Mental Object Rotation and Egocentric Body Transformation:

Two Dissociable Processes?

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Abstract

An important question in studies on mental rotation is the difference between mental object rotation and egocentric body transformation. To test whether these two tasks rely on dissociable mechanisms we tested non-dancers and professional dancers as experts. In both tasks, stimuli rotated in the picture plane (x-axis) and in depth (z-axis) were presented and the participants were engaged in mental rotation tasks. The mental object rotation task (MORT, 3D-cubes used by Shepard & Metzler, 1971) was a same-different task and the mental body transformation task (MBRT, line drawings of human bodies similar to those used by Parsons, 1987) was a left-right decision. We measured response times (RTs) and error rates (ERs) in two randomized blocks. The cubes and body figures were presented in exactly the same rotation conditions; in the picture plane, 0°, 45°, 90°, 135°, and 180°, and in combination with a rotation in depth, 0° (the stimuli are rotated in the picture plane only) and 180°. Moreover, we assessed the participants' imagery abilities with three different questionnaires. In the experimental tasks, we found a linear increase in RT with increasing angle for body figures rotated in the picture plane (back view), for cubes rotated in the picture plane, and for the cubes rotated in the picture plane and in depth. In the MORT it took participants longer to respond to the cubes when they were also rotated in depth except for 180°. The MBRT revealed a different pattern. The RTs were even faster for inverted body figures when they were rotated in depth (front view) compared to when they were rotated in the picture plane only (back view). This finding suggests that participants use different strategies depending on the perceived orientation of the stimulus. The results indicate impaired performance in the MORT for the experts.

Introduction

Mental imagery is often referred to as the ability to generate and manipulate mental representations of objects. Most studies on mental imagery use the mental object rotation task introduced by Shepard and Metzler (1971). This task requires the participants to decide whether two visual objects are the same or different. The larger the angular difference between the two objects, the longer it takes the participants to respond. This finding was interpreted with the principle of transformational equivalence to real rotation of the object (Shepard & Cooper, 1982). However, mental rotation of objects is not the only ability, which requires the use of mental imagery. Different types of mental imagery are used to accomplish different tasks (Kosslyn, Brunn, Cave & Wallach, 1984, Hegarty & Kozhevnikov, 1999, Mast & Kosslyn, 2002, Mast, Ganis, Christie & Kosslyn, 2003).

An important issue is the reference frame involved when we use mental imagery. The mental object rotation tasks (MORTs) as used by Shepard and Metzler (1971) requires a transformation of the relation between the objects while the viewer's position and perspective remains fixed. Other types of tasks, however, require people to mentally change their perspective and thus rotate themselves (i.e., the representation of their body or body parts) rather than the objects. We refer to this type of task as the mental body transformation task (MBRT). In the MBRT, line drawings of human bodies are presented with one arm outstretched (e.g., Parsons, 1987). The participant has to judge which arm of the body figure is outstretched (left-right discrimination).

In everyday life, the abilities underlying these tasks are used frequently in a variety of instances. For example, when we are in the office at work, we can still visually imagine the policeman managing the traffic at the crossway we just passed on our way to work. We can figure out in imagery whether the policeman was using the left or the right arm to signal the drivers when to go and when to stop. To extract more visual details from the imagined scene, we can mentally "zoom in" and thus will be able to discriminate smaller details. For example, we will then be able to judge whether the policeman was wearing glasses or not. Likewise, we can mentally “zoom out” to visualize the entire crossway so that we can judge in which direction the policeman was facing. Evidently, “zooming out” implies a change from small scale space to large scale space. The spatial context of the image becomes more relevant and is in fact needed for successfully navigating. This example illustrates that the level of spatial resolution can be adjusted flexibly depending on the actual task. This is different from spatial perception, which is more or less bound to the physical properties of the immediate environment. Therefore, mental imagery is neither a large scale nor a small scale function. It seems that mental imagery operates widely independent of the spatial scale. Certainly, like for perception, there may also be some constraints of small-scale and large-scale spaces in imagery. Surprisingly, however, only few studies have been conducted on this topic (e.g., Malinowski, 2001). What are the spatial abilities necessary for mental operations in large scale space like navigation? In particular, perspective transformation turns out to be an essential strategy in navigation. You take another person’s perspective when someone on the street asks you for directions how to get to a desired place of interest. This ability is notably interesting because it operates well in different spatial scales, in the immediate visible or tangible environment or in large scale space, which is outside our field of view. For example, we can mentally take the perspective of the Statue of Liberty just as well as the perspective of any normal-sized person.

In fact, there is support for the idea that MBRTs are a special class of mental spatial transformation, which – at least partially – rely on mechanisms separate from those responsible for MORTs. Strong evidence for the existence of two distinct subcomponents is based on behavioral data. In contrast to the MORT, the RTs in the MBRT showed no increase with angle of rotation (Zacks, Mires, Tversky & Hazeltine, 2002). It is noteworthy, however, that there are also findings for the MBRT showing that error rates (ERs) and RTs dependent on angular disparity even though the slopes were less steep than those reported for the MORT (Parsons, 1987, Experiment 1 and 2).

Furthermore, neuroimaging studies revealed differences in brain activation when people are engaged in MORTs and MBRTs (Zacks, Rypma, Gabrieli, Tversky & Glover, 1999, Zacks, Vettel & Michelon, 2003). Moreover, an extrastriate body area in visual cortex was shown to be differently activated when participants viewed body parts compared to non-biological images (Reed & Farah, 1995).

In this study, we pursued the aim to investigate two types of mental transformations further. In particular, we compared the MORT and the MBRT with exactly the same rotation conditions. In fact, the MBRT requires the participants to make a perspective transformation in depth (i.e., z-axis) when the stimuli are presented in front view, facing the participant. However, when the stimuli are presented in back view (i.e., facing away from the participant) the participants can mentally rotate themselves in the picture plane (i.e., x-axis rotation) without any rotation in depth. Most studies using MORTs did not vary the axis of rotation. Therefore, the aim of this study was to compare the MORT and MBRT so that exactly the same geometry can be applied to perform the mental rotation. The rotation required to match the two cubes in the MORT corresponds with the rotation required to align the representation of one’s body with the body stimuli in the MBRT. To our knowledge, no study has yet been conducted comparing the MORT and the MBRT with the same rotation conditions within the same participants.

Two Mental Rotation Tasks

We compared the response times and the error rates of two mental rotation tasks, a mental object rotation task (MORT) and a mental body rotation task (MBRT). The former was the classical Shepard and Metzler rotation task with 3D-cubes and the latter was an egocentric body transformation task. In the MBRT the participants viewed schematic drawings of a body figure, which was presented under varying orientation conditions. The task was to judge whether the body figure's left or right arm was outstretched. The MBRT requires the viewer to mentally transform the representation of this body to change the perspective in imagery. No perspective transformation is required for the MORT as the mental transformation of one or both objects can be performed without changing one's own perspective.

In none of the previous studies using the MBRT or the MORT the rotation conditions were matched properly. Therefore, we designed the two tasks so that they were comparable in terms of the rotation axes and the angle of rotation. This means that we used the identical angles to match the two cubes the MORT and to match the representation of one's body to the body figure on the computer screen. We expect that the response time in the MORT shows a significant increase with increasing rotation angle in plane (i.e., x-axis rotation). When the stimuli are also rotated in depth (z-axis rotation) we hypothesize that an additional mental transformation is required thus leading to longer response times. We then compare these results with the MBRT. A similar increase in response time for the MBRT would not corroborate the assumption of two distinct mechanisms underlying the MORT and the MBRT. Alternatively, however, if the results revealed clear differences between MORT and MBRT, it would speak for a potential dissociation.

Method

Participants. 22 participants, 13 female and 9 male, volunteered to participate in the experiment. 36.4% had a university degree, 54.5 % had attended a comprehensive secondary school (Gymnasium). The mean age was 27.6, *SD* = 4.92. The participants were paid for their participation.

Materials. Two different sorts of stimuli were presented for each task, line drawings of human bodies for the MBRT and 3D-cubes for the MORT. Both types of stimuli could appear rotated in depth (0°/180°) and rotated in plane (0°/45°/90°/135°/180°). For the MBRT we used stimuli similar to those used by Parsons (1987). The stimuli in the cube rotation task were the classical figures used by Shepard and Metzler (1971).

Tasks. In the MBRT, 40 schematic line drawings of human bodies (see Figure 1) were presented on a 12.1” apple computer screen (viewing angle 15.7°). The stimuli were rotated clockwise in 5 different plane rotations (0°/45°/90°/135°/180°) and two different depth rotations (0°/180°). The participants were seated upright facing the computer screen and had to judge whether the left or the right arm of the human body figure is outstretched, using the index finger of the corresponding arm (in the example illustrated in Figure 1, the participant used the index finger of the left hand for a correct answer). The participant responded with the index finger of the same arm she indicated and imagined as outstretched. The 10 possible combinations of rotations were presented with each arm once crossed and once uncrossed (40 Stimuli), each repeated six times (240 Trials). In 50% of the trials the right arm was outstretched and in the other 50% the left arm was outstretched.

Insert Figure 1 about here

Between the blocks a short break allowed the participants to stretch their fingers or relax their eyes. The use of crossed and uncrossed arms discouraged the use of learning strategies based on the visual appearance of the stimuli (e.g., the use of a strategy like “if the stimulus appears in front view then push the button opposite to the side of the outstretched arm” for stimuli presented at 0°). That is, for 50% of the upright stimuli the corresponding arm was not on the same side (e.g., front uncrossed and back crossed). Therefore, the participants were encouraged to perform an egocentric body rotation to give the correct answer.

The MORT was a same-different paradigm with same or mirror-reversed cubes presented in adjacent locations (left side and right side) on the screen. Half of the trials were same trials, the other half were different trials. The task was to decide whether the two cubes presented simultaneously on the computer screen were the same or different. The cubes were presented in exactly the same rotation angles as the line drawings of human bodies (five different angles clockwise in the plane, 0°, 45°, 90°, 135°, and 180°, in two different depth rotations, 0° and 180°). As in the MBRT, the two planes of rotation where combined, so that, unlike in the Shepard and Metzler paradigm (Shepard et al., 1971), a cube could be rotated in plane and in depth. We therefore tested 10 possible rotation conditions either presented with the mirror-reversed cube or the original one, either with the un-rotated cube (i.e., 0° plane rotation, 0° depth rotation) on the left or on the right side in either the same or different condition. Each condition 10 x 2 x 2 x 2) was repeated 3 times (in total 240 trials).

Questionnaires. After each task, the participants were asked about their strategies and about any difficulties they experienced while solving the tasks. Moreover, they filled out three questionnaires; the VVIQ (vivid visual imagery questionnaire, Marks, 1973), the SUIS (Kosslyn, Shepard, Thompson & Chabris, unpublished observations), and the VMIQ (vividness of movement imagery questionnaire, Isaac, Marks & Russel, 1986). To prevent any confusion in rating, we inverted the scale of the VMIQ to match with the scale of the VVIQ (i.e., 5 for the highest imagery rating and 1 for the lowest imagery rating). We only averaged self-ratings of the participants that could be analyzed in both tasks.

Procedure. The participants were tested individually in a quiet room. Before the experiment started, we assessed handedness by means of a questionnaire (Briggs & Nebes, 1975). The instructions to the tasks were standardized and participants could read them on their own. The participants underwent a training session with ten test trials in order to get familiarized with the task and the stimuli. If the error rate (ER) in the test trials was higher than 30% the training session was repeated.

For the experiment proper, the total of 240 trials for both tasks was divided into three blocks. Each combination (e.g., 90° plane rotation, 180° depth rotation, arms crossed) was presented twice in a block. The order of the blocks and the order of the trials within the blocks were pseudo-randomized (i.e., the same combination did not occur more than 2 times in succession). There was no time limit for the two tasks.

Analysis. We used response times (RTs) from correct trials only. Trials with RT values greater (smaller) than the M ±3.0 x SD were defined as outliers and therefore excluded from data analysis. These trials were less than 4% of all correct answers for each participant. Participants with ERs higher than 25% were excluded from data analysis. Up to 50% of their correct and false responses were presumably produced by guessing. For the MBRT we excluded participants with ERs higher than 10% (e.g., M ± 2.5 x SD) because this task was easier than the MORT.

We analyzed for effects of plane rotation and depth rotation. As the MORT and the MBRT have not been matched for difficulty, we analyzed them separately. We computed descriptive data, ANOVAs with the factors plane rotation (0°/45°/90°/135°/180°) and depth rotation (0°/180°), deviation contrasts and Bonferroni post hoc t tests. Furthermore, we computed two-tailed weighted (polynomial) contrasts to test for linear trends. In the MBRT, the rotation angles are defined with respect to the participant. Therefore, the body figures presented in back view are defined as 0° depth rotated, whereas the body figures presented in front view are defined as 180° depth rotated. In the MORT, rotation angles are defined by the angle between the two cubes.

Results

Three participants had to be excluded from data analysis in the MORT. Two of them had more than 25% ERs and the RTs of the third one exceeded 30 seconds in 18.3% of the correct trials. Mean scores of ER (%) and RT (ms) are higher for the MORT than the MBRT as listed in Table 1.

Insert Table 1 about here

A repeated measures ANOVA for ERs with the factors plane rotation and depth rotation revealed significant main effects for both factors in the MORT, $F(4, 72) = 20.63$, $p < 0.001$ for plane, and $F(1, 18) = 14.32$, $p < 0.01$ for depth. The factors plane and depth did not interact, $F > 1$. In the MBRT, the repeated measures ANOVA of ERs showed a main effect for the factor plane, $F(4, 84) = 3.70$, $p < 0.01$. The factor depth showed no main effect but a significant interaction with the factor plane, $F(4, 84) = 5.87$, $p < 0.001$. ERs in the depth rotation condition are higher for angles less than 90° in the MORT and the MBRT (illustrated in Figure 2 and 3). For plane rotations above 90°, stimuli with no depth rotation are more difficult in the MBRT. As the ERs in the MORT (see Figure 3) show an interaction at 90° too, we computed linear contrasts for not depth rotated and depth rotated stimuli separately as well as paired *t* tests (depth rotated vs. not depth rotated stimuli) for both tasks although the factors plane and depth did not interact in the ANOVA we computed for the MORT. Linear contrast analysis showed a significant increase of ERs with increasing plane rotation angle for depth rotated and not depth rotated cubes, $t(61) = 3.36$, $p < 0.01$ for depth rotated cubes, $t(90) = 4.44$, $p < 0.001$ for not depth rotated cubes. In the MBRT, ERs revealed a linear trend without depth rotation, $t(105) = 4.38$, $p < 0.001$. No such linear trend could be observed when the body figures were rotated in depth, $t(105) = 1.11$, $p = 0.27$. Paired *t* tests showed significant higher ERs for depth rotated cubes at all rotation conditions except 90° (see Table 2). Paired *t* tests in the MBRT show again the interaction at 90° with significant lower ERs for back presented body figures below 90° and lower ER for front presented body figures above 90° plane rotation (see Table 2).

Insert Table 2 about here

Insert Figure 2 and 3 about here

Figure 2 and Figure 3 illustrates the RTs for all rotation conditions. The repeated measures ANOVA revealed a significant main effect of the factor plane in both tasks, with longer RTs for increasing rotation angle, $F(4, 72) = 24.88$, $p < 0.001$ for the MORT, and $F(4, 84) = 36.85$, $p < 0.001$ for the MBRT. The additional rotation in depth reveals a significant main effect of depth with longer RT in the MORT only, $F(1, 18) = 52.22$, $p < 0.001$. The two types of rotation interacted in both tasks, $F(4, 72) = 8.42$, $p < 0.001$ for the MORT, and $F(4, 84) = 28.47$, $p < 0.001$ for the MBRT.

Linear trend analysis for the MORT revealed longer RTs with increasing plane rotation without depth rotation, $t(90) = 5.78$, $p < 0.001$, and with depth rotation, $t(90) = 2.32$, $p < 0.05$. The same analysis for not depth rotated body figures revealed significant longer RTs with increasing plane rotation, $t(105) = 7.33$, $p < 0.001$, and a significant quadratic trend, $t(105) = 3.42$, $p < 0.01$. The RTs for depth rotated body figures showed neither a linear nor a quadratic trend. Paired Bonferroni post-hoc comparisons (see Table 2) for the MORT showed that depth rotated cubes have significant longer RTs than not depth rotated cubes for all plane rotation conditions except for 180° plane rotation where the depth rotation showed no significant effect. Comparisons between front and back oriented body figures revealed significant longer RTs for front bodies for all plane rotations below 135°. As can been seen in Figure 3, front bodies show shorter RTs when the body figures are inverted.

Insert Table 2 about here

Independent samples *t*-test for mean ERs (%) of female participants, $M = 11.0$, $SD = 5.4$ (MORT) and $M = 2.2$, $SD = 2.1$ (MBRT), vs. male participants, $M = 13.9$, $SD = 7.4$ (MORT) and $M = 2.1$, $SD = 2.8$ (MBRT) revealed no sex difference. Moreover, independent samples *t*-test do not reveal significant differences in RTs between female, $M = 5206$, $SD = 2486$ (MORT) and *M*

= 1260, *SD* = 530 (MBRT), vs. male participants, *M* = 4775, *SD* = 1267 (MORT) and *M* = 1310, *SD* = 438 (MBRT).

Mean scores for each of the two parts of the VMIQ (imagine oneself moving and imaging seeing someone else moving), for the VVIQ and for the SUIS are listed in Table 3 (see second column). The two parts of the VMIQ differed significantly in a paired *t*-test, $t(17) = 2.65$, $p < 0.05$. There was a strong significant positive correlation between each of the two parts of the VMIQ and the VVIQ, $r = .867$, $p < 0.001$ (imagine oneself moving) and $r = .893$, $p < 0.001$ (seeing someone else moving). The SUIS shows no correlation with any of the two other questionnaires. However, it shows a significant correlation with the RT and the ER of the MORT, $r = 0.40$, $p < 0.05$ for RT, and $r = 0.41$, $p < 0.05$ for ER. The RT of the MORT and the RT of the MORT showed a significant correlation, $r = 0.52$, $p < 0.05$.

Discussion

The results show that the MORT is more difficult than the MBRT. The participants made more errors and it took them longer to respond. The high ERs we found in the MORT were comparable to those of other studies using cubes rotated in depth and in plane (Jordan et al., 2001). Moreover, it has to be noted that the participants in other studies used extensive amount of practice over the sessions (e.g., Shepard & Metzler, 1971, used 1600 pairs divided into blocks of about 200, which were tested in 8 – 10 one-hour sessions). The pattern of the ERs in the MORT shows an increase in task difficulty with increasing angular disparity as revealed by other studies (Wraga, Thompson, Alpert & Kosslyn, 2003, Kosslyn, Thompson, Wraga & Alpert, 2001). The ER is higher for cubes rotated in depth than for cubes rotated in plane only. For the MBRT, however, the orientation of the body figures (back view or front view) interacted with rotation angle. ERs increase with increasing angle when the body figures are seen in back view whereas the ERs remain flat for all angles when the body figures are seen in front view.

The analysis of RTs in the MORT shows the typical increase with increasing angular disparity reported by Shepard and Metzler (1972). This finding has also been confirmed by more recent studies (e.g., Kosslyn et al., 2001, Kosslyn, DiGirolamo, Thompson & Alpert, 1998, Jordan, Heinze, Lutz, Kanowski & Jäncke, 2001). A new finding reported in this study is the linear relationship we found for cubes, which were rotated in depth and in plane. Shepard and Metzler (1972) measured the two axes separately without combining the two rotations. In the MBRT, the RTs for body figures rotated in depth (the body figure is seen in front view) did not vary as a function of rotation angle. This result confirms earlier findings by Zacks et al. (2002) who presented figures in front view only. However, the RTs increased with increasing angle when the stimuli were presented in back view. How can we explain this difference? It is possible that participants make a shortest path rotation when the body figures are rotated in depth. Parsons (1987, Experiment 1) suggested that the shortest path accounts for about 50% of the variance. The idea of a shortest path rotation is supported by the inverse contrast in RT we found for upside down body figures. The RTs were faster when the figures were rotated in depth. We assume that the orientation of the upside down figure is reinterpreted and therefore viewed as someone lying on the back (i.e., supine) rather someone upside down. In fact, several participants described some sort of kinesthetic experience when they solved the task with upside down figures presented in front view. A few participants reported that they mentally rotated themselves backward (similar as if they were slipping on a banana peel). Therefore, no mental rotation about the longitudinal axis (depth rotation) is required to solve this particular condition. Interestingly, we found a similar pattern in the MORT. The RTs were faster at 180° when the cubes were also rotated in depth. Even though this difference did not reach statistical significance we think it could be related to Murray’s (1997) finding, which demonstrated the advantage of a strategy to mentally flip an inverted natural object rather than rotating it in the picture plane.

Contrary to other studies showing sex differences in mental rotation tasks (Emmorey, Klima & Hickok, 1998, Linn & Petersen, 1985, Peters, Laeng, Latham, Jackson, Zaiyona & Richardson, 1995), we found no significant effect of sex in this study. We also found no advantage of participants with high mental imagery scores (VVIQ, VMIQ) with the only exception of the SUIS, which correlated with performance in the MORT (faster RTs and lower ERs).

The idea of different strategies has motivated us to continue collecting data with another group of participants. Unlike other studies, in which the strategy was primed via instruction (e.g., Kosslyn et al., 2001) we were studying expertise and its possible role in acquiring different cognitive strategies. The aim was to compare experts with non-experts to study possible differences in the mechanisms that underlie the MORT and the MBRT.

Effect of Expertise on Mental Rotation

We measured a second group of participants who performed the identical tasks described above. The aim was to study the influence of expertise on performance in the MORT and in the MBRT. If partly the same subsystems are shared by the two tasks we would expect a group with expertise in manipulating rotated stimuli to perform better in both tasks. If, however, the processes involved in the MBRT are – to some extent – different from those involved in the MORT it is possible that expertise is bound to only one of these tasks and therefore does not influence performance in the other task.

Differences in expertise for mental imagery tasks were reported in several studies. For example, pilots (Dror, Kosslyn & Waag, 1993), athletes (Ozel, Larue & Molinaro, 2002) and men (Jordan et al., 2001, Jordan, Wüstenberg, Heinze, Peters & Jäncke, 2002) are faster in MORTs. To our knowledge, no expertise effect has yet been published for the MBRT although several authors suggest a correlation with sport or gymnastic expertise (e.g., Creem, Wraga & Proffitt, 2001). This assumption has its origin in studies on mental practice, which demonstrated an enhancement in performance in the athlete's discipline (Annett, 1995).

We decided to recruit professional dancers as experts. Overby (1990) found significant differences in imagery tests (i.e., body image, cognitive imagery, and spatial imagery) between experienced dancers and novices. He postulated that it is the dancers' physical manipulation of space which enhances their ability in visuo-spatial concepts. Moreover, dancers learn through external feedback via the mirror and from the instructors. Therefore, they acquire a lot of practice in real and imagined body transformations. For example, Ramsay and Riddoch (2001) found greater accuracy for ballet dancers in a position-matching task of the upper limb. Several studies on body representation and sensorimotor perception demonstrated improved proprioceptive discrimination abilities in professional dancers and other athletes (e.g., Barrack, Skinner & Cook, 1984). Taken together, we expected dancers to perform better in the MBRT as a result of their training in mental imagery, kinesthetic experience and postural control. Furthermore, if the MORT shares some common subsystems with the MBRT, the effect of expertise should have an influence on both tasks. The aim was to compare the results we described above (non-experts) with a matched expert group which therefore should differ in their expertise of movement only.

Method

Participants. Twenty-seven professional dancers or dance students (14 female dancers, 13 male dancers) as experts had been matched to the sample of the experiment described in the previous paragraph. The dancers performed the same task as the non-dancers (participants of the previous experiment). The sample criteria for the dancers were that they currently have stage experience or currently work or study as dance teacher, dance choreographer or as high level dance manager in different fields of dance such as ballet, modern dance, contemporary dance, and jazz dance. They have had at least one hour of coordinative dance training per day over the last 5 years (defined as coordinative training per day). The mean age of the dancers was 30.5, *SD* = 6.81. They were given the same instructions as the participants in the previous study. Regarding education, 37% of the dancers have a university degree, 40.7% completed a comprehensive secondary school (Gymnasium). The mean training per day (min) was 213, *SD* = 120.2 and the amount of training per day was normally distributed, df(17) = 0.94, $p = 0.30$ (Shapiro-Wilk test). None of the dancers had participated in any mental rotation experiment prior to this study.

Design. The materials and tasks, the questionnaires, the procedure as well as the data selection are identical to the experiment described above. The analysis differs in the additional between-participants factor expertise (dancers/non-dancers) and the supplementary testing of the factor spatial compatibility in the MBRT (compatible/incompatible). To conduct these between-participants analysis properly, the two independently measured samples (dancers and non-dancers) had to be matched except of their expertise of movement. The expertise of movement was defined as the daily training time in coordinative dance training or other forms of coordinative training over the last two years.

Results

In the following paragraph, we describe the results for the effect of dance expertise on the MORT and on the MBRT. Three female dancers and four male dancers with more than 25% ER had to be excluded from data analysis in the MORT. Two of them and an additional female dancer had ER higher than 10% in the MBRT.

It is noteworthy that the average training time per day for the non-dancers of the first sample differs significantly from a normal distribution df(22) = 0.731, $p < 0.001$ (Shapiro-Wilk test). One participant from the non-dancers group had an average training time per day that exceeded the mean ±3.0 x *SD*. We excluded this participant from the comparisons since his high expertise in snowboard jumping is associated with a heightened spatial awareness similar to the dancers' expertise. A nonparametric test for a comparison between the dancers and the non-dancers indicated that the groups differ significantly in the amount of coordinative training, $M_s = 3.52$, $SD = 2.01$ for the dancers versus $M = 0.35$, $SD = 0.47$ for the non-dancers; Chi-square df(1) = 32.45, $p < 0.001$ (Kruskal-Wallis). However, age, sex or education did not differ between dancers and non-dancers.

The responses for the experts are illustrated in Table 1. In the MORT, the between-participants ANOVA (dancers/non-dancers) with the within-participants factors plane and depth rotation revealed a significant effect of expertise in RTs, $F(1, 36) = 7.43$, $p < 0.05$ and a trend for interaction with the factor plane in the ER, $F(4, 144) = 1.57$, $p = 0.185$. The mean RTs and ERs for the MORT are illustrated in Figure 2 showing the advantage in RT of the non-dancers compared to the dancers. There seems to be a slight advantage in the MBRT too (see Figure 3) but the effect of expertise revealed neither a significant main nor interaction effect in the MBRT.

The factors plane and depth rotation showed significant main and interaction effects in RT in the MORT, $F(4, 144) = 55.9$, $p < 0.001$ for plane, $F(1, 36) = 155.91$, $p < 0.001$ for depth, $F(4, 144) = 16.8$, $p < 0.001$ for plane x depth as well as in the ER in MORT, $F(4, 144) = 40.36$, $p < 0.001$ for plane, $F(1, 36) = 19.78$, $p < 0.001$ for depth, $F(4, 144) = 7.76$, $p < 0.001$ for plane x depth.

In the MBRT, the factor plane revealed a significant main and interaction effect for the RT, $F(4, 140) = 61.5$, $p < 0.001$ for plane, $F(4, 140) = 51.23$, $p < 0.001$ for plane x depth. The factor depth showed no significant main effect for the RT in the MBRT. In the ER, the factor plane showed a significant main and interaction effect, $F(4, 172) = 8.2$, $p < 0.001$ for plane, $F(4, 172) = 11.07$, $p < 0.001$ for plane x depth. The factor depth showed a tendency for a main effect in ER only, $F(1, 43) = 3.23$, $p = 0.079$. As the separate analysis of the dancers sample revealed similar results we reported above for the non-dancers we do not address them in more detail here.

The mean scores of the dancers and the non-dancers in the self-rating questionnaires and their differences are listed in Table 3. The non-dancers' values are described in the paragraph above. For the dancers, the two parts of the VMIQ did not differ significantly in a paired *t*-test and were correlated significantly, $r = .77$, $p < 0.001$. There was no other significant correlation between the three questionnaires. The VMIQ showed a significant negative correlation with ER for MORT, $r = -.53$, $p < 0.05$. The correlation of the VMIQ and RTs was significant for the MBRT, $r = -.66$, $p < 0.01$. The mean RTs in the MBRT correlated with the mean RTs in the MORT, $r = .52$, $p < 0.01$. There are also significant positive correlations between RTs and ERs for both tasks, $r = .67$, $p < 0.01$ for the MBRT, and, $r = .54$, $p < 0.01$ for the MORT.

It is known that in choice response time tasks the RT depends on the spatial relationship between stimulus and response. According to the spatial compatibility effect the RT is slowed down if the stimulus side is not compatible with the side of the requested response (Simon & Rudell, 1967). In the MBRT there are compatible (e.g., stimulus pointing to left and the participant responds with the left hand) and incompatible (e.g., stimulus pointing to the left and the participant responds with the right hand) conditions. For example, for upright body figures in back view the responses are spatially compatible when the arms are uncrossed. An analysis for the compatibility effect with the factors plane and compatibility showed significant main effects for both factors, $F(1, 43) = 87.79$, $p < 0.001$ for compatibility, and $F(1, 43) = 82.17$, $p < 0.001$ for plane. Moreover, the two factors interacted, plane x compatibility, $F(1, 43) = 16.56$, $p < 0.001$. Paired post-hoc Bonferroni *t* tests for spatially compatible vs. spatially incompatible stimuli revealed that RTs for incompatible stimuli are higher at 0° plane rotation, $t(21) = 5.50$, $p < 0.00$, and at 180° plane rotation, $t(21) = 5.32$, $p < 0.001$.

General Discussion

This study pursued two aims. The first aim was to compare the MORT and the MBRT with exactly the same rotation conditions. Previous studies compared behavioral and neuroimaging data with unequal rotation conditions (Zacks et al., 2002, Jordan et al., 2001). For the second aim, we tested professional dancers and compared their performance in the MBRT and MORT to the performance of non-dancers. In particular, we expected the dancers to perform better in the MBRT.

Consistent with many other studies on the mental cube rotation task a linear increase in RT with increasing angle rotation could be found. One of the new findings reported in this study is the linear positive relationship we found for the RT in the MORT when the cubes are rotated in depth and in plane simultaneously. Shepard and Metzler (1972) measured the two axes separately without combining the two rotations. The additional time for depth rotated cubes was required for all plane rotation conditions except for the upside down stimuli where the difference between depth rotated and not depth rotated cubes did not reveal significance. It is probably the case that participants used a more direct path for the inverted cubes (e.g., like flipping the objects as described by Murray, 1997) and thus, they were able to save some processing time in contrast to the 180° plane rotation.

The comparison between the body figures presented in front view and in back view is more difficult. The RTs and ERs were flat for front view stimuli whereas they increased with increasing angle for back view stimuli. It is not clear whether the participants actually perform a mental rotation when they are exposed to the front view stimuli. It is possible that they use a totally different strategy since the behavioral data for the front view stimuli are not dependent of rotation angle. This is similar to other studies showing that a spatial inference in mental environments does not depend on the direction of the body to the object (e.g. Franklin & Tversky, 1990). It is therefore possible that the different results for body figures presented in front and back view implies a change in scale, from small scale for back view to large scale in front view. However, based on our behavioral data, it may be more appropriate to limit the comparison between MBRT and MORT to the back view body figures and the cubes rotated in plane only. In both cases, RT depends on rotation angle and the geometry of the mental rotation is matched. An extension of the results showing the difference between front-view and back-view body figures would clearly be desirable. As far as the results are indicating now, the stimuli rotated in plane only show the same pattern for both types of tasks while the behavioral responses differ when the cubes and the bodies are also rotated in depth. It remains a hypothetical question whether the perspective transformation necessary for the body figures rotated in depth is the only reason for this difference.

Interestingly, in the MBRT, the RTs were faster for upside down body figures in front view (facing the observer) than for upside down body figures in back view. The front view stimuli were thought to require an additional transformation since they were rotated in depth with respect to the participants. However, the participants may have chosen the shortest path when they rotated themselves mentally (Parsons, 1987). This is possible because the stimulus could be viewed in two alternative ways; as a figure turned upside down or as a figure lying on the back (resting in the supine position). Several participants reported after the experiment that they have viewed the 180° stimuli not upside down but rather in the supine position. This suggests that they mentally rotated the representation of their body backward to solve the task. The fact that some participants verbally reported the strategy they used for solving the task (i.e., they mentally rotated themselves backward) is not yet conclusive regarding the mechanisms that underlie their responses. It is noteworthy that no increase of RT was found in the MORT when inverted cubes were rotated in depth.

In this context, it is interesting that Parsons (1987, Experiment 3) revealed a linear increase for body figures in front view presented within a surrounding environment. Parsons' finding suggests that the participants are no longer able to reinterpret the orientation of the stimulus (they then view it upside down instead of lying on the back).

In addition, it is noteworthy that there is a spatial compatibility effect involved in this result. If for example participants identify the outstretched arm (crossed or uncrossed) close to the body (e.g., at the height of the shoulder), correct answers are spatially compatible for the upside down body figures in front view whereas correct answers for upside down body figures in back view are spatially incompatible. Future studies need to separate these two possible explanations.

In the second part we investigated expertise effects in comparing dancers and non-dancers. Even though there was no effect of expertise in the expected direction (dancers' performance better in the MBRT), there was a significant difference between dancers and non-dancers in the MORT. Contrary to Ozel et al. (2002) who found improved performance in mental object rotation for sport experts like gymnasts, the dancers were in fact slower than the non-dancers. The dancers' impaired performance (longer RTs) in the MORT could be due to the fact that they were trying to apply a different strategy to solve the task. Some of the dancers reported during debriefing that they tried to rotate themselves mentally to align with the cubes they saw on the screen which may have more likely resulted in a perspective transformation. Therefore, it is possible that their experience led to an inappropriate strategy and thus interfered with task performance in the MORT. Despite the fact that dancers have improved abilities in the perception of postures (Euzet & Gahery, 1996), a more accurate proprioceptive discrimination (Barrack et al., 1984), and a stronger body representation (Ramsay & Riddoch, 2001), the MBRT did not show any effect of expertise. The lack of expertise effects between the dancers and the non-dancers in the MBRT may have been due to characteristics of the tasks (e.g., difficulty, stillness of the frames) or to capacities of the participants. It is possible that the expertise of dancers concerns a dynamic use of imagery involving complex sequences of movements and highly coordinated motor plans. It could be shown by several authors, that the expertise of movement is crucial in the movement observation and detection (e.g., Beardsworth & Buckner, 1981, Calvo-Merino, Glaser, Grezes, Passingham & Haggard, in press). However, this should not be the case for static body postures. Therefore, the line drawings of human bodies we used for the MBRT could have been just too static for any effect of the dancers' expertise to unfold. This is further supported by the verbal reports from almost all dancers after the experiment. They described their use of mental imagery in a more dynamical context. Furthermore, some dancers indicated that they are able to vividly imagine a pirouette or a battement but not any other types of movements, which are not specific to their field of expertise. Several studies have shown that the effects of expertise acquired in dance or related sports activities do not transfer to other types of movements. Moreover, the relative contribution of vision or proprioception in sport experts and dancers is not yet clear and seems to depend strongly on the actual task (Cremieux & Mesure, 1994, Golomer & Dupui, 1999, Golomer, Dupui, Sereni & Monod, 1999, Hugel, Cadopi, Kohler & Perrin, 1999). However, dancers are used to rapidly imitate and execute a new movement. In the training trials of the experiment, the experimenter could observe that the dancers even had to inhibit their body movements. While sitting in front of the desk, they often tried to bring their upper body part in line with the body figure presented on the computer screen. Therefore, the highly specific and overlearned connection between perception and motor execution in dancers may have interfered with task performrmance. Furthermore, it is certainly possible that more pronounced differences between dancers and non-dancers could have emerged with a more difficult task.

Our results indicate that the time necessary to perform a mental body rotation or a mental object rotation may not only depend on the angle of stimulus presentation. Even though we applied exactly the same rotation conditions to both tasks, two completely different response patterns were revealed. It is unlikely that the stimulus per se is responsible for this difference because both stimuli evoked an increase in RT with increasing rotation angle in plane without depth. However, when the stimuli were also rotated in depth, the response patterns differ and thus may reflect different strategies. The strategy participants use when they are facing the body figures is still not yet clear. However, since the RTs do not vary with the angle of stimulus presentation it seems rather unlikely that mental rotation is the mechanism participants use. Interestingly, task difficulty reversed when the stimuli were inverted and body figures presented in front view were easier. These findings suggest that participants use different strategies depending on the perceived orientation of the stimulus. This tendency seems to be stronger for egocentric body transformation than for the mental object rotation tasks. Finally, we found that dancers' training and expertise in motor imagery does not improve performance in any of these tasks. However, the absence of any difference in performance does not necessarily rule out that there is still a difference in strategy between dancers and non-dancers. Neuroimaging studies would be necessary to further investigate potential differences between dancers and non-dancers.

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Figure Captions

Figure 1: Stimuli of the two tasks for both samples in the 45° plane rotation condition. Left side (i.e., a, b): MBRT (one stimulus was presented at time). Right side (i.e., c, d): MORT (two stimuli were presented simultaneously). Upper row: 180° depth, 45° plane rotation. Lower row: 0° depth, 45° plane rotation condition.

Figure 2: Left scale: Response times in ms (*M* and *SE*) in the MORT for all stimuli rotations of dancers (experts in the second sample) and non-dancers. Right scale: Error rates in percentages (*M*).

Figure 3: Left scale: Response times in ms (*M* and *SE*) in the MBRT for all stimuli rotations of dancers (experts in the second sample) and non-dancers. Right scale: Error rates in percentages (*M*).

Figures

Figure 1

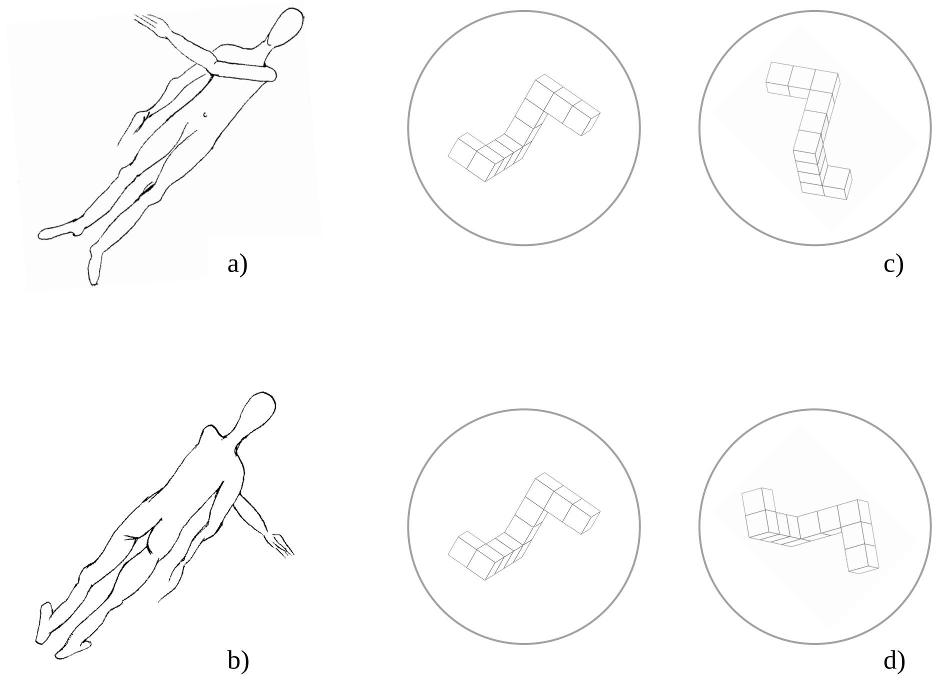

Figure 2

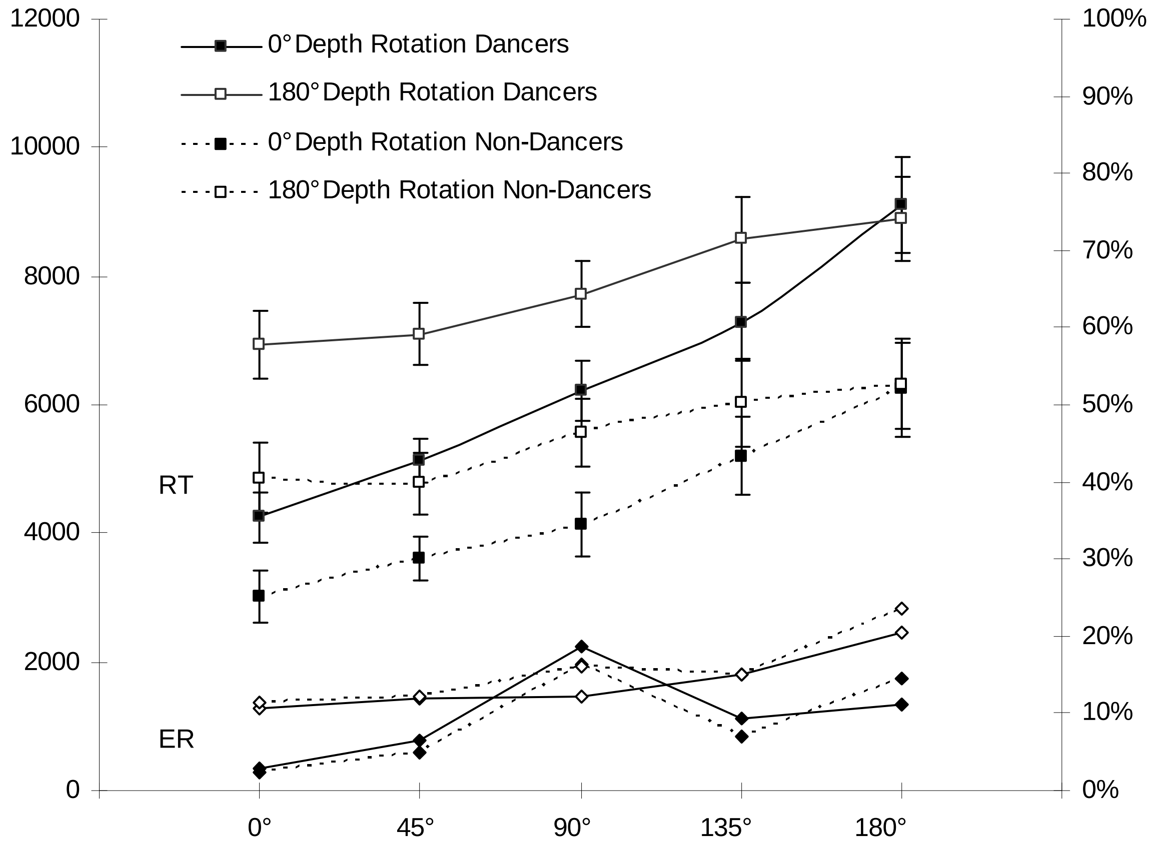
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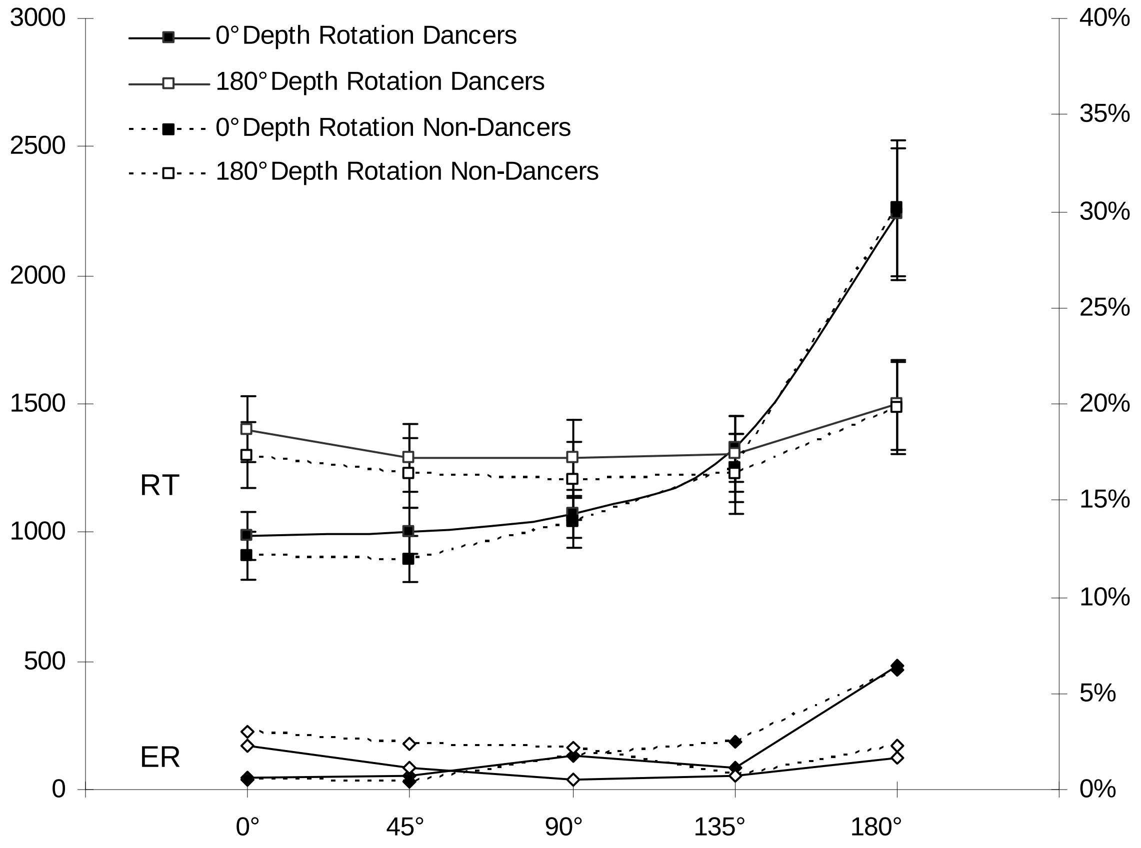
Figure 3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180° Depth Rotation Dancers
0° Depth Rotation Non-Dancers
180° Depth Rotation Non-Dancers
RT
ER
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90°
135°
180°

Tables

Table 1

Percentage of Error Rates and Mean Response Times in ms for Dancers and Non-Dancers in each Type of Task (Mean ± Standard Deviation).

	Mental Object Rotation		Mental Body Rotation	
	Dancers (N = 20)	Non-Dancers (N = 19)	Dancers (N = 24)	Non-Dancers (N 22)
Error rates	11.8 ± 5.67	12.4 ± 6.38	1.6 ± 1.84	2.2 ± 2.29
Response times	6791 ± 2447	5002 ± 1963	1453 ± 715	1280 ± 484

Table 2

Analysis Sample of Paired Contrasts (2-tailed) for the Type of Rotation in Depth (0°-180°) in Mean Response Times in ms and in Percentage Error Rates.

	mean response time	standard deviation	T-value		% error rate	standard deviation	T-value	
Mental Object Rotation (df = 18)								
0°	-1935.8	1179.4	7.15	***	8.95	12.01	3.25	**
45°	-1244.9	945.2	5.74	***	7.33	14.18	2.25	*
90°	-1425.6	1227.1	5.06	***	-0.34	15.19	-0.10	n.s.
135°	-812.3	1304.9	2.71	*	7.82	13.03	2.62	*
180°	-66.5	1062.5	0.27	n.s.	9.08	16.65	2.38	*
Egocentric Body Transformation (df = 21)								
0°	-422.3	279.6	7.08	***	2.39	3.25	3.45	**
45°	-348.4	274.4	5.95	***	1.96	4.73	1.94	†
90°	-154.5	218.2	3.32	**	0.43	5.26	0.38	n.s.
135°	22.2	310.0	-0.34	n.s.	-1.76	3.67	-2.25	*
180°	774.4	726.3	-5.00	***	-3.96	6.93	-2.68	*

Note: † $p < 0.07$, * $p < .05$, two-tailed. ** $p < .01$, two-tailed. *** $p < 0.001$, two-tailed.

Table 3

Mean, Standard Deviation, Chi-square (df=1) and p-value of the Kruskal-Wallis H-test for the vividness of movement imagery questionnaire (VMIQ, maximum score 120 for both parts), vivid visual imagery questionnaire (VVIQ, maximum score 80) and the SUIS (maximum score 60) of the dancers and non-dancers sample (Mean ± Standard Deviation).

	Dancers (N = 19)	Non-Dancers (N= 18)	Chi-square (df = 1)
VMIQ (imagine somebody else)	96.7 ± 23.8	90.3 ± 16.2	3.56 †
VMIQ (imagine oneself)	99.9 ± 15.4	99.5 ± 14.6	.01 n.s.
VVIQ	65.5 ± 7.6	63.7 ± 8.4	.51 n.s.
SUIS	41.8 ± 7.9	37.4 ± 9.2	2.18 n.s.

Note: † $p < 0.07$