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RESEARCH ARTICLE

Dissociating object-based from egocentric transformations in mental body rotation: effect of stimuli size

Hamdi Habacha[1,2] · **David Moreau**[3] · **Mohamed Jarraya**[4] · **Laure Lejeune-Poutrain**[1] · **Corinne Molinaro**[1]

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Abstract The effect of stimuli size on the mental rotation of abstract objects has been extensively investigated, yet its effect on the mental rotation of bodily stimuli remains largely unexplored. Depending on the experimental design, mentally rotating bodily stimuli can elicit object-based transformations, relying mainly on visual processes, or egocentric transformations, which typically involve embodied motor processes. The present study included two mental body rotation tasks requiring either a same–different or a laterality judgment, designed to elicit object-based or egocentric transformations, respectively. Our findings revealed shorter response times for large-sized stimuli than for small-sized stimuli only for greater angular disparities, suggesting that the more unfamiliar the orientations of the bodily stimuli, the more stimuli size affected mental processing. Importantly, when comparing size transformation times, results revealed different patterns of size transformation times as a function of angular disparity between object-based and egocentric transformations. This indicates that mental size transformation and mental rotation proceed differently depending on the mental rotation strategy used. These findings are discussed with respect to the different spatial manipulations involved during object-based and egocentric transformations.

Keywords Mental rotation · Object-based transformations · Egocentric transformations · Mental size transformations · Motor processes.

✉ Hamdi Habacha
hamdi.habacha@gmail.com

1 Laboratoire Psychologie de la Perception (UMR CNRS 8242), 45 rue des Saints Pères, 75006 Paris, France

2 Université de Caen Basse-Normandie CesamS, EA 4260, UNICAEN, 14032 Caen, France

3 School of Psychology and Centre for Brain Research, University of Auckland, Auckland, New Zealand

4 Research Unit (EMCS), High Institute of Sport and Physical Education, Sfax University, Sfax, Tunisia

Introduction

Mental rotation and mental size transformation

Interaction with objects from everyday life takes place through several mental processes. Among these processes, mental rotation (MR), the ability to generate and rotate internal representations of objects, seems to play a crucial role in the identification of and the interaction with objects. Mental rotation concept was first introduced as a seminal paradigm in cognitive psychology by Shepard and Metzler (1971). In their classic chronometric MR task, Shepard and Metzler asked participants to judge whether two rotated images of asymmetric objects depict identical or different objects. Reaction times (RT) on this task increased as a function of the angular disparity between the target and comparison stimulus matching the increasing physical rotation time of a real object. These results show the equivalence between mental and real rotation, and suggest that mental rotation process is an internal equivalent to the physical rotation of a real object (Shepard and Metzler 1971).

Moreover, objects of everyday life are present in very different sizes. Considering the large differences between their sizes, processes of mental size transformation seem to be as critical as mental rotation itself to effectively interact with objects. Mental size transformation is another form of mental imagery where subjects mentally transform the size of an image. This is an active field of research; for example, the display size of stimuli was shown to influence performances in spatial tasks (Tan et al. 2006) and to influence the recognition of same or different objects differing by size (Bundesen and Larsen 1975). In the latter experiment, participants were asked to judge as quickly as possible if two stimuli presented simultaneously were the same or different regardless of their size and orientation. Results showed that RTs were a linear function of the size ratio of the two stimuli. According to Larsen (1985), in such tasks, the decision may be broken down into three successive steps: (1) encoding a visual representation of one of the stimuli as a mental image; (2) transforming this image, such that the represented size and orientation gradually change to those represented in the visual impression of the other stimuli; and (3) matching this impression against the transformed mental image. For simultaneous presentation of the stimuli as for successive presentation, linear RTs functions for size transformation were found (Bundesen and Larsen 1975; Larsen et al. 1999). Accordingly, the more the size disparity was, the longer participants took to make a decision.

Several studies have explored the interaction between mental rotation and mental size transformation processes. For example, Suzuki and Nakata (1988) investigated the effect of stimuli size on a mental object rotation task and showed that mental rotation of small-sized pairs was slower than mental rotation of medium- or large-sized pairs. More recently, Olsen, Laeng, Kristiansen, and Hartvigsen (2009, 2013) compared performances of males and females in a mental object rotation task. They showed that males and females did not differ significantly in performance in the standard size condition (stimuli displayed in a computer screen), but females performed faster than males in the large display condition.

Two dissociable strategies of mental rotation

Although the aforementioned studies show the clear effects of the stimuli size on mental rotation performance, their results remain limited to their stimuli (abstract objects) and lack precision given the complexity of the mental rotation process. Indeed, depending on the used stimulus, mental rotation can involve two different strategies. When abstract objects are used, object-based transformations are classically engaged (Shepard and Metzler 1971), this class of transformations requires transformation of the object's reference frame relying mainly on visual processes. However, the use of bodily stimuli classically implies egocentric transformations (Parsons 1987) that require mental updating of the observer's egocentric frame involving motor processes (Grabherr et al. 2011; Jola and Mast 2005; Kozhevnikov and Hegarty 2001; Kozhevnikov et al. 2006; Zacks et al. 2002). Evidence for the dissociation of these two classes of transformations comes from neuroimaging studies revealing differences in brain activation during object-based and egocentric transformations (Zacks et al. 1999a, b, 2003), and from behavioral studies showing different response times (RTs) patterns between the two classes of transformations (Shepard and Metzler 1971; Parsons 1987). That is, a linear increase of RTs with increasing angular disparity is classically observed when object-based transformations are used (e.g., Corballis 1982; Shepard and Cooper 1982; Shepard and Metzler 1971), whereas RTs remain fairly constant at low angles—in contrast with RTs of object-based transformations—but suddenly increase with greater angles when using egocentric transformations (Graf 1994; Keehner et al. 2006; Habacha et al. 2017; Kozhevnikov and Hegarty 2001; Michelon and Zacks 2006; Kaltner et al. 2014). Indeed, lower orientations of human body image correspond to possible positions of the human body (i.e., upright and lying position) that can be easily emulated by egocentric transformations, whereas greater orientations correspond to impossible body positions that are difficult to emulate and thus emulated more slowly (Habacha et al. 2017). In addition, egocentric transformations seem to be faster and more accurate than object-based transformations (Keehner et al. 2006; Wraga et al. 1999; Zacks and Michelon 2005). The object-based transformations are thought to be more reliant on additional cues provided by the environmental frame, causing deficits when imagining the cohesive rotation of the object's intrinsic frame, making them more difficult. In contrast, egocentric transformations are thought to be almost immune to effects of other frames and performed cohesively and thus more easily (Wraga et al. 1999).

Furthermore, it is noteworthy, however, that object-based transformations are not necessarily incompatible with bodily stimuli. In mental rotation tasks of human body figures, a same–different judgment triggers object-based transformations, whereas a laterality judgment triggers egocentric transformations (Habacha et al. 2017; Steggemann et al. 2011; Zacks et al. 2002).

Goals and hypotheses of the present study

Despite the extensive literature documenting the interaction of stimuli size with mental rotation of abstract objects engaging object-based transformations, the extent to which mental size transformations interact with egocentric transformation remains to be understood. This question is especially relevant given that the previous mental body rotation experiments involving object-based and egocentric transformations have shown considerable variability in the display size of stimuli, and that the literature on spatial ability has underlined the influence of stimuli size on performance (Tan et al. 2006). The main objective of our study is to answer to this question by means of behavioral data.

We first intended to confirm the influence of the type of judgment required on the mental strategy favored during a mental body rotation task (Habacha et al. 2014, 2017; Jordan et al. 2001; Steggemann et al. 2011; Jola and Mast 2005; Zacks et al. 2002). Second, we used different stimuli sizes to elicit mental size transformations during the two mental body rotation tasks. This manipulation was intended to allow exploring interactions between size and each of the two dissociated strategies.

We postulated a monotonic increase of RTs with greater angular disparity in the same–different task, a finding that would confirm the use of object-based transformations (Shepard and Metzler 1971; Steggemann et al. 2011). The linear increase of RTs was only expected in great angular disparities during the laterality judgment task in accordance with the previous studies using similar tasks, pointing the involvement of egocentric transformations (Habacha et al. 2017; Steggemann et al. 2011).

To further differentiate between the two mental rotation strategies, we extracted size transformation times (STTs) from RTs during the two tasks. Differences in STTs according to the used strategy are thought to provide additional evidence for different mental processing during object-based and egocentric transformations. In addition, the comparison of STTs trends as a function of angular disparity between the two mental rotation strategies was to bring new insights on the interactions between mental rotation and size transformations.

Methods

Participants

Thirty-four male individuals (mean age 23.26 years, SD = 3.84) volunteered to participate in this study. Only male participants were included in the study to avoid effects of male–female differences on the patterns of RTs and STT, since mental rotation performances of males and females are different dependent on the stimuli size (Olsen et al. 2009, 2013). All participants had normal or corrected-to-normal vision, were naive to the purpose of the experiment, and provided their informed consent.

Stimuli and task

Stimuli were images of a male person with the left or right arm outstretched, presented either in a front view or back view perspective. Images were rotated according to eight angular disparities in the picture plane ranging from 0° to 315°, with a 45° increment. The experiment included two tasks, involving a laterality judgment or a same–different judgment. Both tasks also included two conditions: a small-size condition and a large-size condition.

In the laterality judgment task, a single image was displayed at the center of a large projection display. The image could appear in eight angular disparities in picture plane (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°) and in two different sizes. In the small-size condition of this task, a single image (35 cm in diameter) appeared in the center of the screen (Fig. 1a). In the large-size condition, the image was 175 cm in diameter (Fig. 1b).

Participants had to judge whether the human body figure's left or right arm was outstretched as quickly and accurate as possible and regardless of its orientation and size. For this purpose, two buttons of a keyboard were colored and labeled as "left arm" (stimulus left arm outstretched) and "right arm" (stimulus right arm outstretched). Participants had to press the button corresponding to their decision with their index fingers.

In the same–different judgment task, two images either identical or mirror image reversals of each other were presented simultaneously on the large screen and in different size conditions. The reference images were always displayed in an upright position (0°) on the left side of the projection screen. The comparison images were presented on the right side and were rotated randomly in picture plane (clockwise 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°), see Fig. 1c. In the small-size condition of this task, the two images were always presented in identical size (35 cm). In the large-size condition, the two images were presented simultaneously,

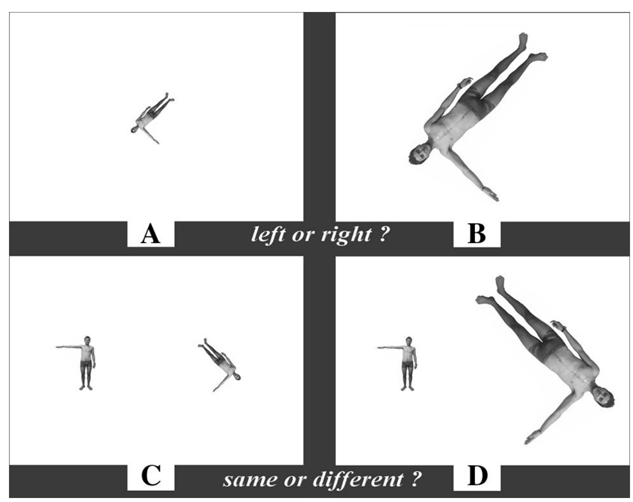

Fig. 1 Examples of the two tasks: **a** laterality judgment task of a single image rotated over 225° in the small-size condition. **b** Laterality judgment task of a single image rotated over 225° in the large-size condition. **c** Same–different judgment task; the comparison image is rotated over 225° in the same small size of the reference image. **d** Same–different judgment task; the comparison image is rotated over 225° and presented in a large size, while the reference image is always presented in an upright position 0° and in small size

but in different sizes, so that the retinal size of each was different to incite participants to use size transformations processes in order to compare the two images. The reference image appeared always in a small size (35 cm) in an upright position (0°) on the left side of the projection display. The comparison image appeared always in a large size (175 cm) on the right side according to the same angular disparities as in the small-size condition (Fig. 1d). In both conditions, participants were instructed to judge whether the two images were identical or different regardless of their orientation and size. For this purpose, two buttons on the keyboard were colored and labeled as "same" and "different" and as previously, participants pressed one of them to give their answer.

Design and procedure

Participants were tested individually in a darkened room. They were provided standardized instructions by the experimenter to begin the test trials. In the two tasks (same–different task and laterality judgment task), the stimuli were presented on a large screen (200 × 300 cm) using an HD video projector (see experimental setup, Fig. 2). Participants were seated in front of the screen at a distance of about 4 m. The order of the two tasks was counterbalanced across the participants. After completing 40 practice trials, participants performed the two tasks. They were then asked to report upon their strategies for performing the task. The experimenter first recorded free oral descriptions of each participant's strategies and then collected their answers to two questions: "what mental transformation did you do first, rotation or size transformation?" and "which task was more difficult?" The aim was to compare participants' descriptions to our interpretations of results.

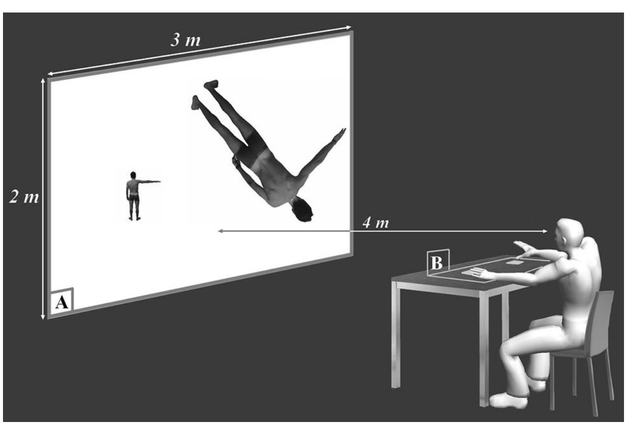

Fig. 2 Experimental setup: **a** Large projection display. **b** Keyboard. Participants sat in front of the large screen at a distance of 4 m. Here, the left image consists of a small-sized back view of the human body with the right arm outstretched, while the comparison image on the right is a life-size back view with the left arm outstretched and rotated over 135°

Each trial started with a blank screen that remained 1500 ms. A black fixation cross then appeared for 1000 ms, followed by the stimulus until a response was made, for a maximum of 5000 ms. The next trial started after the response had been made, or after the maximum time elapsed. The stimuli were displayed via a software program developed in our laboratory that computed response times (RTs) and errors (REs) from the moment the stimulus appeared until a response was generated.

In the laterality judgment task, each stimulus was displayed three times according to eight angular disparities (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°), two size conditions (small or large size), two perspectives (front or back), and two laterality possibilities (left or right arm outstretched) resulting in 192 test trials. Stimuli presentation was randomized, so that identical angular disparity and size condition could not be presented more than twice in succession.

The same–different judgment task consisted of 384 test trials: three times presentation of eight angular disparities (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°), two size conditions (small or large size), two perspectives (front or back), two laterality possibilities (left or right arm outstretched), and two response possibilities (same or different). Specific angular disparities or size conditions were never presented more than twice successively.

Results

Response time

Consistent with the previous research using similar tasks and stimuli (Amorim et al. 2006; Habacha et al. 2014; Hall and Friedman 1994; Steggemann et al. 2011), only RTs from correct trials were submitted to statistical analyses, with RTs faster than 300 ms and slower than 3000 ms defined as outliers and, therefore, excluded from statistical analyses. In addition, and because participants in mental body rotation tasks classically choose the shortest path to align their body representation with the stimuli (Parsons 1987; Zartor et al. 2010), we computed mean RTs of angular disparities for which the shortest rotation path between stimulus and target was the same (45°–315°; 90°–270°; 135°–225°). This is consistent with the previous literature using similar tasks (Habacha et al. 2014; Steggemann et al. 2011). Out of the eight angular disparities tested, five were included in a repeated measures analysis of variance (RM-ANOVA) with the within-subject factors Task (same–different, laterality), Perspective (front, back), Size (small stimuli, large stimuli), and Angular disparity (0°, 45°, 90°, 135°, and 180°). All significant effects are reported below.

A significant main effect of the *Task* was observed: $F(1,33) = 216.17$, $p \leq 0.001$, $\eta_p^2 = 0.87$. Participants performed the same–different task ($M = 1548$ ms, SD = 27) slower than the laterality judgment task ($M = 1150$ ms, SD = 40). The main effect of *Perspective* reached significance, $F(1,33) = 7.89$, $p = 0.008$, = 0.19, indicating higher mean RTs for front view stimuli ($M = 1386$ ms, SD = 26) compared to back view stimuli ($M = 1312$ ms, SD = 40). Analyzes also revealed a significant main effect of the *Size:* $F(1,33) = 17.30$, $p \leq 0.001$, $\eta_p^2 = 0.34$. Accordingly, mental rotations of large stimuli ($M = 1308$ ms, SD = 32) were performed faster than those of small stimuli ($M = 1389$ ms, SD = 34). The main effect of *Angular disparity* was significant, $F(4,132) = 573.63$, $p \leq 0.001$, $\eta_p^2 = 0.95$. Bonferroni post hoc tests revealed that RTs increased significantly from each angular disparity to the next contiguous one ($p < 0.001$ for all comparisons).

In addition, the RM-ANOVA revealed four two-way interactions. The interaction between *Task* and *Perspective* reached significance, $F(1,33) = 5.06$, $p = 0.031$, $\eta_p^2 = 0.13$. Bonferroni post hoc tests showed faster RTs for back view stimuli only in the laterality judgment task ($p = 0.009$), in the same–different judgment task RTs were nearly similar for the two perspective views (Fig. 3a).

The interaction between *Task* and *Size* was significant, $F(1,33) = 161.91$, $p \leq 0.001$, $\eta_p^2 = 0.83$. Interestingly, Bonferroni post hoc tests revealed that, in the laterality judgment task, RTs were significantly longer for small stimuli ($M = 1328$ ms, SD = 41) than for large stimuli ($M = 972$ ms, SD = 40). Conversely, in the same–different judgment task, RTs were significantly longer for the large stimuli ($M = 1644$ ms, SD = 34) than for the small stimuli ($M = 1451$ ms, SD = 32), see Fig. 3b.

A significant interaction between the factors *Task* and *Angular disparity* indicated different RTs profiles for the laterality and the same–different judgment tasks, $F(4,132) = 51.13$, $p \leq 0.001$, $\eta_p^2 = 0.61$. As illustrated in Fig. 4a, higher RTs for each consecutive angular disparity were observed only in the same–different judgment task (all p's < 0.001). However, in the laterality judgment task, RTs remained fairly constant until 90° and increased significantly after (all p's < 0.001).

Finally, the interaction between the factors *Size* and *Angular disparity* also reached significance, $F(4,132) = 26.53$, $p \leq 0.001$, $\eta_p^2 = 0.45$. Bonferroni post hoc tests revealed a significant increase of RTs from each angular disparity to the next contiguous one (all p's < 0.001) for the two sizes. Furthermore, RTs for small stimuli were significantly longer than RTs for large stimuli only when images were rotated over 135° and 180° (all p's < 0.001; see Fig. 4b).

Size transformation time

We postulated that the duration difference between a test trial for a large stimulus and a small stimulus presented at the same angular disparity should correspond to the duration of size transformation process. STTs were thus calculated as the difference between the RTs for large stimuli and RTs for small stimuli. Since the RTs were longer for small stimuli than for large stimuli in the laterality judgment task and inversely in the same–different judgment task, STTs were expressed in absolute value:

$$\text{STT} = |\text{RTs for small stimuli} - \text{RTs for large stimuli}|.$$

Mean STTs were calculated for each participant in the two tasks and for every angular disparity before being

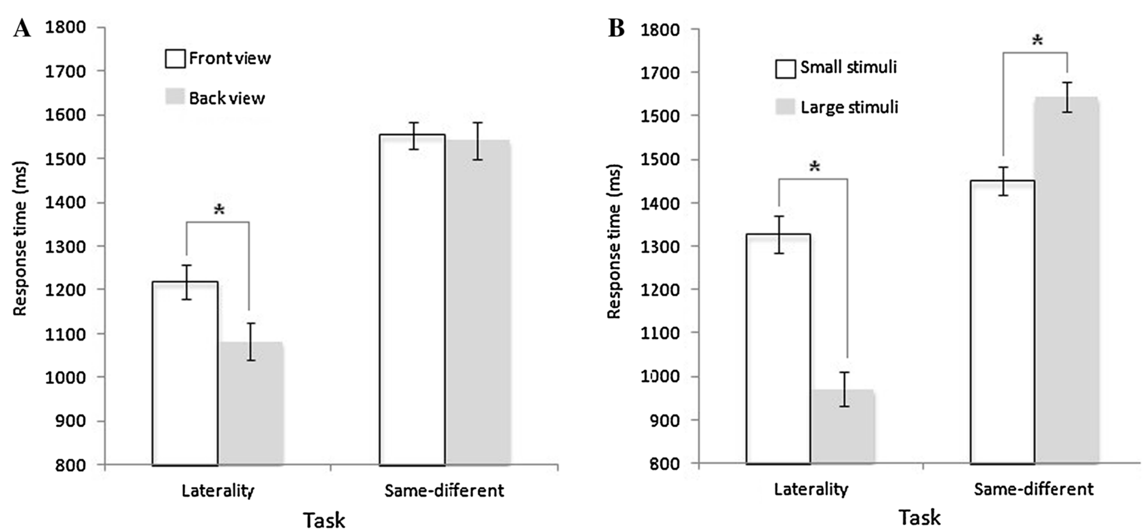

Fig. 3 Mean response times (RTs) in milliseconds (± SD). RM-ANOVA—Bonferroni: * $p < 0.05$. **a** Effect of perspective view. **b** Effect of stimuli size

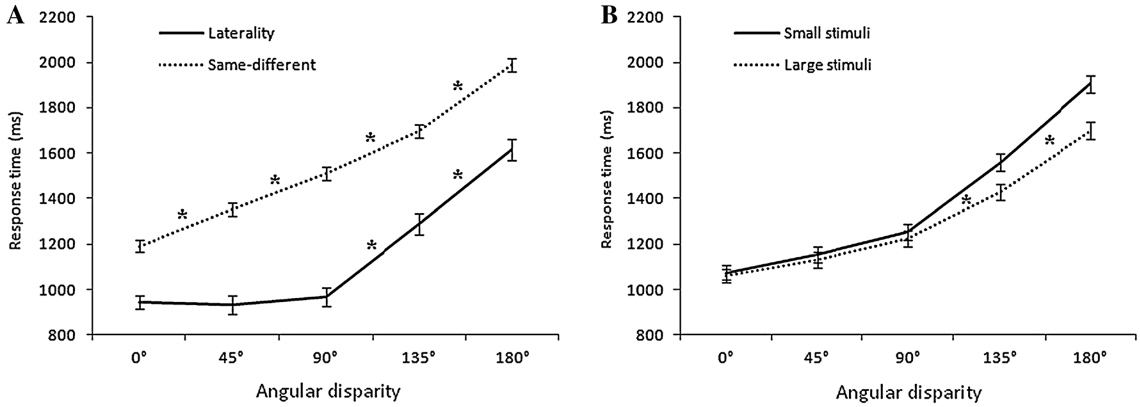

Fig. 4 Mean response times (RTs) in milliseconds (± SD) for all angular disparities dependent on task and size. RM-ANOVA—Bonferroni: * $p < 0.05$. **a** Split by task. **b** Split by stimuli size

submitted to a 2 (Task) × 2 (perspective) × 5 (Angular disparity) RM-ANOVA.

The effect of *Task* was significant, $F(1,33) = 17.30$, $p \leq 0.001$, $\eta_p^2 = 0.34$. STTs during the laterality judgment task ($M = 356$ ms, SD = 15) were longer than STTs during the same–different judgment task ($M = 194$ ms, SD = 38). The main effect of *Angular disparity* also reached significance, $F(4,132) = 26.08$, $p \leq 0.001$, $\eta_p^2 = 0.44$. Figure 5a illustrates the evolution of STTs as a function of angular disparity, Bonferroni post hoc tests revealed that only the difference between 90° ($M = 212$ ms, SD = 27) and 135° ($M = 327$ ms, SD = 23) was significant.

Interestingly, the interaction between *Task* and *Angular disparity* was significant ($F(4,132) = 26.53$, $p \leq 0.001$, $\eta_p^2 = 0.47$). Bonferroni post hoc tests revealed that STTs during the laterality judgment task were significantly longer than STTs during the same–different judgment task only for 135° and 180°. Furthermore, different profiles of STTs as a function of angular disparity for the two tasks were observed (Fig. 5b). For the same–different judgment task, STTs remained fairly constant for all angular disparities. However, for the laterality judgment task STTs remained fairly constant until 90° and increased significantly between 90° and 135° ($p \leq 0.001$) and between 135° and 180° ($p = 0.002$).

Response accuracy

To analyze the percentage of response errors (REs), a 2 (Task) × 2 (Perspective) × 2 (Size) × 5 (Angular disparity) RM-ANOVA was conducted. Analyzes revealed a significant main effect of *Task*, $F(1,33) = 41.00$, $p \leq 0.001$, $\eta_p^2 = 0.55$. Participants made more errors in the same–different judgment task (10.6%) than in the laterality judgment task (4.2%). The main effect of *Angular disparity* reached significance, $F(4,132) = 33.77$, $p \leq 0.001$, $\eta_p^2 = 0.51$. Figure 6a illustrates the evolution of REs as a function of angular disparity. Bonferroni post hoc tests revealed that REs remained fairly constant until 90° and increased significantly after ($p = 0.001$, and $p = 0.034$).

The RM-ANOVA revealed a significant interaction between *Task* and *Angular disparity*, $F(4,132) = 5.65$, $p \leq 0.001$, $\eta_p^2 = 0.15$. Bonferroni post hoc tests revealed

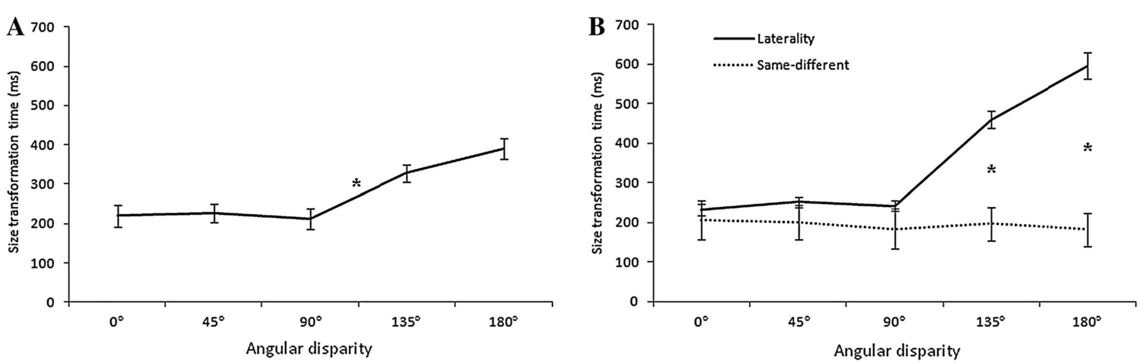

Fig. 5 Mean size transformation times (STTs) in milliseconds (± SD) for each angular disparity, broken down by task. RM-ANOVA–Bonferroni: * $p < 0.05$. **a** Average across conditions. **b** Split by condition

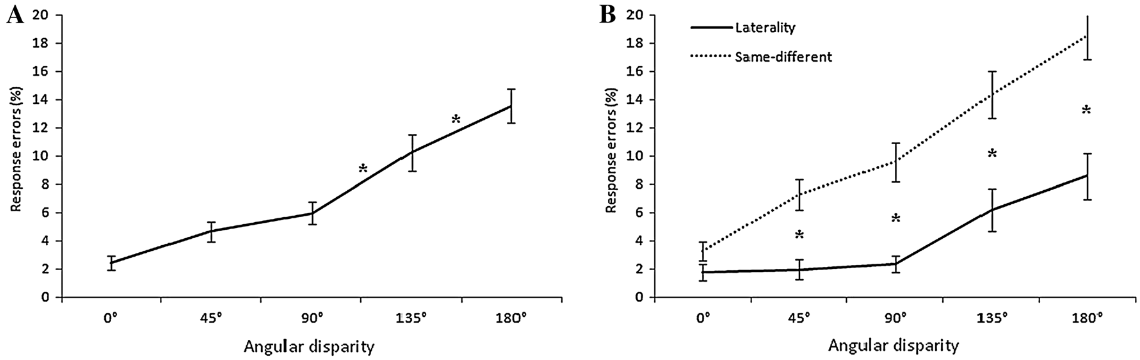

Fig. 6 Mean response errors (REs) in percentage (±SD) for each angular disparity and dependent on task. RM-ANOVA–Bonferroni: * $p<0.05$. **a** Average across conditions. **b** Split by condition

that only the difference between 90° (9.6%) and 135° (14.4%) was significant for the same–different judgment task ($p=0.026$), but no significant difference was observed between all angular disparities for the laterality judgment task. Furthermore, participants performed the laterality judgment task more accurately than the same–different judgment task for all angular disparities (all p's <0.001) except for 0° (Fig. 6b).

Discussion

The present study sought behavioral evidence for different processes underlying object-based transformations and egocentric transformations. In line with our hypotheses, RTs for the same–different judgment task increased as a function of angular disparity, confirming the engagement of object-based transformations. This class of transformations is mainly based on visual imagery processes and thus reflects the metric properties of physical object rotations through real space (Shepard and Metzler 1971; Wohlschläger and Wohlschläger 1998). Also as predicted, different RTs as a function of angular disparity patterns were observed for the laterality judgment task confirming the use of egocentric body transformations to align one's body mental image with the stimuli. This strategy mainly relies on embodied processes of translations and rotations of one's own body mental image involving motor and proprioceptive information (Amorim et al. 2006; Arzy et al. 2006; Habacha et al. 2014; Huttenlocher and Presson 1979; Kessler and Thomson 2010; Zacks and Michelon 2005). RTs in tasks involving embodied perspective transformations are, therefore, constrained by physical limits of the human body (Habacha et al. 2014; Ionta and Blanke 2009; Ionta et al. 2007). In the current study, RTs for the laterality judgment task remained fairly constant at lower angular disparities but increased with angles greater than 90°, as previously reported (Graf 1994; Keehner et al. 2006; Kozhevnikov and Hegarty 2001; Michelon and Zacks 2006; Kaltner et al. 2014). These lower angular disparities in the present study corresponded to standing (0°) and lying down (45°, 90°) positions of the human body which are physically attainable and may thus be mentally emulated quite easily by aligning one's own mental body image with the stimuli. However, angular disparities beyond 90°corresponded to physically unfamiliar positions and were thus executed slower. From these RTs patterns, we propose two explanations. First, participants could have used different mental transformations according to body orientations (Jola and Mast 2005). When body positions were familiar, egocentric transformations could have been automatically engaged leading to flat RTs as a function of angular disparity. In contrast, when body positions were unfamiliar, mental strategies could have worked at a more abstract level of representation (Zacks et al. 2000) and visual processes might have been used leading to sudden increase of RTs. Second, according to Krüger, Amorim, and Ebersbach (2014), bodily stimuli automatically trigger embodied processes that may, under certain conditions, even impede spatial performance. It is thus possible that participants maintained embodied egocentric transformations even for unfamiliar positions which are much more difficult to emulate and became thus slower.

Moreover, the same–different task was performed slower and less accurately than the laterality judgment task for all angular disparities. This finding is in line with the previous research suggesting that object-based transformations are more difficult than egocentric transformations (Jola Mast, 2005; Jordan et al. 2001; Keehner et al. 2006; Wraga et al. 1999; Zacks and Michelon 2005) and supports the dissociation of these two classes of mental transformations.

Additional evidence for different mental processes involved between object-based and egocentric transformations comes from the significant interaction between "task" and "perspective view". In the same–different judgment task, RTs for front and back views of the human figure were similar; however, back views led to shorter RTs than front views in the laterality judgment task. This is in accordance with a recent study by Ebersbach and Krüger (2017) that compared mental rotation of human figures rotated from back view to front view along a vertical axis. Their results confirmed that presenting figures from the back seems to improve performance compared to figures presented from the front, and that individuals mentally rotate these stimuli around a vertical axis, with a linear relationship between RTs and angular disparities.

Indeed, in the same–different judgment task, the two images presented simultaneously did not differ in perspective views. Engaging mainly visual processes, participants mentally rotated one of the images in the picture plane until alignment with the other without referring to the mental image of their own body. For the laterality judgment task, embodied perspective transformations were engaged to align one's own mental body image with front and back views of human body. When the stimuli depicted back views, rotations over the sagittal body axis appear to be sufficient to align one's body image with the stimuli. However, when the stimuli depicted front views (facing the participants), an additional rotation over the vertical body axis is required and lead to more processing and thus longer RTs.

In addition to the present findings, multiple previous studies already provided quite enough behavioral and neuroimaging evidence for two different classes of spatial transformations (Jola and Mast 2005; Parsons 1987; Steggemann et al. 2011; Zacks and Tversky 2005; Zacks et al. 2002). However different stimuli sizes were used in these studies, which may influence the performances on spatial tasks (Tan et al. 2006). Another novel contribution of the current study is the examination of stimuli size effect on mental body rotation tasks with different judgment types. To this end, stimuli were displayed in two different sizes and RTs for both conditions were compared according to both classes of mental transformations.

Our results revealed that, in the same–different judgment task, RTs were longer for the large stimuli than for the small stimuli. In contrast, RTs in the laterality judgment task were shorter for the large stimuli. Based on the processing stages described by Larsen and Bundesen (1975, 1978) and on the underlying mechanisms of the two classes of transformations involved in the present study, we propose the following explanations.

First, it is important to point out that two types of size transformations might have been used when the comparison human figure was larger than the reference image in the same–different judgment task. Participants could have performed size transformations by encoding the visual representation of the small reference figure, "zooming in" this mental image and rotating it until reaching the size and the orientation of the comparison image. Otherwise, they could have encoded and transformed the visual representation of the large comparison figure by "zooming out" to the small size of the reference figure. However, when the two figures were displayed in a small size, no mental size transformations were required and only mental rotations were performed leading to shorter RTs. Whatever the strategy, participants generally performed the task based on visual strategies to manipulate visual patterns of the stimuli saved in short-term memory (Larsen and Bundesen 1978; Muthukumaraswamy et al. 2003).

Furthermore, in the laterality judgment task, participants engaged egocentric transformations that are embodied spatial manipulations involving motor and proprioceptive information (Amorim et al. 2006; Arzy et al. 2006; Habacha et al. 2014; Huttenlocher and Presson 1979; Kessler and Thomson 2010; Zacks and Michelon 2005). Embodied spatial transformations are performed by mentally transforming own body representations stored in the long-term memory and constantly updated (Amorim el al., 2006; Ionta and Blanke 2009; Ionta et al. 2007). Consequently, in the laterality judgment task, a comparison between the stimuli and the own body representation has to be done. Therefore, human figures presented in a large size provided the closest size depictions to the real size of one's own body. Mental size transformation in this case has probably been barely used or not used at all, reducing mental processing and leading to shorter RTs for large depiction than for small depictions of the human figure. However, when small stimuli were presented, participants had to perform a size transformation to match their own body mental image with the stimuli. Since egocentric transformations suggest the mental transformation of own body image (not the stimuli mental representation), we suggest that only a "zooming out" of own body mental image would be performed until reaching the small size of the stimuli.

Interestingly, longer RTs for small stimuli than large ones were observed only when the human body figures were presented in unfamiliar orientations (135°, 180°). This result suggests that the more the angular disparity was, the more the stimuli size affected mental processing. That is, unfamiliar orientations of the human figure requiring more mental rotation led to slower size transformation, suggesting that both processes would run simultaneously (in parallel) and not successively (serial). Extracting the duration of size transformation process might help verifying this suggestion. For this aim, we computed STTs and compared them dependent on task, perspective, and angular disparity. Analyzes revealed that STTs were performed slower in the laterality judgment task than in the same–different task for unfamiliar orientations (135°, 180°). These results suggest that mental size transformation and mental rotation during egocentric body transformations might proceed in parallel and thus interfere leading to more processing, whereas object-based transformations and size transformations might proceed serial.

On one hand, object-based mental rotations and mental size transformations share similar processing stages: (1) visual encoding, (2) mental rotation, (3) response selection, and (4) response production (Cooper and Shepard 1973). After encoding a visual representation of the stimuli, participants could mentally manipulate it by performing mental size transformation before mental rotation and vice versa. We may suggest that performing mental size transformation before mental rotation could be more efficient and faster than the reverse strategy. Indeed, once you begin rotating an object's visual representation to align it with the visual impressing of another object, it would be difficult to decide in which orientation to stop the mental rotation, while the two visual images still have different sizes. Whereas once mental size transformation of an object's representation is done, its rotation until alignment of two images of equal size would be sufficient. This assumption is partially supported by verbal reports of most participants who mention that they used both strategies in the first trials, but performed size transformation before mental rotation in the remaining trials.

On the other hand, egocentric transformations involve embodiment processes that would be performed both at spatial and motoric levels (Amorim et al. 2006). "Spatial embodiment" would be performed by encoding the body posture of the stimuli and mapping one's own body axes onto it. Simultaneously, "Motoric embodiment" would help to maintain the encoded body posture to mentally rotate it with respect to motor affordances of the human body until alignment with the comparison posture. "Spatial embodiment" might underlie mental size transformations whereas "Motoric embodiment" might underlie mental rotations. Accordingly, simultaneous processing of the spatial and motoric embodiment (Amorim et al. 2006) is consistent with our suggestion that, when small stimuli are used in the laterality judgment task, mental size transformation and mental rotation would proceed in parallel. All participants reported automatically performing the mental size transformation and the mental rotation simultaneously to give a fast decision, which partially supports our suggestion.

The patterns of STTs as a function of angular disparity in the two tasks might provide some support for these assumptions. Indeed, in the same–different task, STTs remained nearly constant for all angular disparities, suggesting that participants performed size transformations and rotations sequentially, without interference effects. However, in the laterality judgment task, STTs remained fairly constant until 90° and suddenly increased passed this threshold, consistent with RTs evolving as a function of angular disparity in this task. Familiar body positions may require easy mental rotations of one's own body representation that might not considerably restrain and interfere with mental size transformations, whereas unfamiliar body postures could require difficult mental body rotations limited by the physical constraints of the human body and might thus critically interfere with mental size transformations and slow down their processing.

Future experiments using neuroimaging data could further confirm these effects and support the findings of the current study. Because size transformation ability shows important inter-individual difference, we propose that mental rotation studies take this factor into account when analyzing and interpreting results. When uncontrolled, we recommend that research on the different factors influencing egocentric body transformations uses large stimuli displays, to prevent mental size transformations and interference effects, or at least report stimuli size parameters to avoid unwarranted generalizations. These measures could help further improve reliability in the overall literature, a critical aspect given the growing emphasis on reproducibility and replicability in the cognitive sciences.

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