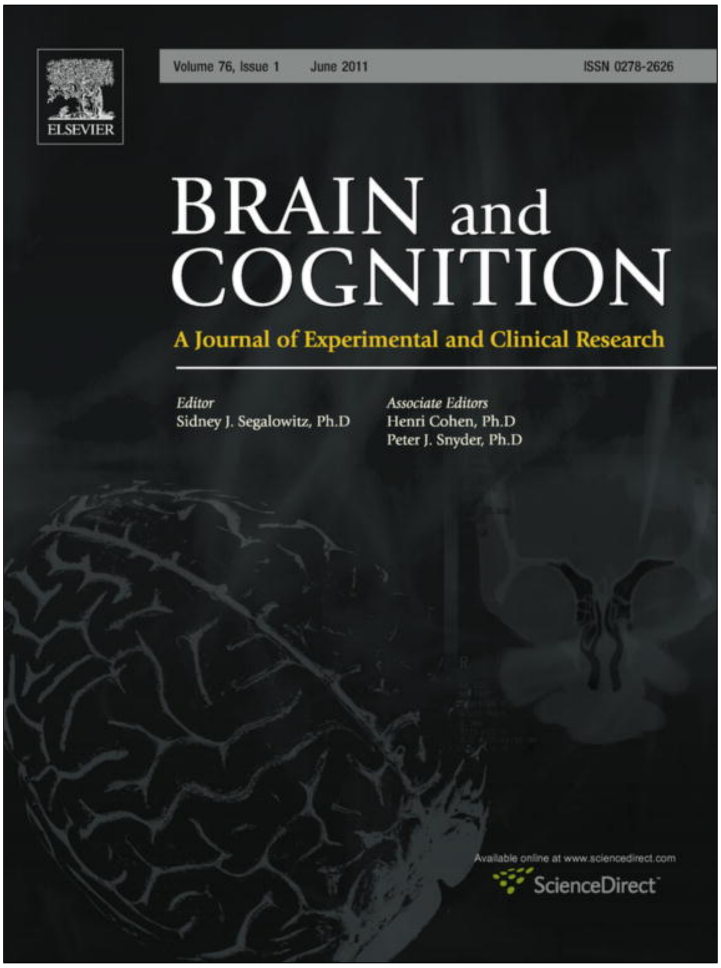
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Selective effects of motor expertise in mental body rotation tasks: Comparing object-based and perspective transformations

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A R T I C L E   I N F O

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A B S T R A C T

Brain imaging studies provide strong evidence for the involvement of the human mirror system during the observation of complex movements, depending on the individual's motor expertise. Here, we ask the question whether motor expertise not only affects perception while observing movements, but also benefits perception while solving mental rotation tasks. Specifically, motor expertise should only influence the performance in mental body rotation tasks (MBRT) with left–right judgment, evoking a perspective transformation, whereas motor expertise should not affect the MBRT with same-different judgment, evoking an object-related transformation. Participants with and without motor expertise for rotational movements were tested in these two conditions in the MBRT. Results showed that motor experience selectively affected performance in the MBRT with the left–right judgment, but not with same-different judgment. More precisely, motor expertise only benefited performance when human figures were presented in (for non-experts) unfamiliar, upside-down body orientations.

1. Introduction

Imagine yourself watching the world championships in artistic gymnastics on TV. You might see outstanding performances from the best gymnasts in the world at different apparatus (e.g., high bar, floor exercise, and the rings), performing a series and combinations of swings, turns and rotations. First, from a psychological point of view one might ask, what happens in the observer's brain while watching such movements? One reflection suggests simulation processes that run in our brains when we observe the actions of other individuals (Jeannerod, 2001, 2003). Thus, perceived actions are mirrored in one's mind's eyes and are mentally simulated without executing them. Second, one might ask, whether there are individual differences in perceiving the actions of others, e.g., differences between the lay audience and other experienced gymnasts. If so, do people with motor expertise benefit from their experiences and are therefore able to perceive and process relevant information faster and more proper? The aim of the present paper was to explore these possible differences between people when they perceive human body postures. We hypothesized that people with extensive motor expertise for rotational movements are able to mentally rotate body postures faster and more accurate than comparable controls. Moreover, this advantage of motor expertise should be limited to tasks that induce an alignment of the participant's own reference frame with the observed human body. In contrast, tasks that can be solved by a comparison of two stimuli were not expected to be influenced by motor expertise. To this end, we conducted two classical mental rotation tasks, which required the processing of (human) whole-body stimuli.

A large number of studies has shown that when an individual observes the actions of others, a corresponding representation is activated in the observer's motor system (e.g., Iacoboni et al., 1999; Grèzes, Armony, Rowe, & Passingham, 2003). This finding suggests a system of brain areas (the so called *mirror system*) that simulates the actions we observe, by mapping them onto a motoric representation of these actions in the observing person (Jeannerod, 2001, 2003). Such a mirror system can be seen as the neural substrate of common representations linking perception and action (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1997). On a functional level, Prinz (1997) has specified this coupling of perception and action in a way that perceptual and motor processes are commensurate and information are coded on a common representational level.

A variety of empirical evidence from studies that investigated motor experts shows that motor experience can modulate action perception (e.g., Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Cross, Hamilton, & Grafton, 2006; Haueisen & Knoesche, 2001) For instance, brain imaging studies (functional magnetic resonance imaging; fMRI) of expert dancers, observing their own and unknown dance movements, provide strong

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evidence for the involvement of the human mirror system while observing complex movements, which can be modulated by an individual's motor expertise (Calvo-Merino et al., 2005). Calvo-Merino and colleagues (2005) asked classical ballet and capoeira dancers to watch short video sequences of ballet and capoeira moves. These researchers found greater activity in the premotor areas, parietal cortices and superior temporal sulcus of the dancers especially when they observed videos of their own athletic profession as compared to videos showing movements that have not been acquired respectively. In other words, ballet dancers showed stronger activity when watching ballet moves, whereas capoeira dancers showed the same effect for capoeira moves. These brain areas are associated with classical mirror regions (cf. Grèzes & Decety, 2001; Rizollatti, Fogassi, & Gallese, 2001). In addition, a further study conducted by Calvo-Merino, Grèzes, Glaser, Passingham, and Haggard (2006) supported these results by separating visual from motor components of action observation. They found that mirror system activity depends on possessing the motor representation for an observed action, and not merely on the visual experience of what is observed. These findings support the hypothesis that motor-related areas of the brain not only subserve the production of movements, but also the observation of actions. Schütz-Bosbach and Prinz (2007) subsumed this coactivation on a shared representational level under the term *perceptual resonance*. According to this concept, action production will prime perception in such a way, that observers are selectively sensitive to those actions of other individuals that are related or similar to their own action repertoire.

Taking these concepts into consideration, we asked the question of whether motor expertise not only affects the perception of familiar movements, but also benefits perceptual processes while solving other higher cognitive tasks (e.g., mental rotation tasks). To this end, motor experts should be able to perceive action-relevant information better and more quickly than people without motor expertise when observing the actions of other individuals, because of their distinct action representation resulting from their specific physical training. Before this assumption is further specified and transferred into research hypotheses, we will provide a short review on the mental rotation paradigm and the basic findings of the literature, which is relevant to the present study.

Shepard and Metzler (1971) defined and introduced the concept of mental rotation, which has become a seminal paradigm in cognitive psychology. Mental rotation is the ability to manipulate spatial information mentally. In this paradigm, participants are asked to view images of three-dimensional (3D) objects at various orientations; in each trial, a pair of images was placed side-by-side. Observers usually judge whether two images of asymmetric objects depict the same or different objects, regardless of any differences in orientation. The typical results show the following pattern for solving mental rotation tasks, both in picture plane and in depth plane: Response time (RT) increases linearly with increasing Angular Disparity between the two images (e.g., 3D objects) presented. This RT pattern suggests that participants solve the task by mentally rotating one of the objects until both objects are mentally aligned, before comparing the two images. Shepard and Metzler (1971) assumed this mental rotation process to be an internal counterpart of a physical rotation of a real object. Thus, in both real and mental rotation, participants chose the shortest rotation path to align two objects. The common-processing hypothesis (Wohlschläger & Wohlschläger, 1998) suggests that a single underlying process controls the rotation of objects with motor commands and mental changes in a visuospatial representation (for empirical evidence, see Ruddle & Jones, 2001; Wexler, Kosslyn, & Berthoz, 1998). Most of the existing research on mental rotation has been conducted with the classical mental rotation task to discriminate between two 3D images of objects. Early variations of Shepard and Metzler's experiment, however, have also included two-dimensional (2D) objects (Cooper, 1975), pictures of unfamiliar polygons (Cooper & Podgorny, 1976), and asymmetrical alphanumeric characters (Cooper & Shepard, 1973).

Another class of objects, which may be subject to special processing, involves images of human faces, whole bodies, and body parts (e.g., Petit, Pegna, Mayer, & Hauert, 2003; Reed, Stone, Grubb, & McGoldrick, 2006; Thayer, Johnson, Corballis, & Hamm, 2001). Jola and Mast (2005) labeled mental rotation tasks involving human full body postures as Mental Body Rotation Task (MBRT, Jola & Mast, 2005). Combined with judgment about handedness or laterality, such stimulus material evokes an internal, embodied experience. Accordingly, the human's ability to move around and to functionally use faces and other body parts can influence the visual identification of other faces and body parts. The first study using photographs of line drawings of human bodies was published by Parsons (1987), in which participants had to decide whether the left or right arm of the figure was extended. As opposed to the experiments with mental object rotation, Parsons (1987) found no linear correlation between RT and orientation. From these results, he suggested that participants solve the left–right judgment by imagining themselves in the position of the human figures and that this type of imagined spatial transformation differs from that of other stimuli, such as characters and numbers, as well as abstract 2D and 3D shapes. Further evidence for this notion comes from Amorim, Isableu, and Jarraya (2006), who found that adding cylindrical "heads" to Shepard and Metzler's 3D objects can induce embodiment effects. Such information about different spatial transformations and the accompanying internal representations are useful in understanding some fundamental processes of spatial cognition.

Hence, in principal, two types of mental transformations can be distinguished in spatial cognition: *object-based (spatial) transformations* and *perspective (egocentric) transformations* (Zacks, Mires, Tversky, & Hazeltine, 2002). Object-based transformations are imagined rotations or translations of objects relative to the reference frame of the environment and to the viewer's perspective. Perspective transformations are imagined rotations and translations of one's point of view in relation to that reference frame and to external objects. Different relationships between the observer and the object are updated in the two transformations: In the case of an object-based transformation, the relationship between the environment and the observer's egocentric frame stays fixed, while each of their relationships with an object's coordinate frame are updated. In the case of an egocentric perspective transformation, the relationship between the environment and the object's frame remain fixed, while each of their relationships with the observer's egocentric frame are updated. Whereas objects are mostly mentally rotated under an object-based transformation, observer's experiences with human bodies are more varied. Human bodies can induce both object-based and perspective transformations. In fact, how people solve a mental rotation task with pictures of human bodies (MBRT) depends fundamentally on the type of judgment that has to be made. Asking people to perform a *same-different judgment* for two images is essentially an object-based transformation (to align the reference frame of one of the bodies with that of the other body). A *left–right judgment* for a single picture of a human body (e.g., left or right arm) causes a perspective transformation. The latter task evokes an alignment of the participant's reference frame with that of the presented body.

For the first time, Jola and Mast (2005) examined the effects of motor expertise by comparing professional dancers and non-dancers in these two different kinds of mental transformation tasks. More specifically, they studied the influence of expertise on performance in a Mental Object Rotation Task (MORT) with object-based transformation (i.e., same-different judgment) and in an MBRT with perspective transformation (i.e., left–right judgment). As one would expect, motor expertise did not influence participant's performance in the MORT with same-different judgment. Most surprisingly, however, motor expertise did also not affect mental rotation in the MBRT with left–right judgment. This is surprising, because several authors have shown that motor expertise affects movement observation (e.g., Calvo-Merino et al., 2005; Casile & Giese, 2006). This lack of expertise effect can be explained by the characteristics of the task (e.g., static body postures) or by the participant's field of expertise. Accordingly, line drawings of a human body in the left–right decision task could be too static to evoke any effect on the dancer's expertise. Another explanation could be that dancers are more experienced in movements with rotations around the longitudinal body axis (e.g., pirouette) than around the sagittal body axis and that these experiences therefore do not benefit mental rotation tasks in which bodies are rotated in picture plane. Thus, in the study by Jola and Mast (2005) the motor experience of dancers may not have been beneficial to solve the MBRT, because their movement expertise relates to moving around a different rotational axis (e.g., the longitudinal body axis during pirouettes).

For the present experiments, we therefore decided to recruit artistic gymnasts, aero wheel gymnasts, trampolinists, and judoka as motor experts. It was expected that these athletes perform better in an MBRT with left–right judgment – which evokes perspective transformations – because of the athlete's long-standing practice in real and imagined body transformations in space and around all three body axes (e.g., cartwheels, flips, and twists). The aim of the following two experiments was therefore to investigate the selective influence of motor expertise in mental rotation tasks with human figures. In particular, we compared two different MBRTs under the same rotation conditions in picture plane. Evoking an object-based transformation in Experiment 1, participant's task was to judge whether two pictures presented simultaneously on a computer screen were the same or different. Evoking a perspective transformation in Experiment 2, participants had to decide whether a human figure's left or right arm was outstretched. We hypothesized that motor experience affects the performance selectively in the MBRT with left–right judgment, whereas an effect of motor expertise should be absent in the MBRT with same-different task.

2. Experiment 1: MBRT with same-different judgment

In Experiment 1, we compared RTs and response errors (REs) of expert participants with motor expertise for rotational movements around different body axes in space with those of non-experts in an MBRT. Similar to the study by Parsons (1987), participants simultaneously viewed *two images* of a female person with either the left or the right arm extended. The person in the lower image was presented in varying orientations. Participants were asked to decide whether the two images depicted the same or different (mirrored) images. This required a same vs. different judgment by the participants. In addition, participants performed an MORT, using an identical design as in the MBRT. To the best of our knowledge, this is the first time that participants are tested for their ability to solve mental rotation tasks with objects and human bodies under similar instructions. This allows for the comparison of mental rotation performance for objects and human bodies, as well as for the examination of potential motor expertise effects on these tasks. The specific predictions for participant's performance in these two tasks are stated in the following paragraphs.

First, it is assumed that a same vs. different judgment induces an object-based transformation, irrespective of whether an object or a human body is presented. That is, pictures of human bodies should be processed in the same way as man-made objects and therefore, be mentally rotated in a holistic manner, analogous to physical (manual) object rotations. In other words, presenting pictures of human bodies should not induce a perspective transformation in the observer. This implies that the MBRT and the MORT should reveal similar patterns of RT and RE for the different rotational conditions. Accordingly, it is predicted that a same-different judgment evokes an object-based transformation both in the MORT and the MBRT, which leads to a similar linearly increasing relationship between Angular Disparity and RTs (or REs respectively).

Second, it is assumed that an MBRT with same-different judgment does not cause expertise effects. Because human bodies are processed like objects for such a required task, participants with motor expertise for rotational movements should not have an advantage in this task. Therefore, it is predicted that motor expertise should not have an effect on MBRT and MORT. Similar patterns concerning RT and RE are expected in experts and non-experts.

2.1. Methods

2.1.1. Participants

A total of 54 volunteers (28 female and 26 male; mean age = 23.1 years, *SD* = 3.7 years, age range 15–31 years) with normal or corrected-to-normal vision participated in this experiment. All participants characterized themselves as neurologically healthy. Before being tested, each participant gave his or her written informed consent. They were not paid for their participation. The study was approved by the local ethics committee and was carried out in accordance with the Helsinki Declaration of 1975.

The *expert group* with motor expertise for rotational movements consisted of 27 athletes (16 female and 11 male; mean age = 21.3 years, *SD* = 3.6 years) with several years of experience in sports, such as artistic gymnastics ($n = 16$), aero wheel gymnastics ($n = 6$), and trampolining ($n = 5$). There were 26 right-handed athletes and 1 left-handed athlete. The inclusion criteria into the expert group were that these athletes were currently practicing their sport and that they have had regular training over the last 5 years. The mean training experience was 12.3 years (*SD* = 4.8 years). None of the athletes took part in any mental rotation experiment prior to this study.

The *control group* consisted of 27 participants (12 female and 15 male; mean age = 25.0, *SD* = 2.8). Among these participants, 26 were right-handed and 1 was left-handed. Most of the participants were students at the University of Bielefeld, Bielefeld, Germany. Great care was taken to include only such participants, who did not have any further experience in the sports of the expert group, or in any other sport that involves a lot of spins and turns around different body axes. To exclude that any performance differences to be found relate to mere physical activity (and not to the experts' specific motor expertise), we included athletes from different disciplines into the control group. The athletic backgrounds of these participants ranged from team sports (e.g., lacrosse, handball, and soccer), to individual sports (e.g., track and field, rowing, and swimming), to outdoor activities (e.g., climbing and horseback riding). Both groups differed in age ($t(52) = 4.292$, $p < .001$), with the motor experts being slightly younger than the non-experts.

2.1.2. Apparatus

Participants viewed the experimental stimuli on an Acer Aspire notebook computer with a 15.4" (39 cm) LCD color screen. Responses were given with the index fingers by pressing either a left (A) or a right button (Ä; on a German keyboard) on the keyboard. Both buttons were color-coded and labeled with small signs as "same" and "different". The assignment of the buttons to left or right key presses was counterbalanced across participants and groups. The test and reference stimuli appeared in a size of 7.5 cm in diameter on a black screen.

2.1.3. Stimulus material

In each trial, two images were presented simultaneously on the screen, one above the other respectively. These images were either identical or mirror image reversals of each other. In each pair, the upper image was arranged in an upright position (0°) and the orientation of the image at the bottom was rotated randomly in picture plane (clockwise 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°).

Two different types of stimuli were presented: In the MBRT, images of a female person in front view and with either the left or the right arm extended (see Fig. 1A), and in the MORT, the asymmetrical uppercase character "R" (see Fig. 1B). Both the female person and the character appeared under similar Angular Disparities (i.e., five different angles rotated in picture plane: 0°, 45°, 90°, 135°, and 180°). For the MBRT, we used pictures of a human body that were similar to those used by Parsons (1987), with the following exception: Instead of line drawings, real images of a person were used in order to show stimuli that were as natural as possible. Photos were taken in front of a bright and homogenous background with a digital photo camera and the resulting images were subsequently edited with Corel Paint Shop Pro and Microsoft Office Power Point. The character "R" used in the MORT was similar to the characters used by Cooper and Shepard (1973). The chosen character font was Arial. The uppercase letter either appeared as a normal image or as its mirrored version.

2.1.4. Procedure and task

Participants were tested individually in a separate room at the university or in a separate room at a gymnasium. The room was darkened during the sessions to prevent reflections on the screen. Task instructions were standardized and participants could read them out on their own. After taking note of the written instructions, participants were seated in front of the computer screen at a distance of about 50 cm.

In both the MORT and the MBRT, participants were asked to determine as quickly and as accurate as possible whether the two images presented simultaneously on the computer screen were the same (i.e., copies that differ only in Rotation Angle) or different (i.e., mirror-reversed images). Before starting the experiment, participants performed a short training session with 32 test trials to familiarize themselves with the task and the stimuli. The order of the test trials within the experimental blocks was randomized. Moreover, the order of the two experimental blocks (MORT vs. MBRT) and judgments about same and different pictures by pressing the assigned buttons were counterbalanced over all participants. The whole experiment took about 30 min. A short break allowed participants to relax their eyes and to stretch out arms and fingers between the blocks. They could decide themselves at which point they wanted to continue with the second block.

The entire experiment consisted of 320 test trials, which were divided into two test blocks, one block with images of the asymmetrical character "R" and the other block with images of the female person in front view. Each combination of eight angular orientations of the lower image (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), stimulus pairs (same or different), and two images (original, mirrored) was presented once in the training sessions and five times in each experimental test block. Half of the trials showed the same (i.e., identical images), and the other half different images (i.e., mirrored images).

Each trial started with a blank screen. After 2000 ms, a white fixation cross appeared for 500 ms, whereupon the two images (test and reference stimulus) were presented. Images remained until the response was carried out. In the case of a wrong answer, participants immediately received feedback and the German word "Fehler" (for wrong answer) appeared on the screen.

2.2. Data analysis

Only RTs from correct trials were submitted to a repeated analysis of variance (ANOVA) with the within-subject factors Task (MBRT, MORT) and Angular Disparity (0°, 45°, 90°, 135°, and 180°) and the between-subject factor Expertise (expert participants vs. non-experts). RTs faster than 300 ms (0.0%) and slower than 3000 ms (0.25%) were defined as outliers and therefore excluded from further statistical analysis. Data from incorrect trials (5.74%) were also discarded from data analysis for RTs. These error trials were computed separately in another repeated ANOVA.

3.2. Results

3.2.1. Response time

The pattern of RT for the two groups in the MBRT and the MORT can be seen from Fig. 2. The ANOVA revealed a main effect for Task, $F(1, 52) = 38.801$, $p < .001$, $\eta_p^2 = .43$. Accordingly, participants were significantly slower for the MORT ($M = 1040$ ms, $SD = 213$ ms) than for the MBRT ($M = 907$ ms, $SD = 132$ ms). The main effect of Angular Disparity was also significant, $F(4, 208) = 256.957$, $p < .001$, $\eta_p^2 = .83$, with the RTs steadily increasing as a function of the difference in orientation between two images from 0° to 180°. Post-hoc *t*-test revealed that RT differed significantly from each Angular Disparity to the next contiguous one (all *p*'s < .001). The interaction of Angular Disparity and Task was not significant ($F(4, 208) = .351$,

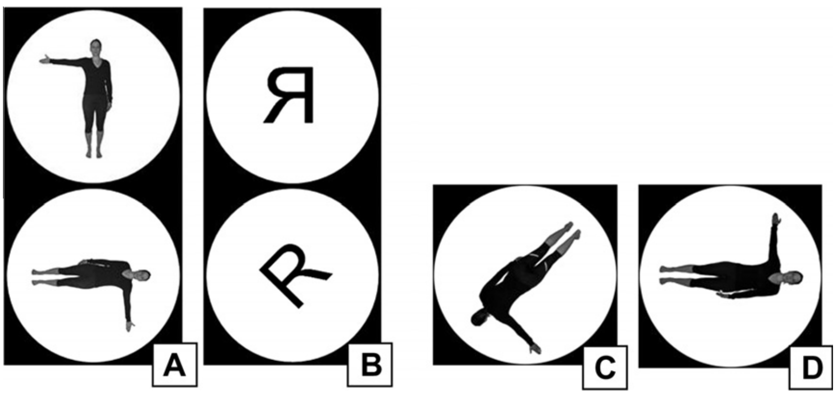

Fig. 1. Examples of stimuli used in Experiment 1 with same-different judgment (A and B) and Experiment 2 with left–right judgement (C and D). (A) MBRT, 90° Angular Disparity, different pictures; (B) MORT, 45° Angular Disparity, different pictures (two stimuli were presented simultaneously). (C) MBRT in back view, 225° orientation, left arm outstretched; (D) MBRT in front view, 90° orientation, right arm outstretched (one stimulus was presented at a time).

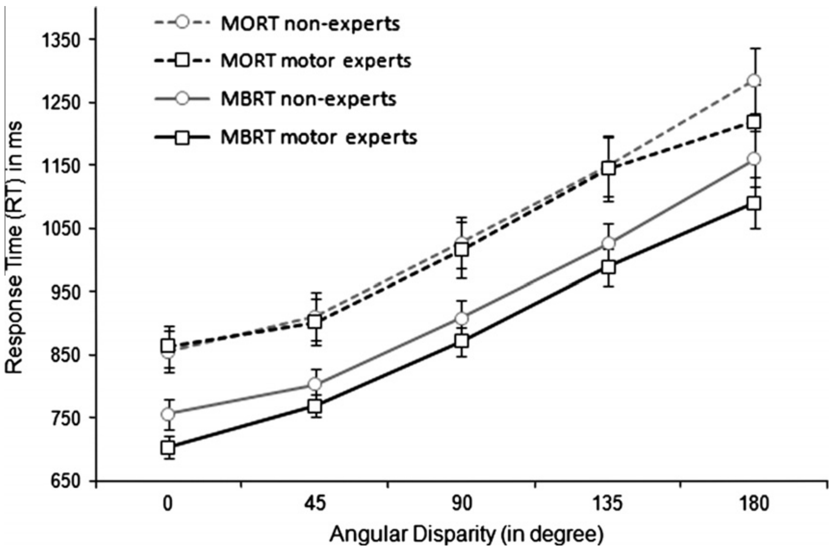

Fig. 2. Experiment 1: Mean response times (RT) in milliseconds (±*SE*) for all angular disparities between two images in MBRT and MORT of expert and control participants.

$p = .843$, $\eta_p^2 = .01$), which was reflected in a nearly parallel pattern of RT in these two tasks (mental rotation speed: MORT: 103°/s; MBRT: 101°/s). Neither the main effect of Expertise ($F(1, 52) = .442$, $p = .509$, $\eta_p^2 = .01$) nor any interaction of Expertise with the within-subject factor Task ($F(1, 52) = .604$, $p = .441$, $\eta_p^2 = .01$) or Angular Disparity ($F(4, 208) = .965$, $p = .428$, $\eta_p^2 = .02$) was significant. Also, the three-way interaction between Task, Angular Disparity and Expertise failed to reach significance ($p = .710$). This indicates that expert participants (949 ms) were not faster than non-experts (977 ms) for their same-different judgments about the two images, irrespective of whether they mentally rotated human bodies or objects.

3.2.2. Response errors

Fig. 3 provides the pattern of mean REs for both groups in the MORT and the MBRT. The ANOVA revealed a main effect of Task, showing that participants made significantly more errors in the MORT (7.3%) than in the MBRT (4.2%), $F(1, 52) = 18.749$, $p < .001$, $\eta_p^2 = .27$. Also, REs increased significantly, the more two images differed in their orientation, as supported by the main effect of Angular Disparity, $F(4, 208) = 34.735$, $p < .001$, $\eta_p^2 = .40$. However, there was a significant interaction of Task and Angular Disparity ($F(4, 208) = 7.752$, $p < .001$, $\eta_p^2 = .13$), showing a greater increase of RE in the MORT, as compared to the MBRT. Post-hoc *t*-tests for paired samples (two-tailed) showed significant differences between the MORT and MBRT at conditions with an Angular Disparity of 45° (MORT: 4.88%, MBRT 2.82%), 90° (MORT: 5.19%, MBRT 3.53%), 135° (MORT: 9.76%, MBRT 5.47%) and 180° (MORT: 14.24%, MBRT 6.86%) ($p < .05$), but no differences at 0° condition (MORT: 4.29%, MBRT 3.24%; $p = .32$). There was a main effect of Expertise, $F(1, 52) = 6.788$, $p = .012$, $\eta_p^2 = .12$, and a significant interaction of Expertise and Task, $F(1, 52) = 5.170$, $p = .027$, $\eta_p^2 = .09$. Post-hoc comparisons (two-tailed *t*-tests for independent samples) showed that motor experts committed more errors particularly in the MORT (9.40%, compared to non-experts with 5.15%, $p < .05$) than in the MBRT (4.66%, compared to non-experts with 3.78%, $p > .05$). No further interactions reached significance.

3.3. Discussion

Consistent with previous studies on mental rotation in which participants had to determine the similarity of two objects rotated

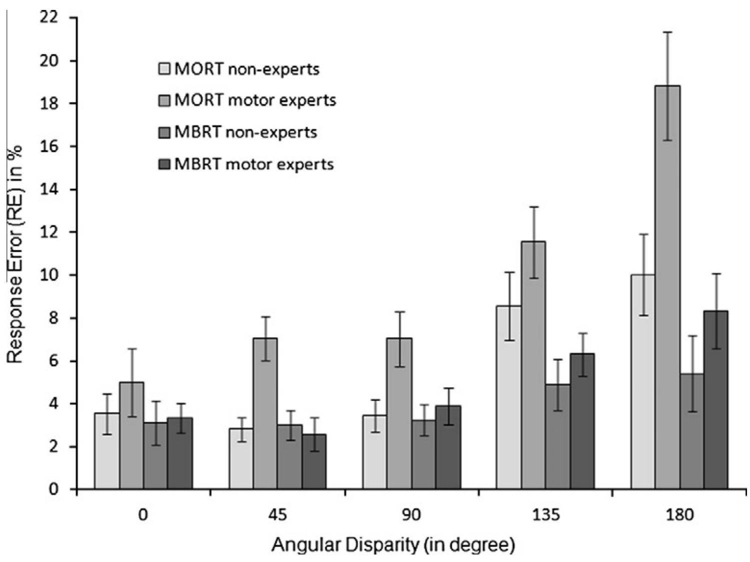

Fig. 3. Experiment 1: Mean response errors (RE) as percentages (±*SE*) for all angular disparities between two images in MBRT and MORT for expert and control participants.

in space (e.g., Shepard & Metzler, 1971), the results of Experiment 1 showed a linear increase of RT as a function of Angular Disparity. Most notably, participant's performance was affected by Angular Disparity in the MORT and the MBRT in a similar manner. Following this result, two important aspects are highlighted in the next paragraphs.

First, the comparison between MORT and MBRT shows that it makes no difference whether two bodies or two objects have to be aligned in a same vs. different judgment. RTs for rotating human bodies showed the typical increase with increasing Angular Disparity, which was similar to that for rotating objects. Accordingly, participants seem to have chosen the shortest path to align one of the images to the other (Wohlschläger & Wohlschläger, 1998). Interestingly, participants were faster and more accurate in the MBRT than they were in the MORT. At the moment, we are not sure why participants were able to align two images of bodies faster than the two images of the character. It may be speculated, however, that the overall shape of the person was more salient than the shape of the letter, resulting in a generally faster encoding of information. This result is inconsistent with the findings by Cooper (1975) and Cooper and Podgorny (1976), who reported that the complexity of the images does not affect the speed and accuracy of rotation. However, Bethell-Fox and Shepard (1988) reported that complexity does affect the speed of rotation and argued that increasing complexity simplifies the distinction between two stimuli. Hence, the more complex the images are the earlier the success of the comparison, because there are more differences to be found. Another possible explanation is that human stimuli are more familiar than non-human stimuli, which (again) could result in a faster encoding of information and thus, better performance in the MBRT. Please note, however, that the difference between human bodies and objects seems to be confined to the first encoding of the stimuli and not to its processing, because the speed of mentally rotating the objects (i.e., mental rotation speed) thereafter was similar for both task, the MBRT and the MORT respectively. To sum up this aspect of the results, a same-different judgment induces an object-based transformation, regardless of whether human bodies or objects are rotated.

Second, motor expertise did not have an influence on the mental rotation of human bodies (or objects) when performing a same-different judgment. RTs of motor experts were not different to those of non-experts, which was shown by a similar increase of RT as a function of Angular Disparity. At a first glance, this result is surprising, because a number of studies suggest that motor expertise can modulate the perception of other people's action (e.g., Calvo-Merino et al., 2005, 2006; Casile & Giese, 2006; Sebanz & Shiffrar, 2009). Such an expertise-dependent modulation of performance was not found in the present two tasks (MBRT and MORT respectively). It could thus be that motor expertise does generally not affect performance in mental rotation tasks. This notion is supported by the study of Jola and Mast (2005), who also did not observe differences in mental rotation performance between dancers and non-dancers. However, it could also be that the absence of an effect of motor expertise relates to the specific judgment. That is, participants performed a same-different judgment, which induced an object-based transformation of the stimuli. Thus, motor experts were not encouraged to "use" their specific expertise to solve the task. This should be different in a mental rotation task with left–right judgment, when the task's focus is changed to the acting body part (i.e., one arm stretched out). It has been argued that this kind of task induces a perspective transformation (Zacks & Tversky, 2005; Zacks et al., 2002). Therefore, when the task's focus is on the acting body part of a human stimulus, motor experts with expertise for rotational movements should perform better in a left–right decision task. This prediction is tested in Experiment 2.

4. Experiment 2: MBRT with left–right judgment

Experiment 2 examined the effect of motor expertise on the performance in a MBRT requiring a left–right judgment. Participants again watched pictures of a female person, who was shown in a body posture with either her left or right arm outstretched. This task should induce a perspective transformation in which participants mentally rotate themselves into the perspective of the observed person. If motor expertise for rotational movements around different body axes facilitates perspective transformations and affects the perception of different body orientations, then expertise-dependent modulations of performance should be observed. In particular, athletes like artistic gymnasts and aero wheel gymnasts should benefit because of their kinesthetic experience of unusual body positions in space. More specifically, it is expected that these motor experts perform better (compared to controls), the more the human figure is presented in an upside-down orientation.

4.1. Methods

4.1.1. Participants

Thirty-two participants (20 female and 12 male) with normal or corrected-to-normal vision took part in the experiment (mean age = 24.9 years, *SD* = 3.4 years, age range = 20–36). All participants gave their informed consent prior to the experiment, and none of them participated in Experiment 1. There was no financial benefit for participation. The study was approved by the local ethics committee and was carried out in accordance with the Helsinki Declaration of 1975.

The group of experts with motor expertise for rotational movements was composed of 16 athletes (nine female and seven male; mean age = 24.4 years, *SD* = 4.0 years), 15 of whom were right-handed and one of whom was left-handed. They had long-term experience in artistic gymnastics ($n = 6$), aero wheel gymnastics ($n = 2$), judo ($n = 6$), and vaulting ($n = 2$). On average, they had been practicing their sports for 12.4 years (*SD* = 4.4 years).

The control group without motor expertise for rotational movements consisted of 16 sports students (nine female and seven male) from the Faculty of Psychology and Sports Sciences at Bielefeld University (mean age = 25.4 years, *SD* = 3.0 years). Among these students, three were left-handed by self-report. Again, to exclude that any performance differences to be found relate to mere physical activity (and not to the experts' specific motor expertise), we included people from different athletic disciplines (similar to those of the non-expert group in Experiment 1) into the control group. Experts and controls did not differ in age ($p = .456$).

4.1.2. Apparatus and stimulus material

A single image, 7.5 cm in diameter, depicting a female person with either the left or the right arm outstretched, appeared in the center of a black screen. The person in the image was presented either in a front view or back view perspective (see Fig. 1C and 1D). The images in the front view condition were similar to those of Experiment 1. The same female person was also shown in the back view condition. Otherwise, the test setup was similar to Experiment 1. That is, participants used their index fingers by pressing either a left (A) or a right button (Ä) on the keyboard. Buttons were color-coded and labeled as "left arm" and "right arm".

4.1.3. Procedure and task

Participants were tested individually in a separate room at the university or in a separate room at a gymnasium. The room was darkened during the sessions. After filling out a short questionnaire and giving informed consent, participants received written instructions for performing the left–right decision task. To familiarize participants with the task and stimuli, a short training session composed of 16 trials was performed before the test blocks. During the training sessions, the experimenter remained in the room to ensure that participants followed the instructions and to answer questions. During the test blocks, the experimenter left the room.

Participants were instructed to judge whether the human figure's left or right arm was outstretched as quickly and accurate as possible. Participants performed two test blocks; one with the female person presented in front view and the other with the female person in back view. The order of test blocks was counterbalanced across participants and groups.

The within-trial procedure was similar to Experiment 1, with the exception that only a single stimulus image was presented. Each block consisted of a combination of Stimulus Perspective (front view vs. back view), Rotation Angle (clockwise 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°), and Arm Outstretched (left arm vs. right arm). Each stimulus combination was presented 10 times, resulting in 320 test trials, 160 trials per block. All trials were presented randomly. The whole experiment lasted for 30 min.

4.2. Data analysis

Data were analyzed within a three-way ANOVA, including the factors Stimulus Perspective (front view vs. back view), Rotation Angle (0°, 45°, 90°, 135°, 180°), and Expertise (motor experts vs. non-experts). The factors Stimulus Perspective and Orientation were treated as within-subject factors, whereas Expertise served as the between-subject factor. RTs faster than 300 ms (0.0%) and slower than 3000 ms (0.58%) were excluded from statistical analysis. Data from incorrect trials (4.86%) were discarded from data analysis for RTs and instead, were separately analyzed for RE.

4.3. Results

4.3.1. Response time

Fig. 4 illustrates the RTs for the front view and the back view perspective for motor experts and non-experts. The ANOVA revealed significant main effects for Stimulus Perspective, $F(1, 30) = 148.394$, $p < .001$, $\eta_p^2 = .83$, and for Rotation Angle, $F(4, 120) = 65.003$, $p < .001$, $\eta_p^2 = .68$. Participants were significantly faster for stimuli shown in the back view perspective (571 ms), as compared to the front view perspective (767 ms). Also, RTs became slower, the more the human figure was presented in an upside-down orientation. Post-hoc paired t-tests (two-tailed) showed that RT differed significantly (all p's < .001) from each Rotation Angle condition to the next contiguous one, except of the difference between the 0° (602 ms) and 45° condition (606 ms, $p = .434$). However, these main effects were modulated by the significant interaction of Stimulus Perspective and Rotation Angle, $F(4, 120) = 17.687$, $p < .001$, $\eta_p^2 = .37$. Post-hoc paired t-tests (two-tailed) showed significant differences between the front view and back view perspective at conditions with Rotation Angle of 0° (back view: 461 ms, front view: 753 ms), 45° (back view: 477 ms, front view: 740 ms), 90° (back view: 547 ms, front view: 760 ms), 135° (back view: 644 ms, front view: 786 ms) ($p < .001$), but no differences at 180° condition (back view: 786 ms, front view: 830 ms, $p = .211$). Accordingly, the advantage for stimuli presented in a back view perspective vanishes with increasing Rotation Angle.

Most important for the present experiment, there was no main effect of Expertise ($F(1, 30) = 2.090$, $p = .159$, $\eta_p^2 = .07$), but (as predicted) a significant interaction of Expertise and Rotation Angle, $F(4, 120) = 3.144$, $p = .017$, $\eta_p^2 = .10$. This interaction indicates that the performance of motor experts suffered to a smaller degree (compared to non-experts) when the stimuli were presented in an upside-down orientation. In other words, motor experts benefited for the processing of the human figure in unfamiliar orientation. This was supported by significant post-hoc t-test (unpaired) for the Rotation Angles (clockwise) of 135° (experts: 702 ms, non-experts: 748 ms) and 180° (experts: 759 ms, non-experts: 860 ms) (both p's < .05). All other comparisons between both experimental groups did not reach significance. None of the other interactions were significant.

4.3.2. Response errors

Fig. 4 depicts the REs for motor experts and non-experts under the different conditions. The ANOVA revealed a main effect for Stimulus Perspective, $F(1, 30) = 13.478$, $p < .001$, $\eta_p^2 = .31$), and Rotation Angle, $F(4, 120) = 18.161$, $p < .001$, $\eta_p^2 = .38$. REs increased in a progressive manner the more the human figure was presented in an upside-down orientation. This was supported by post-hoc

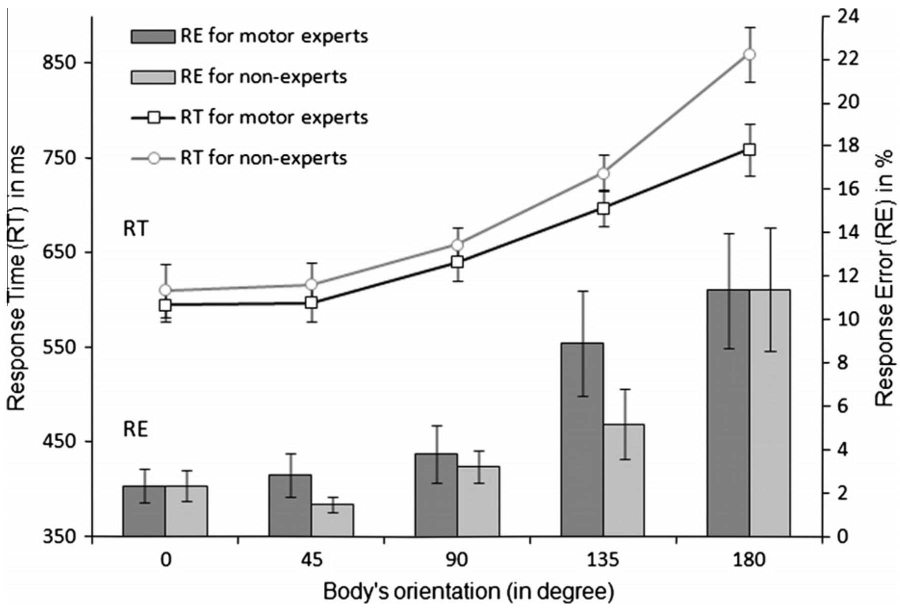

Fig. 4. Experiment 2: Left scale: Mean response times (RT) in milliseconds (±SE) averaged over stimulus Perspective and as a function of orientation angle and participant's expertise. Right scale: Mean response errors (RE) as percentages (±SE).

t-tests showing that REs differed significantly from each Rotation Angle to the next contiguous one (all p's < .05), except of the first step between 0° (2.37%) und 45° (2.15%) rotation condition. However, participants committed significantly fewer errors when the stimuli were shown in the back view perspective (2.66%) than in the front view perspective (7.13%). The interaction of Stimulus Perspective and Rotation Angle failed to reach significance. There was no effect of motor expertise for REs. Neither the factor Expertise nor any of the remaining interactions were significant. Hence, both motor experts and non-experts made a similar number of mistakes in this task, and their REs increased similarly with orientation angle.

In order to exclude speed accuracy trade-off effect, we calculated Inverse Efficiency Scores (IE = movement time/proportion of correct responses) and submitted them with Orientation as within-subject factor and Expertise as between-subject factor to a repeated-measures ANOVA. Of particular importance for our research question: We found neither a main effect for Expertise ($F(1, 30) = 1.052$, $p = .313$, $\eta_p^2 = .03$) nor an interaction of Expertise and Orientation ($F(4120) = 2.224$, $p = .070$, $\eta_p^2 = .07$). There was no difference in IE scores between experts (IE = 708) and non-experts (IE = 743) in general and in none of the five rotation angels (all p's > .05). That implies that experts solve this task as efficient as non-experts. Thus, a speed accuracy trade-off could be excluded.

4.4. Discussion

Experiment 2 compared participants with and without motor expertise for rotational movements in a MBRT. The task required to judge whether a female person, presented on a single stimulus image, was shown with her left or right arm outstretched. Most importantly, motor expertise *selectively* affected RT. That is, the performance of motor experts benefited the more the human figure was presented in an upside-down orientation. Thus, motor experts were not generally faster in encoding the picture of a person, but they benefited when the person was presented in an otherwise unfamiliar orientation. For familiar orientations, ranging from the upright orientation (e.g., experienced during standing and walking) to the horizontal orientation (e.g., experienced during lying down on the sofa or bed), non-experts were as fast as motor experts. This suggests that motor experts only benefit when they are able to use their movement specific knowledge (e.g., expertise-specific body representations in space) gathered through kinesthetic experiences in unusual body orientations.

In addition, making judgments about human figures presented in a front view perspective takes considerably longer (and is more error prone) than when this person is shown in back view. Moreover, the perspective of the person displayed interacted with the Rotation Angle. This pattern of result is comparable to the findings of previous studies, which tested participants in the MBRT and which required a left–right decision (e.g., Jola & Mast, 2005; Schönenberger, Long, Ryf, Mast, & Schwaninger, 2006). When the stimuli are presented in a back view perspective, the RT pattern shows a (roughly) linear increase, whereas the RT pattern is flat (or only slightly becoming steeper) for stimuli in front view. This can be explained as follows: To solve the mental rotation task in the back view conditions, it should be sufficient to align one's own viewpoint and reference frame with that of the human figure presented by mentally rotating in only one rotation plane (i.e., the sagittal body axis). In other words, one only has to mentally "take a step forward" and to imagine himself/herself into the position of the person presented. For stimuli presented in front view facing the observer, however, an additional transformation is necessary. Arguably, this additional transformation around the longitudinal body axis requires more processing and thus, takes longer to be fully completed. Interestingly, there were no differences between the stimulus perspectives for the greatest Rotation Angle (i.e., upside-down orientation of 180°), which suggests that both processes, the one supporting the mental rotation along the sagittal body axis and the one along the longitudinal body axis, run in parallel (and not serial).

Also, it has to be noted that the analysis did not reveal a linear relationship between RT and Rotation Angle when a left–right judgment is required. This is in contrast to the linear increase of RTs with same-different judgment in Experiment 1 and to the findings of earlier studies using the classic MORTs (Cooper, 1975; Shepard & Metzler, 1971). Other researchers suggested different mechanisms to subserve object-based transformations and perspective transformations (Jola & Mast, 2005; Parsons, 1987; Zacks & Tversky, 2005; Zacks et al., 2002). The differences in the relationship between RT and Rotation Angle between Experiment 1 (requiring object-based transformations) and Experiment 2 (requiring perspective transformations) can be interpreted as to support this notion of distinct mechanisms.

5. General discussion

The present study aimed to compare the ability to solve mental rotation tasks in motor experts with expertise for rotational movements with the performance of non-experts. Therefore, motor experts and non-experts performed in two MBRTs, one inducing an object-based (spatial) transformation (same-different judgment; Experiment 1), and the other inducing a perspective transformation (left–right judgment, Experiment 2). In addition, and as a control condition, pairs of objects (i.e., characters) were presented in Experiment 1, which allowed comparing participant's performance in mentally rotating objects vs. human bodies both requiring a same-different judgment. In Experiment 1, it was expected that the object-related same-different judgment would cause an object-based transformation of the stimuli (characters and human bodies), which should be reflected in a linear relationship between RT and Angular Disparity. This assumption was based on earlier findings by Zacks and colleagues (2002, 2005) and the theoretical assumption that object-based transformations are the mental analogon to physical object manipulations in real space (Wohlschläger & Wohlschläger, 1998). In Experiment 2, it was expected that a left–right judgment for a single image showing a female person with either the left or right arm extended would induce a perspective transformation in the observer. Prior research showed that such an instruction leads to a different pattern of RTs as a function of the human figure's perspective (Jola & Mast, 2005; Parsons, 1987; Zacks et al., 2002). Finally, across the two experiments, it was predicted that participant's motor expertise would selectively affect performance in the two rotation tasks: Performance differences were predicted in the MBRT with left–right judgment, favoring motor experts for stimuli of a female person in unusual orientation (Experiment 2). No such differences, however, were predicted when participants performed a same vs. different judgment in the MBRT and in the MORT (Experiment 1).

As predicted, there was a nearly linear increase in RT with larger Angular Disparity between two stimuli (similar for objects and human bodies) in the tasks requiring a same-different judgment (Experiment 1), but no linear relationship in the task with a left–right judgment (Experiment 2). Also as expected, no effect of motor expertise on participant's performance was present in the same-different judgment task, which induced an object-based transformation (Experiment 1). Most importantly, however, there was a selective effect of motor expertise on participant's RT in the left–right judgment task, which induced a perspective transformation (Experiment 2). Specifically, motor experts showed superior performance for stimuli in which the human figure was presented in upside-down orientations.

Taken together, these findings indicate that motor expertise affects performance in the MBRT only when a perspective transformation is induced. Participants with experience in physical body rotations were able to identify a human figure that was rotated into an upside-down position more quickly than were participants without such motor expertise. This effect of motor expertise on performance in the mental rotation task did not appear in an object-related comparison of two stimuli (objects and bodies). Therefore, motor expertise facilitates the ability to change one's personal point of view and to shift the egocentric perspective, in order to better imagine oneself into another person's orientation. This seems to be especially the case for images of body orientations, which are unfamiliar to most of us in everyday life. For common orientations of the human body, ranging from upright standing and walking to more horizontal orientations (e.g., when lying on the sofa or on the bed), everyone should have an expert representation of one's own body in space. Moreover, we walk around the world and use the ability to imagine ourselves into another person's perspective or to manipulate objects mentally. Because imagining and reasoning about changes of objects and perspectives is an important ability in everyday cognition, no general effect of expertise occurs while observing and indentifying other persons. In unfamiliar body positions, differing considerably from common positions of the body (135° and 180°), motor experts benefited from their better body representation in different orientations in space. These experts gained their experiences not only from turning and twisting around all of the three body axes, but presumably also from watching other athletes performing the same movements. The influence of motor expertise and visual experience on mental rotation performance, however, cannot be dissociated in the present study, but should be the focus of further experiments.

In contrast, the comparison of two stimuli does *not* induce a perspective transformation, which includes the observer's own body representation and perspective relative to the stimuli. Instead, mentally rotating one stimulus as a whole to align it with the second stimulus is sufficient to solve the task. As mentioned earlier, this mental transformation is assumed to follow the same processes and rules as a physical object rotation (Wohlschläger & Wohlschläger, 1998). In this case, participants perceive images of two persons in the same way as images of two objects. Therefore, motor experts do not benefit in the MBRT with same-different judgments, evoking object-based transformations.

The finding that motor experts are faster in solving the MBRT under perspective transformations suggests that motor expertise not only modulates action perception (Calvo-Merino et al., 2005; Cross et al., 2006), but also benefits perception while solving other higher cognitive tasks, such as mental rotation tasks. However, motor expertise does not influence performance in mental rotation tasks in general. Jola and Mast (2005), for instance, compared dancers and non-dancers in an MBRT and found no effect of expertise in the expected direction. These investigators assumed that professional dancers are able to vividly imagine dance-specific movements, but not any other movements that are not in their field of expertise. Gymnasts, trampolinists, and judoka (experts of this study) have many experiences in turning around all three body axes, not only around the longitudinal body axis. Thus, they were able to imagine themselves into the person's orientation more quickly. Moreover, the chosen instruction (same-different vs. left–right judgment) appears to be critical of whether motor expertise affects reaction time or not. Finally, motor expertise selectively improves performance in MBRT. These findings provide further evidence for the notion that action and perception are closely linked and draw on shared representations (Hommel et al., 2001; Prinz, 1997).

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