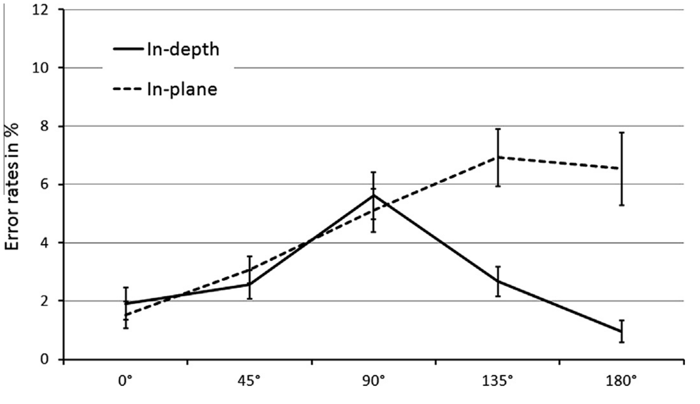

Fig. 5. Error rates according to the two-way interaction between orientation and rotation axis.

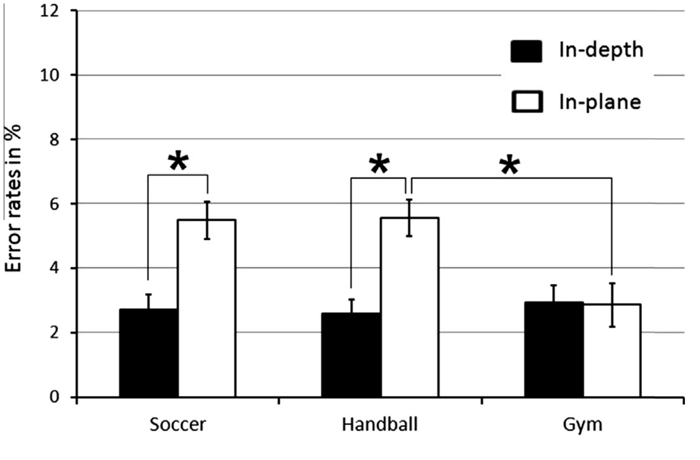

Fig. 6. Error rates according to the two-way interaction between rotation axis and sport.

4. Discussion

In the present study, we investigated the effect of the specific components of motor expertise on the mental rotation ability by studying the influence of the rotation-axis and the limb predominantly involved during a mental body rotation task. To address this aim, handball players, soccer players and gymnasts, whose physical activity differently involved these components, performed a mental rotation task using full body posture stimuli that depicted handball strike moves (arm movement) and soccer strike moves (leg movement) that were rotated over different in-plane and in-depth orientations.

The results showed a linear trend of the RTs and error rates as a function of the rotation angle. As mentioned previously, the literature did not show consistent RT and error rate patterns in perspective transformation tasks contrary to object-based transformation tasks. Interestingly, the RTs and error rates for in-plane rotations, but not for in-depth rotations, showed a linear trend, suggesting different mental transformations according to the rotation axis. The in-plane rotations revealed the classical linear increase in the RTs and error rates. We suspect that perspective transformations to adopt in-plane body orientations rely mainly on mental rotation processes (Parsons, 1987; Wraga, 2003; Wraga et al., 2000, 2004; Zacks et al., 2002). However, the RT and error rate patterns for in-depth rotations were clearly distinguishable from the classical linear increase reported for object rotation, which suggests that the perspective transformation to adopt in-depth orientations relies more on embodied perspective transformations (Creem et al., 2001; Parsons, 1987; Zacks et al., 2002). However, the preference for different strategies according to the rotation axis cannot be completely specified based on the current findings and thus warrants further investigation.

The mental rotations were faster for in-depth-rotated stimuli than for in-plane-rotated stimuli. This result is consistent with the experience gained both in everyday life and during physical practice because body rotations around the longitudinal body axis (in-depth) are more frequent than rotations over the sagittal body axis (in-plane). Aligning the mental representation of one's body with the in-depth rotated stimuli leads to faster mental rotation because the participant may perform a simple rotation over the longitudinal body axis until it is aligned with the stimulus or may only drag the mental image of his body forward to align it with the largest orientations, corresponding to back views of the body. In-depth rotations would thus rely more on perspective translation, which is easier and requires less processing time than perspective rotation (Creem-Regehr, 2003; Rieser, 1989). Aligning one's mental body image with a human figure rotated in-plane necessitated additional rotations over the sagittal body axes and therefore required more time to be completed.

We expected mental rotation processes to be influenced by the specific components of given physical activities, such as the frequency of body rotations around specific axes. We hypothesized that soccer and handball players will perform better using in-depth-rotated stimuli and that gymnasts would perform equally well in in-plane and in-depth rotations because they execute movements around both body axes over a wide range of orientations, including upside-down body positions. The results confirmed this hypothesis because soccer and handball players performed in-depth rotations faster than in-plane rotations and no difference was observed between the two ration axes for gymnasts. This finding supports a close relationship between the physical movement and mental execution (Decety, Jeannerod, & Prablanc, 1989; Decety & Michel, 1989; Gerardin et al., 2000; Jeannerod, 2001; Roland, Skinhøj, Lassen, & Larsen, 1980; Stephan et al., 1995) and highlights that the specific components of a physical activity influence the mental rotation performance. However, contrary to the study by Steggemann et al. (2011), the group of gymnasts was not significantly faster than the other athletes (i.e., handball and soccer players) during in-plane rotations. Given that soccer and handball players committed more errors for in-plane rotations than gymnasts, the most plausible explanation is that soccer and handball players used other strategies based on the visual appearance of the stimuli (Jola & Mast, 2005) or engaged fast guesses leading to similar RTs than those of gymnasts while generating more errors. Another explanation relies on the fact that some activities in the non-expert group studied by Steggemann and colleagues (track and field, rowing, and swimming) developed poorer spatial abilities than handball and soccer.

The type of stimulus also influences the mental rotation performances: mental rotations were slower for handball strike moves than for soccer strike moves. More importantly, among the three groups of athletes, only soccer players performed significantly slower for handball strike move. This finding partially supports our hypothesis regarding the specific effects of physical activity on mental rotation, because the least use of arms in soccer players appears to influence their mental rotation performance. Indeed, a mental rotation task that requires the athlete to mentally adopt a full body posture, including arm movements, may be difficult for soccer players. Despite a slight difference, handball players did not perform slower for soccer strike moves than handball strike moves. This finding may be explained by the fact that handball players use their legs to defend or perform technical gestures, such as to feint to dodge the opponent, and these movements may provide a certain type of expertise with leg movements. As expected, gymnasts performed the two types of strike moves equally well because gymnastics involve the movement of both the arms and legs.

Independent of sport, the current study allowed the investigation of the influence of additional unaddressed stimuli features and their combination on the mental body rotation performances in a single study. To our knowledge, previous studies have not investigated the influence of human body orientations ranging from 0 degrees to 180 degrees around two rotation axes on the mental body rotation ability in the same participants. The results showed that the mental rotation of handball strikes required more time than that of soccer strikes, especially for in-plane rotations. Previous studies have demonstrated that RT patterns change as a result of modifying the participant's posture (de Lange, Helmich, & Toni, 2006; Helmich, de Lange, Bloem, & Toni, 2007; Ionta & Blanke, 2009; Ionta, Fourkas, Fiorio, & Aglioti, 2007; Parsons, 1994; Sirigu & Duhamel, 2001). In the current study, aligning the mental image of one's own body with the handball strike figure may require simulated hand movements, which are subject to increased biomechanical constraints because the hand is placed on the keyboard. Thus, transformations around more than one body axis are necessary to align the hand with that of the handball figure. However, the alignment of the mental image of one's leg with that of the stimulus figure may require a simple transformation and thus less time.

The present study confirms a relationship between the mental imagery of movement and skill. More specifically, it demonstrated that some important components of a physical activity (such as the rotation axis and limb movements) influence the mental rotation performance. While the body rotation axes clearly influenced the mental rotation performance, the influence of the predominant limb was partially evidenced in the present study. Indeed, the mental rotations of human body figures with an outstretched arm may cause difficulties for soccer players. In addition, the similar RTs observed in handball players for handball and soccer moves suggests that arm and leg movements may be more important in handball practice than initially supposed. Other sports that require the excessive use of one limb would be interesting to study to assess the contribution of the limb to mental rotation. To establish further the links between specific motor skills and mental rotation in sports, an accurate description of the physical activity and the development of mental rotation tasks that involve manipulation of the major components of this physical activity are needed.

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