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Stimulus size matters: do life-sized stimuli induce stronger embodiment effects in mental rotation?

Sandra Kaltner[a], Petra Jansen[a] and Bernhard E. Riecke[b]

[a]Institute of Sport Science, University of Regensburg, Regensburg, Germany; [b]School of Interactive Arts and Technology, Simon Fraser University, Surrey, BC, Canada

ABSTRACT

Against the background of the embodied cognition approach this experiment investigated the influence of motor expertise on object-based vs. egocentric transformations in a chronometric mental rotation (MR) task using images of either the own or another person's body as stimulus material. The present study aimed to clarify two issues: (1) whether stimulus size (life size vs. small) is able to induce embodiment effects and (2) which role self-awareness processes play when using stimuli of the own body. The same design was conducted twice using both small stimuli (Study 1) and life-size human figures (Study 2). Using life-sized figures in Study 2 resulted in an explicit advantage of self-related stimuli and improved performance for motor experts compared to non-motor experts in both object-based and egocentric transformations. In conclusion, these results suggest that life-sized figures do indeed induce stronger embodiment effects in MR.

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Mental rotation

Mental rotation (MR) as a specific visuo-spatial ability involves the process of imagining how a two- or three-dimensional object would look if rotated away from its original upright orientation (Shepard & Metzler, 1971). In a classic chronometric MR task two stimuli are presented simultaneously on a screen. The left stimulus is the "comparison object" and presented in upright orientation. The participants have to decide as fast and accurately as possible if the rotated right stimulus represents the identical object or a mirror-reversed version of the left object. From trial to trial angular disparities are varied systematically and response times as well as accuracy rate are assessed as dependent variable. In the original MR task, Shepard and Metzler (1971) observed a positive linear relation between response time and angular disparity.

In MR two different classes of transformation types are distinguished: object-based and egocentric transformations (Zacks, Mires, Tversky, & Hazeltine, 2002). In the case of an object-based transformation, two images are presented side-by-side on a screen and participants have to judge whether the two drawings are identical ("same", that is non-mirror-reversed) or mirror-reversed ("different") versions of each other. Regarding egocentric transformations, participants have to decide which arm (left, right) of a single human figure presented on the middle of the screen was outstretched (Steggemann, Engbert, & Weigelt, 2011). Thus, in object-based transformations the observer's position remains fixed and participants are thought to mentally rotate the stimulus like an object, whereas in egocentric transformations participants are believed to change their own perspective to solve the task. Specifically, subjects are assumed to imagine rotating their own body in order to make a decision, which is a simulative process recruiting the representation of our own body (Devlin & Wilson, 2010; Kessler & Rutherford, 2010).

The notion of object-based and egocentric transformations being implemented by two different processing systems is supported by a typical response time pattern in MR: reaction times (RTs) linearly increase with increasing angular disparity between the two presented stimuli (Shepard & Metzler, 1971). However, this pattern is more evident in object-based transformations than in egocentric ones (Jola & Mast, 2005; Michelon &

CONTACT Sandra Kaltner sandra.kaltner@ur.de

Zacks, 2006). Specifically, in egocentric transformations RTs tends to show a significant increase only for angles above 60° or 90° (Keehner, Guerin, Miller, Turk, & Hegarty, 2006; Michelon & Zacks, 2006), resulting in a U-shaped pattern for egocentric transformations, as compared to the V-shaped pattern for object-based transformation. Kessler and Thomson (2010) ascribed this finding to two different strategies for solving egocentric transformation tasks: whereas visual matching is used for smaller angles, larger angles involve greater mental efforts because of the need for perspective transformation (see "reference-frame conflict", Wraga, 2003; Wraga, Creem, & Proffitt, 2000 for more details).

Shepard and Metzler (1971) interpreted the linear relationship in object-based transformations and concluded that the process of mentally rotating an object is a covert manual rotation of an object. Using functional imaging, Wohlschläger and Wohlschläger (1998) corroborated this assumption by showing that mental object rotation and actual rotatory object manipulation share common neural processes, resulting in the *common-processing hypothesis* for manual and MR. Thus, this literature suggests that there is a link between motor and mental processes.

Embodiment of MR

The embodied cognition approach is a theoretical framework claiming a tight link between motor and mental processes. This theory implies that many cognitive processes that were originally thought to be purely cognitive seem to also have a motor component. Therefore, embodiment claims that the brain is not the sole cognitive resource we make use of when solving cognitive operations but also our body and its corresponding motions (Wilson, 2002).

In the case of MR, the sensorimotor system serves to embody abstract cognitive processes like spatial transformations (Amorim, Isableu, & Jarraya, 2006). According to these authors, there are two kinds of embodiments, which can explain how spatial transformations are performed: spatial and motoric embodiment. First, spatial embodiment is a kind of bodily projection of the own body axes (front–back, left–right, head–feet) onto the embodied object such as the stimulus material in the case of MR (Lakoff & Johnson, 1999). Second, motoric embodiment suggests that imagining, observing, and executing actions share the same motor representations (cf. Decety, 2002, for a review).

The idea of spatial embodiment is supported by a series of experiments of Parsons (1987, 1994), who showed that time needed for a handedness-judgment (left vs. right) of randomly oriented hands correlated with the time needed for the corresponding real actions. This led the author conclude that the MR of body parts is performed through the observer's simulation of rotating the hand stimuli (Parsons, 1994). This assumption is supported by the results of Ionta, Fourkas, Fiorio, and Aglioti (2007), who showed that a biomechanically constrained hand posture (hands crossed behind the back) lead to a decreased performance in a left–right-judgment task. However, this effect did not emerge when hands were lying on the knees and were therefore not constrained. Neuropsychological evidence is provided by Funk and Brugger (2002), who assessed amputated patients and revealed increased RTs for hands stimuli corresponding to the missing limb. Similarly, Arzy, Overney, Landis, and Blanke (2006) revealed that patients with asomatognosia, who are characterised by a loss of recognition and awareness of body parts, show impaired MR performance for hands stimuli but not for letters. However, the idea that the use of body stimuli is equated with better performance is contestable. For example, Krüger, Amorim, and Ebersbach (2014) showed that embodiment can be detrimental to MR performance with adverse stimuli. Based on the paradigm of Amorim et al. (2006), who assessed standard cube combinations reflecting a human pose, Krüger et al. (2014) investigated, among others, one further condition where they added body parts to Shepard and Metzler (S–M) cubes at locations that were incompatible with human anatomy. Results showed that error rates and response times were significantly increased when stimuli were presented, which prevented a projection of the body.

Interestingly, object-based and egocentric transformations differ in the amount of embodiment. Specifically, Kessler and Thomson (2010) showed in a series of four experiments that egocentric transformations were embodied to a greater extent, since interference effects between the own body posture and the direction of MR solely emerged in egocentric transformations, whereas no influence of posture emerged in object-based transformations. Accordingly, object manipulations rely on object-rotation motor representations, whereas perspective transformations rely on simulated bodily movements (Zacks & Michelon, 2005), where proprioceptive information is more relevant (Kessler & Rutherford, 2010; Kessler & Thomson, 2010; Tversky & Hard, 2009).

In the context of this theoretical background, Kaltner, Riecke, and Jansen (2014) assessed two factors which might influence MR performance: (1) motor expertise; (2) self-related stimuli (e.g. stimulus is a picture of the own person). Considering the fact that observing, imagining, and executing actions share the same representations, Moreau, Clerc, Mansy-Dannay, and Guerrin (2012) concluded that motor experts (elite wrestlers) should outperform non-motor experts because of their frequent manipulation of motor representation when watching bodily transformations of others or performing real actions during training sessions. That is, motor experts tend to engage motor resources to a greater extent compared to non-motor experts. Since egocentric transformations require this kind of inner motor simulation, this advantage of motor experts should be more pronounced in egocentric transformations (cf. Steggemann et al., 2011). In this work, the group with motor expertise consisted of athletes with several years of training in sports such as artistic gymnastics, aero wheel gymnastics, or trampolining. The influence of self-related stimuli is based on the findings of an improved performance for self-related stimuli compared to stimuli of another person's body (Frassinetti, Maini, Romualdi, Galante, & Avanzi, 2008). This self-advantage, the fact that MR performance is improved when using self-related stimuli, is more pronounced for egocentric transformations (Ferri, Frassinetti, Costantini, & Gallese, 2011; for a detailed understanding see Kaltner et al., 2014). Kaltner et al. (2014) investigated the influence of motor expertise on object-based vs. egocentric transformations using images of either the own or another person's body as stimulus material. Results of Kaltner et al. (2014) showed better performance of motor experts, who were trained in various athletic backgrounds such as football, basketball, table tennis, volleyball, tennis, and badminton, compared to non-motor experts solely for egocentric transformations, but could not replicate the advantage of self-related stimuli provided by previous literature (Ferri et al., 2011; Frassinetti et al., 2008). In contrast, they found a "self-disadvantage", expressed by higher RTs for self-related stimuli, restricted to object-based transformations. They proposed that self-related awareness-processes might distract cognitive resources from the actual MR task, which results in a decreased performance in object-based rotations. The present study was designed to test this hypothesis by assessing the effect of stimulus size by comparing life-sized stimuli with artificial small stimuli in this context.

Goals and hypotheses of this study

Two manipulations to the design of Kaltner et al. (2014) were made to investigate whether self-related awareness-processes lead to a decreased performance in object-based rotations: (1) Stimuli were presented in life size, similar to a reflection in a mirror. This modification was chosen to strengthen both embodiment effects through body stimuli (cf. Amorim et al., 2006) and self-awareness processes (cf. Kaltner et al., 2014); (2) an additional recognition task was conducted to expose potential resource-demanding self-related thoughts.

In the following, we will discuss the influence of stimulus size in the context of two theoretical frameworks (1) distraction of cognitive resources through self-awareness and (2) the embodiment approach. Concerning the first theoretical framework, we hypothesise that stimuli in life size might be more effective than smaller figures in triggering self-related thoughts. This self-awareness through self-related thoughts might distract attention-demanding resources away from the MR task, because it is negative attributed. Research has shown that seeing a photograph from one's self or the own person in the mirror results in a feeling of embarrassment and awkwardness, because we are confronted with our "imperfection" (i.e. Rochat, 2009, 2010). Further evidence is provided by Mor and Winquist (2002), who showed that self-focused attention is associated with negative effect such as depression, anxiety and negative mood. For example, depression and anxiety are in turn correlated with decreased MR performance (Chen et al., 2014; Kaltner & Jansen, 2014).

In contrast to this, the embodiment approach claims that a life-sized stimulus triggers embodiment automatically and to a greater extent compared to an artificial small stimulus because a life-size figure represents more body-related characteristics (cf. Krüger et al., 2014), which might ease the MR performance (Alexander & Evardone, 2008; Amorim et al., 2006) since MR of body parts is a covert simulation of the own body (Arzy et al., 2006; Funk & Brugger, 2002; Ionta et al., 2007; Parsons, 1987; 1994; Sack, Lindner, & Linden, 2007). Therefore, we replicated and expanded on the design of Kaltner et al. (2014) by including hypotheses about embodiment effects and information-processing through the manipulation of the stimulus material. To this end, we compared data from Study 1 of Kaltner et al. (2014) with data of the current Study 2 by using "study" as between-subject factor in the statistical analysis (cf. methods below).

Hypothesis 1—Effects of stimulus size on MR: Stronger embodiment and self-awareness effects are predicted for the life-size figures in the current Study 2 compared to the laptop-screen sized figures in the prior Study 1. Hypothesis 1 is divided into the following sub-predictions.

Hypothesis 1a—MR advantage for motor experts, especially for life-size and thus more embodied stimuli: Relative to non-motor experts, motor experts should show improved performance especially for the egocentric transformation task as it is assumed to be more embodied than the object-based task, which was expected to have a reduced embodied component (cf. Kaltner et al., 2014). This effect should be more pronounced for life-sized stimuli in Study 2 compared to Study 1 due to expected enhanced embodiment effects, expressed by an interaction "group * study" for egocentric transformations.

Hypothesis 1b—Increased vs. decreased front-view disadvantage for mentally rotating life-size self-stimuli predicted by self-awareness vs. embodiment frameworks, respectively: Kaltner et al. (2014) reported a "front-view-disadvantage of the self" and explained it as follows: Stimuli of the self, presented frontally and thus facing the participants, require an additional in-depth rotation to match the participant's orientation. Hence, performance should be slower overall for the front view as compared to the back view that does not require an in-depth rotation. For the current Study 2 which used life-sized figures instead of small stimulus sizes, the resource-demanding self-awareness vs. embodiment framework results in two opposing predictions: (1) The self-awareness frameworks predicts an increased "front-view-disadvantage of the self" for the life-sized stimuli in Study 2 due to enhanced self-awareness processes; (2) the embodiment framework predicts stronger embodiment effects of Study 2 using life-sized stimulus, leading to a compensation of this disadvantage. That is, the stimulus size manipulation allows us to investigate whether the self-awareness or embodiment predictions dominate over the other one in MR. Both predictions are expressed by a three-way interaction "stimulus type * view * study" in object-based transformations.

Hypothesis 2—Advantage vs. disadvantage for recognising self-stimuli predicted by self-awareness vs. embodiment frameworks, respectively: The present study was also designed to assess whether and to which extent self-awareness processes might be responsible for the decreased overall performance for self-related stimuli found by Kaltner et al. (2014). To this end, an additional recognition task was conducted. Analogous to Hypothesis 1b, two different theoretical frameworks are contrasted: (1) According to resource-demanding self-awareness processes a "disadvantage of the self" is expected; and (2) the embodiment approach claims that there is an advantage of self-related stimuli, expressed by decreased RTs and a higher accuracy rate for recognising images of the own body compared to human figures of another person.

Methods

Participants

Seventy-three adults between 18 and 32 years old participated in this study. The participants consisted of 38 motor experts recruited from an athletic group (mean $\text{age}_A = 21.9$, $SE_A = 2.3$) and 35 non-motor experts referred to as the non-athletic group (mean $\text{age}_{NA} = 24.1$, $SE_{NA} = 3.4$), $t(71) = -3.29$, $p = .002$, $d = 0.85$. Even though both groups differ regarding age, age-related declines in MR performance are not expected within this age range since processing speed is at its highest level in this period (cf. Salthouse & Kail, 1983).

The groups (motor experts vs. non-motor experts) differed in the amount of training sessions by practising more often (3.9 times/week on average, $SE = 0.2$) compared to the non-athletic group (1.1 times/week, $SE = 0.2$), $t(71) = 8.44$, $p < .001$, $d = 14.00$. The motor experts identified themselves as a motor expert and were sport students at the University of Regensburg, whereas the non-motor experts were students from other courses of studies beyond sport science. The motor experts had various athletic backgrounds such as football, basketball, table tennis, volleyball, tennis, and badminton. The inclusion criteria into the motor-expert group were that these athletes were currently practising their sport for at least three training sessions per week, whereas non-motor experts should not exceed one training session per week.

Regarding intelligence, the results of the Number Connection Test (Zahlenverbindungstest; ZVT; Oswald & Roth, 1987) showed no differences between the groups (mean $IQ_A = 118.1$, $SE_A = 2.8$, mean $IQ_{NA} = 110.0$, $SE_{NA} = 2.9$), $t(71) = 1.79$, $p = .077$, $d = 2.84$, see Table 1. Concerning gender, the motor experts group consisted of 20 females (mean $age_f = 22.0$, $SE_f = 2.2$) and 18 males (mean $age_m = 21.7$, $SE_m = 2.4$). In the non-athletic group 21 females (mean $age_f = 23.5$, $SE_f = 2.8$) and 14 males (mean $age_m = 25.1$, $SE_m = 4.2$) took part in this study. Sex differences exist in performing spatial transformations (cf. Zacks, Mires, et al., 2002). For example, the male advantage in MR is a well-established finding mainly in psychometric tests, which use object-based measurements (Voyer, Voyer, & Bryden, 1995). Therefore, sex was balanced between both groups but was not taken into further consideration because they were not the focus here. Subjects participated as part of a University course. None of the participants had participated in MR tests before. All participants gave informed consent prior to participation. The study was conducted in accordance to the declaration of Helsinki for the guidelines of ethical considerations. Since Study 2 is compared with Study 1, the descriptive data of the sample of Study 1 published in Kaltner et al. (2014) is also included in Table 1.

Apparatus and stimuli

ZVT (Oswald & Roth, 1987): The ZVT (Oswald & Roth, 1987) measures cognitive processing speed. The test consists of 4 sheets, where the numbers 1–90 are presented in a scrambled order in a matrix of 9 rows and 10 columns. The participants were instructed to connect the numbers as fast and correct as possible in ascending order, and the time for connecting the numbers was assessed. The total test administration takes about 10 min. None of the participants missed one number; all sheets were solved correctly. The evaluation reveals ZVT-scores, which are then transferred to corresponding IQ values. The correlation (e.g. Raven-Spearman, Culture Faire Test-30) ranged between $r = 0.60$ and 0.80 (Vernon, 1993). The six-month test–retest reliability as well as the internal consistency of the ZVT is about 0.90–0.95.

MR test: The chronometric mental rotation task (cMRT) was run on a laptop with a 17″ monitor located approximately 60 cm in front of the participants. Stimuli were presented by using the software "Presentation" (Neurobehavioural Systems). There were four stimulus-conditions, two object-based and two egocentric ones, which were in turn split into two further categories, specifically "self" and "other", thus resulting in: (1) object-based-other, (2) object-based-self, (3) egocentric-other, (4) egocentric-self. Each condition was presented in a separate block, as shown in Figure 1. The order of the blocks was counterbalanced.

The size of the figure on the screen was about 100 cm, which is about the size of a mirror reflection on an actual mirror. Thus, each photo was projected on a screen in a distance of about 3 m away from the participant while he or she leaned on a barstool for a more comfortable completion of the experiment, see Figure 2. The visual angle was 19°. Here, each participant was instructed in a certain way to avoid too much variability concerning the position. This kind of presentation may induce the effect of a reflection in a mirror, which should enhance embodiment effects. However, it should be noted here that a photo differs from the view in a mirror since no human being is symmetrical. The position of the stool relative to the screen was modified in dependence of the participant's height to ensure a comparable visual angle of the stimulus between the subjects. For a better impression of a reflection in a mirror, the participants worked on the cMRT standing up. That is, participants were standing while performing the task because the stimuli were also standing. Due to this similarity, the stimuli looked closer to what an actual mirror reflection would look like. The idea of a mirror reflection was reinforced by the instructions given to the participants. Response selection was conducted by using a wireless mouse placed on the thigh of the participant.

Object-based vs. egocentric transformations

For the object-based transformation, two pictures of the same human figure were presented simultaneously, that is side-by-side, in the centre of the computer screen (see Figure 1, left). The left stimulus, the so-called comparison figure, was always presented upright in the normal chirality and the right stimulus was displayed in five different angular disparities of 0°, 45°, 90°, 135°, or 180°. The right human figure was rotated in the picture plane in a

Table 1. Descriptive data for the group, the IQ and the amount of training sessions per week (mean RT and *SE*) with the corresponding *p*- and *d*-values of the *t*-tests.

Study		Group	*M*	*SE*	*t*	*p*	*d*
1	Age	Motor experts	22.4	1.9	−0.45	.002	0.14
		Non-motor experts	22.7	2.7			
	IQ	Motor experts	117.3	17.1	1.88	.063	7.15
		Non-motor experts	111.1	12.2			
	Training sessions/week	Motor experts	4.9	1.3	11.38	.000	3.51
		Non-motor experts	1.0	0.9			
2	Age	Motor experts	21.9	1.3	−3.29	.002	0.85
		Non-motor experts	24.1	3.4			
	IQ	Motor experts	118.1	2.8	1.79	.077	2.84
		Non-motor experts	110.0	2.9			
	Training sessions/week	Motor experts	3.9	0.2	8.44	.000	14.00
		Non-motor experts	1.1	0.2			

clockwise direction. Half of the trials were pairs of identical objects and half were mirror-reversed images, resulting in a same–different judgment. In the egocentric condition only one human figure was presented in one of the orientations mentioned above (see Figure 1, right). The stimulus was from the same view (front or back) and the view only changed between trials and not within trials. This figure raised either the left or the right arm. Thus, a left–right decision was required.

Self vs. other trials

"Self" trials consisted of photographs of the own body with each participant wearing standardised

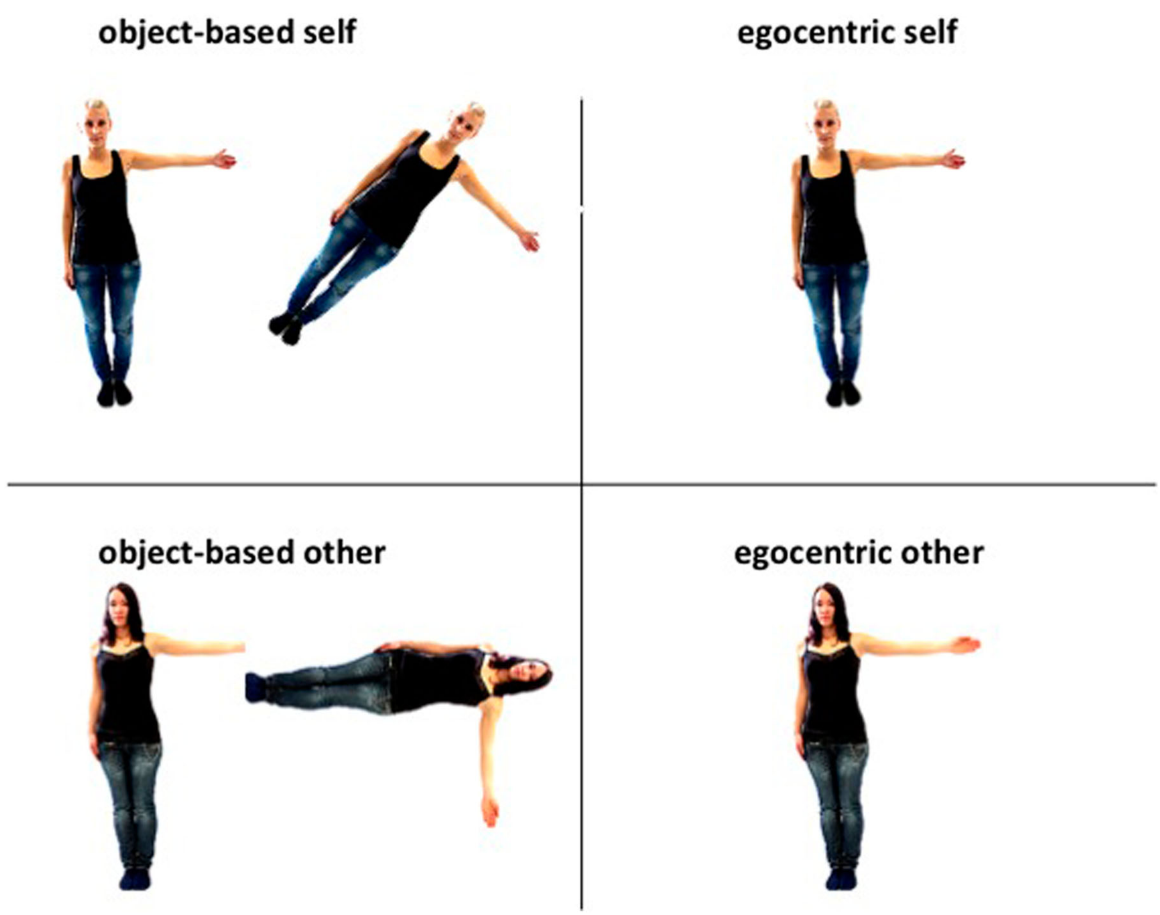

Figure 1. Examples of the stimuli used for the different conditions. Top stimuli show pictures of participants' own body (self), whereas bottom stimuli depict images of another person's body (other). Left: sample stimuli used in the same–different object-based transformation task, for disparities of 45° (top) and 90° (bottom). Right: stimuli used in the egocentric transformation task for the 0° condition.

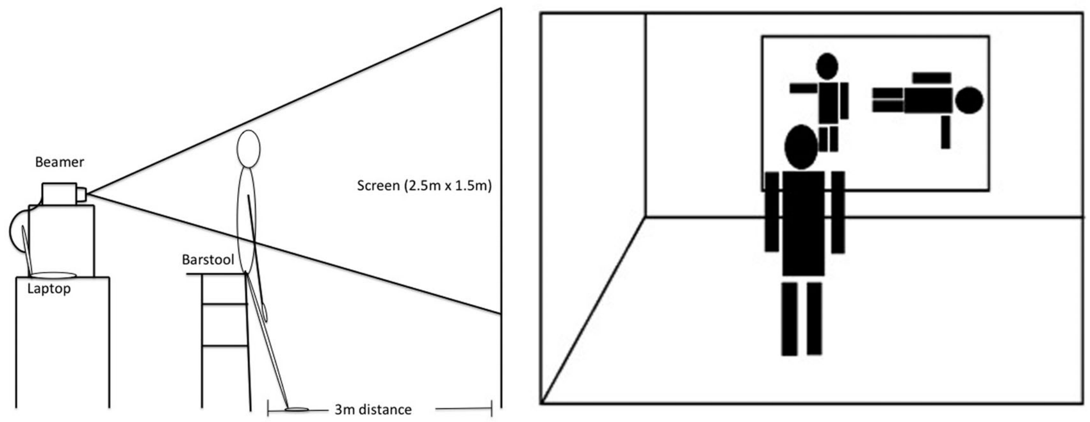

Figure 2. Test setup illustrating the participant facing a stimulus (self vs. other) using life-sized stimuli in the object-based condition.

clothes, that is blue trousers with black shirt and socks (see Figure 1, top). Participants were photographed in a controlled setting with constant artificial lighting from a fixed distance and in the same position with one outstretched arm (either left or right), and either from a frontal or back perspective. Thus, in total four pictures were taken of each participant: 2 arm (left/right) × 2 view (front/back). Afterwards, photographs were edited with Adobe Photoshop software to ensure a completely white background. In contrast to self-related stimuli, "other" trials consisted of pictures of another person that was matched in gender and clothes, see Figure 1 (bottom).

Recognition task: Identical to the cMRT, photographs of the participants were projected on a screen in life size and presented by the software "Presentation" (Neurobehavioural Systems). This kind of presentation similar to a reflection in a mirror was chosen to strengthen both embodiment effects trough body stimuli (cf. Amorim et al., 2006) and self-awareness processes (cf. Kaltner et al., 2014). In contrast to the cMRT, participants were not required to make a decision (same/different; left/right). Instead, they were instructed to state whether the presented stimulus is an image of themselves or of another person. In addition to displaying stimuli in an upright (0°) orientation, the stimuli were also displayed in an orientation of 135° in half of the trials for two reasons: (1) We chose an orientation which is not familiar to the participants (cf. Moreau et al., 2012; Steggemann et al., 2011); (2) we wanted to investigate the reference-frame conflict (May & Wendt, 2012), which may support the embodiment approach.

In total, 48 trials were presented composing of: 2 * decision type (self vs. other) × 3 * angular disparity (0°, 135°, −135°) × 4 * kind of stimulus (back view/front view × left arm/right arm) × 2 * repetitions of each combination. The order of stimulus presentation was randomised.

Procedure and experimental design

The individual test session, which lasted about 60 min, took place in a laboratory at the University of Regensburg. After pictures were taken from each person, they were inserted in the stimulus presentation software "Presentation" while the participants filled out the demographic questionnaire, followed by the ZVT (Oswald & Roth, 1987).

Afterwards, the cMRT was conducted with a standardised task instruction and illustrated in Figure 1. Regarding the two object-based conditions (self vs. other) participants had to press the left mouse button (left-click) when the two stimuli were "same", that is when the stimulus on the right side was identical (that is only rotated) to the comparison stimulus (shown on the left side). Conversely, participants were instructed to press the right mouse button (right-click) when the two stimuli were "different", which implies that the stimulus on the right side was a mirror version of the left stimulus.

In the two egocentric transformations (self vs. other), participants had to press the right mouse button when the right arm of the figure was outstretched or the left mouse button in the case of the left arm (see Kaltner et al., 2014).

The cMRT consisted of 4 blocks, whereby 10 practice trials preceded each block. During each block, a pause of 15 s was given after every 20 trials. At the beginning of each trial, a fixation cross was presented for 1 s. After that, the two human stimuli in the object-based transformation task or one single figure in the egocentric condition appeared and stayed on the screen until participants pressed the mouse button. For correct responses a "+" appeared in the centre of the screen and for incorrect responses a "–" appeared. The next trial began after 1,500 ms. However, feedback was solely given within the practice trials.

The experiment contained four blocks of 80 experimental trials, resulting in 320 trials: 2 transformations (object-based/egocentric) × 2 stimulus types (self/other) × 5 angular disparities (0°, 45°, 90°, 135°, or 180°) × 4 repetitions of each combination × 4 stimuli per block (front vs. back view × left vs. right arm raised). The order of stimulus presentation was randomised.

At the end, the recognition task was run. Since MR results were our main focus, we did not want to risk potential effects of the recognition task on the MR performance. Therefore, we did not vary the order of the tasks, which resulted in always presenting the cMRT prior to the recognition task.

Statistical analysis

According to previous literature, "object-based" and "egocentric" transformations differ in the following aspects: visual stimulation (2 stimuli vs. 1 stimulus, cf. Zacks, Ollinger, Sheridan, & Tversky, 2002), instruction (Borst, Kievit, Thompson, & Kosslyn, 2011) and type of judgment (same–different vs. left–right, cf. Steggemann et al., 2011). Thus, a

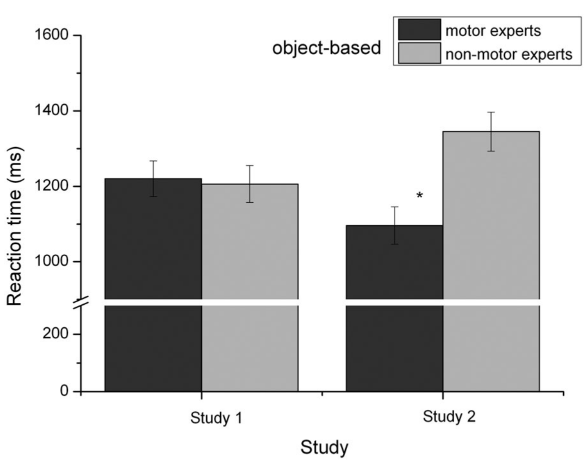

Figure 3. RT (mean and *SE*) dependent on group and study for the object-based transformations.

repeated-measures ANOVA using "angular disparity" (0°, 45°, 90°, 135°, 180°) and "transformation type" (object-based vs. egocentric) as factors and "RT" and "accuracy rate" as dependent variables was conducted first to analyse whether the transformation types differ or not. Even though there was no accuracy rate difference between both transformation types, $F(1,72) = 2.09$, $p = .153$, $\eta_p^2 = 0.03$, results of RTs showed that the egocentric condition ($M =$ 1,018.1 ms, $SE = 26.5$) was solved significantly faster compared to the object-based condition ($M =$ 1,216.2 ms, $SE = 34.2$), $F(1,72) = 39.84$, $p < .001$, $\eta_p^2 = 0.36$. In addition to the methodological reasons mentioned above, this RT difference provided the basis for a separate analysis of object-based and egocentric transformations. RT data were trimmed within subjects and means were taken. Data of no participant had to be excluded because no RT was higher than two standard deviations above the mean of the specific stimulus. Only correct trials were included in the analyses.

cMRT: The main analysis regarding Hypotheses 1a and 1b was conducted to compare Studies 1 and 2 and consisted of two repeated-measures ANOVA using "RT" and "accuracy rate" as dependent variables. The between-subject factors were "group" (motor experts vs. non-motor experts) and "study" (Study 1 vs. Study 2). Within-subject factors were "angular disparity" (0°, 45°, 90°, 135°, 180°), "stimulus type" (self vs. other), and "view" (front vs. back). Since angular disparity is not clearly defined for mirror-reversed responses (Jolicœur, Regehr, Smith, & Smith, 1985), we excluded all the responses for the mirrored trials from the analysis. The significance levels of the ANOVA results were corrected according to Greenhouse–Geiser to compensate for potential non-sphericity of the data.

Recognition task: To investigate Hypothesis 2, a repeated-measures ANOVA was conducted. The factor "group" was used as between-subject factor, whereas "angular disparity" (0°, 135°) and "stimulus" (self vs. other) served as the within-subject factors. "RT" and "accuracy rate" were the dependent variables.

Results

cMRT: Hypothesis 1

Object-based transformations: RT

Regarding RT, repeated-measures analysis of variance using "study" as between-subject factor and "angular disparity", "stimulus type", and "view" as within-subject factors found no main effect of "study", $F(1,150) = 0.02$, $p = .882$, $\eta_p^2 = 0.00$. That is, Study 1 does not differ from Study 2 in overall RTs of object-based transformations.

There was one significant two-way interaction: The interaction between "group" and "study" was significant, $F(1,150) = 7.09$, $p = .009$, $\eta_p^2 = 0.05$ and is illustrated in Figure 3. Whereas in Study 1 there was no difference between motor experts (M = 1,220.0 ms, $SE = 56.7$) and non-motor experts (M = 1,206.9 ms, $SE = 47.9$) regarding their performance in object-based transformations, $t(79) = 0.19$, $p = .851$, $d = 0.25$, for the life-sized stimuli in Study 2 motor experts (M = 1,096.9 ms, $SE = 36.7$) solved object-based transformations significantly faster than non-motor experts (M = 1,345.6 ms, SE = 51.4), $t(71) = -3.98$, $p < .001$, $d = 5.57$. Note that this result does not match the prediction of Hypothesis 1a, which predicted that a group effect should emerge only for egocentric transformations but not for object-based transformations.

Besides, two significant three-way interactions emerged:

(1) The "group * angular disparity * study"-interaction reached significance at the .05-level, $F(4,600) = 2.91$, $p = .021$, $\eta_p^2 = 0.02$, and is shown in Figure 4. Whereas in Study 1 there was no difference between motor experts (M_{Diff} = 1,002.7 ms, $SE = 82.7$) and non-motor experts (M_{Diff} = 856.1 ms, $SE = 68.8$) regarding the increase of RT with increasing angular disparity between the angular disparities of 0° and 180°, $t(152) = 1.35$, $p = .374$, $d = 1.93$, for the life-sized stimuli in Study 2 there was a steeper increase of RTs for non-motor experts (M_{Diff} = 874.9 ms, $SE = 64.5$) than for motor experts (M_{Diff} = 707.8 ms, $SE = 52.3$), expressed by a greater difference between the angular disparities of 0° and 180° for non-motor experts, $t(152) = 2.03$, $p = .046$, $d = 2.87$.

(2) The "view * stimulus type * study"-interaction was significant, $F(1,150) = 8.84$, $p = .003$, $\eta_p^2 = 0.06$, see Figure 5. Whereas in Study 1 there were higher RTs in both self-stimuli (M_{front} = 1,314.5 ms, $SE_{\text{front}} = 49.3$ vs. M_{back} = 1,224.3 ms, $SE_{\text{back}} = 43.9$), $t(80) = 4.76$, $p < .001$, $d = 2.08$, and other-stimuli (M_{front} = 1,182.1 ms, SE_{front} = 33.7 vs. M_{back} = 1,235.8 ms, $SE_{\text{back}} = 33.0$), $t(80) = 3.38$, $p = .001$, $d = 1.63$, in Study 2 using life-sized figures this front-view disadvantage occurred only for other-stimuli (M_{front} = 1,203.9 ms, $SE_{\text{front}} = 37.2$ vs. M_{back} = 1,143.7 ms, $SE_{\text{back}} = 32.1$), $t(72) = 3.34$, $p = .001$, $d = 1.75$, but not for images of themselves (M_{front} = 1,261.4 ms, $SE_{\text{front}} = 40.9$ vs. M_{back} = 1,255.6 ms, $SE_{\text{back}} = 39.8$), $t(72) = 0.27$, $p = .788$, $d = 0.15$. That is, the "front-view-disadvantage of the self" of Study 1 disappeared here for self-stimuli. Thus, this special front-view disadvantage found in Study 1 is compensated by the presentation of the stimuli in life size, which supports the compensation-prediction of Hypothesis 1b based on the embodiment. This suggests that embodiment effects dominated over potential effects of resource-demanding information-processing which was also predicted to be increased for life-sized figures.

Summary of the main results: Object-based transformations revealed (1) reduced response times for motor experts over non-motor experts; and (2) improved performance of motor experts compared to non-motor experts, which is expressed by a flatter increase of RTs with increasing angular disparity of motor experts compared to that of non-motor experts. This effect did not emerge for the smaller stimuli in Study 1. Furthermore, the "front-view-disadvantage of the self" of Study 1 diminishes for the life-sized figures used in Study 2, as predicted by embodiment but not resource-demanding information-processing theories.

Egocentric transformations: RT

There was no main effect of the factor "study" on response times, $F(1,150) = 0.04$, $p = .382$, $\eta_p^2 < 0.01$. In contrast to Hypothesis 1a, the interaction between the factors "group" and "study" did not reach significance, $F(1,150) = 0.77$, $p = .382$, $\eta_p^2 <$ 0.01.

There was one three-way interaction: The "stimulus type * view * study"-interaction was significant, $F(1,150) = 7.97$, $p = .005$, $\eta_p^2 = 0.05$, and is illustrated in Figure 6. *Post hoc* tests for Study 1 showed no difference between self- and other-stimuli for neither front (M_{self} = 1,139.2 ms, $SE_{\text{self}} = 40.3$ vs. M_{other} = 1,154.5 ms, $SE_{\text{other}} = 40.6$), $t(80) = -0.59$, $p = .557$, $d = 0.38$, nor back view (M_{self} = 896.3 ms, $SE_{\text{self}} = 27.3$ vs. M_{other} = 909.4 ms, SE_{other} = 24.9), $t(80) = -0.86$, $p = .391$, $d = 0.15$. However,

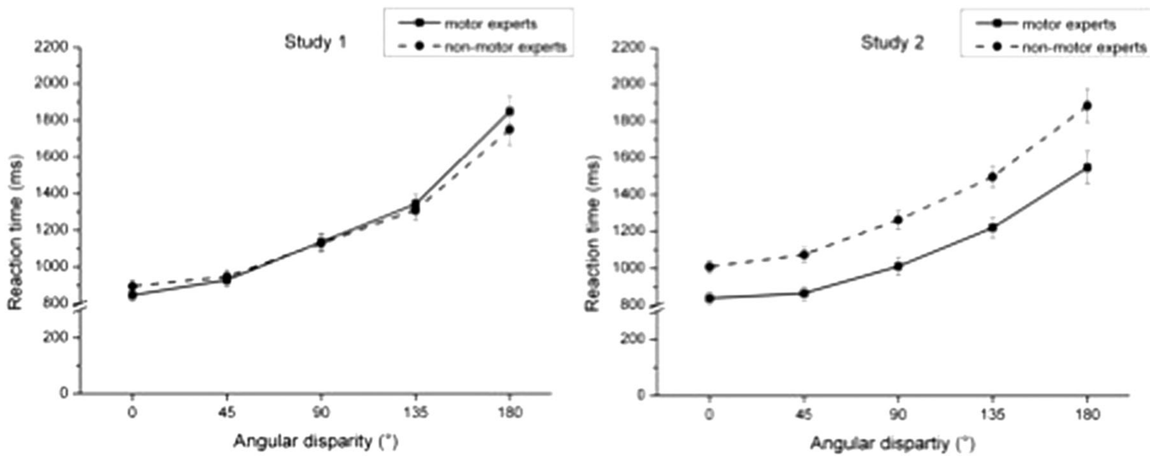

Figure 4. RT (mean and *SE*) dependent on group and angular disparity for object-based transformations in Study 1 (left) and in Study 2 (right).

in Study 2 self-related stimuli were solved 50 ms faster than other-stimuli in the back view (M_{self} = 890.7 ms, SE_{self} = 20.5 vs. M_{other} = 941.4 ms, SE_{other} = 25.9), $t(72) = 2.98$, $p = .004$, $d = 2.21$, but there was no such self-advantage for the front view (M_{self} = 1,122.4 ms, SE_{self} = 34.8 vs. M_{other} = 1,117.9 ms, SE_{other} = 34.1), $t(72) = -0.18$, $p = .845$, $d = 0.13$. Thus, a so-called "self-advantage" emerged only for the back view and only for the life-sized figures. This is the first result of the present study to show a direct advantage of self-related stimuli.

Summary of the main results: Egocentric transformations showed reduced response times for self-related stimuli in the back view, but only for Study 2 where life-sized stimuli were used.

Object-based transformations: accuracy

There was no significant main effect of the factor "stimulus size" on accuracy, $F(1,150) = 0.16$, $p = .198$, $\eta_p^2 = 0.01$. That is, Study 1 (M = 92.7%, SE = 0.9) does not differ from Study 2 (M = 91.0%, SE = 0.9) in overall accuracy of object-based transformations. The only significant main effect was for the factor "angular disparity", $F(4,600) = 17.20$, $p < .001$, $\eta_p^2 = 0.10$. Bonferroni-corrected *t*-tests revealed that accuracy decreased significantly between the angular disparities of 90° and 135°, $t(153) = 3.00$, $p = .003$, $d = 0.23$, and between 135° and 180°, $t(153) = 2.93$, $p = .004$, $d = 0.23$. There was no significant difference in the accuracy between the angular disparities of 0° and 90° (0–45°: $t(153) = 2.26$, $p = .020$, $d = 0.19$; 45–90°: $t(153) = -0.32$, $p = .751$, $d = -0.02$).

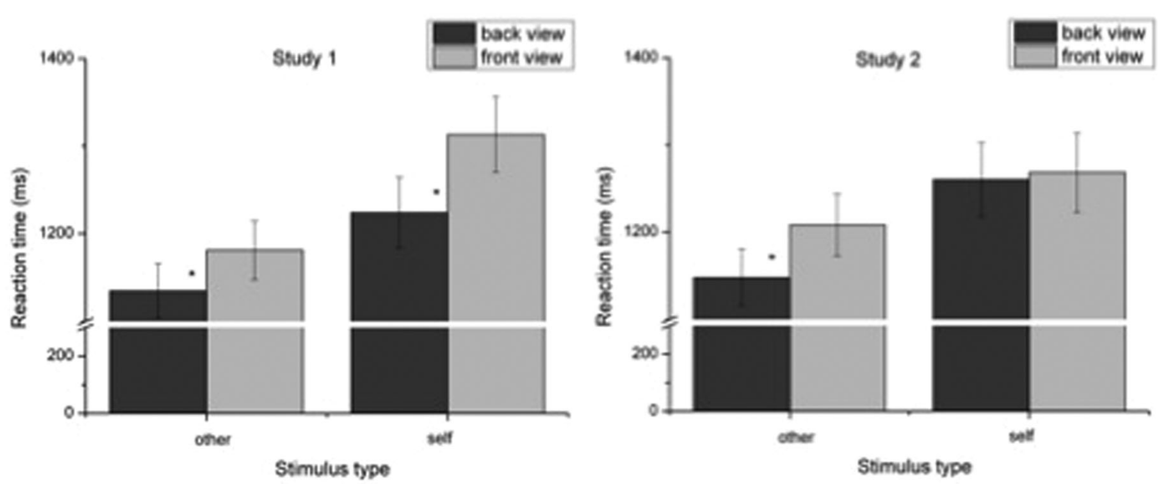

Figure 5. RT (mean and *SE*) dependent on view and stimulus type for object-based transformations in Study 1 (left) and in Study 2 (right).

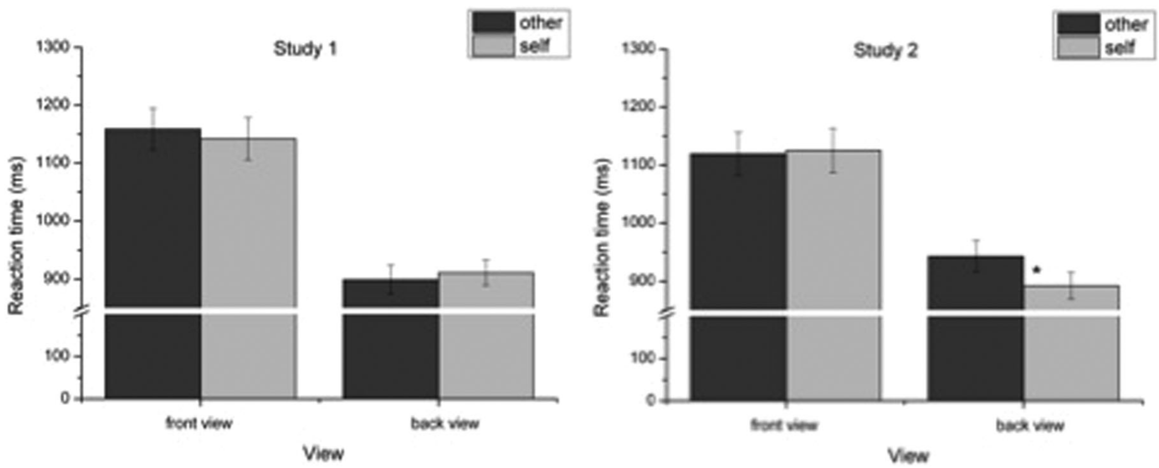

Figure 6. RT (mean and *SE*) dependent on view and stimulus type for egocentric transformations in Study 1 (left) and in Study 2 (right).

Egocentric transformations: accuracy

The repeated-measures ANOVA showed no significant main effect for "study", $F(1,150) = 1.85$, $p = .175$, $\eta_p^2 = 0.01$, indicating that there is no accuracy rate difference between Study 1 ($M = 94.8\%$, $SE = 1.2$) and Study 2 ($M = 93.9\%$, $SE = 0.9$) in egocentric transformations. The only significant main effect was for the factor "view", $F(1,150) = 28.39$, $p < .001$, $\eta_p^2 = 0.16$, indicating that accuracy was higher for the back view ($M = 94.3\%$, $SE = 0.6$) compared to the front view ($M = 89.8\%$, $SE = 1.1$). Besides, there was one significant interaction between "angular disparity" and "study", $F(4,600) = 3.38$, $p = .001$, $\eta_p^2 = 0.02$. Whereas in Study 1, there was a significant difference in the accuracy between the angular disparities of 90° and 135°, $t(180) = 3.38$, $p = .001$, $d = 0.36$, in Study 2 the difference between the angular disparities of 0° and 45° reached significance, $t(72) = 3.56$, $p = .001$, $d = -0.36$.

Thus, neither object-based nor egocentric transformation tasks showed any overall influence of stimulus size (Study 1 vs. Study 2) on MR accuracy.

Recognition task: Hypothesis 2

RTs

Regarding RT, one significant main effect for the factor "stimulus type" emerged, $F(1,71) = 16.36$, $p < .001$, $\eta_p^2 = 0.19$. That is, participants took longer to recognise depictions of their own figures ($M = 661.3$ ms, $SE = 14.3$) compared to depictions of another person ($M = 636.4$ ms, $SE = 13.7$), confirming the "self-disadvantage" predicted in the self-awareness approach of Hypothesis 2.

Accuracy rate

The factor "stimulus type" showed a significant main effect on recognition accuracy, $F(1,71) = 6.84$, $p = .011$, $\eta_p^2 = 0.09$. That is, participants were more accurate in recognising depictions of others ($M = 98.2\%$, $SE = 0.7$) than for depictions of themselves ($M = 97.1\%$, $SE = 0.8$). This corroborates the idea of resource-demanding self-awareness processes for the self-related stimuli proposed in Hypothesis 2.

Summary of the main results: Participants were both slower and less accurate in recognising depictions of themselves compared to depictions of another person.

Discussion

Based on the design of Kaltner et al. (2014), described as Study 1, we compared the performance of motor experts and non-motor experts in object-based vs. egocentric transformations using depictions of themselves vs. another person. Instead of using small artificial stimuli like in Study 1, we presented body stimuli in life size in Study 2 and compared both experiments statistically to investigate the influence of this stimulus size manipulation. We hypothesised that life-sized figures should result in stronger embodiment effects and self-awareness processes, especially for depictions of one's own body. The main goal was to investigate, whether embodiment effects or self-awareness processes dominate when performing this stimulus size manipulation.

Regarding the influence of motor expertise, two effects partly support *Hypothesis 1a* predicting a

MR advantage for motor experts compared to non-motor experts that is more pronounced for life-sized stimuli in Study 2 than for Study 1 especially in egocentric transformations: Specifically, (1) motor experts outperformed non-motor experts for the life-sized figures in Study 2, whereas no performance difference could be observed for the small stimuli in Study 1; and (2) motor experts showed a flatter increase of RTs with increasing angular disparity compared to non-motor experts for the life-sized stimuli in Study 2, whereas no such performance difference between these groups was observed in Study 1. Interestingly, both results emerged only for object-based but not for egocentric transformations, even though one would have expected egocentric transformations to have a stronger embodiment component than object-based transformations. Therefore, these results solely partly support Hypothesis 1a, where a group effect should have been emerged exclusively in egocentric transformations. It will be discussed later, why especially object-based transformations seem to profit from the stimulus size manipulation of the present study.

Hypothesis 1b contrasted different predictions based on self-awareness vs. embodiment frameworks: Whereas using life-sized figures in Study 2 would predict an increased front-view disadvantage based on increased resource-demanding self-awareness processes, the embodiment framework would predict that the enhanced embodiment benefits of life-sized figures in Study 2 would compensate for the front-view disadvantage observed for laptop-screen sized stimuli in Kaltner et al. (2014). In line with the embodiment prediction (but distraction of cognitive resources through self-awareness processes), results showed that the "front-view-disadvantage of the self" found in object-based rotations in Study 1 disappeared in Study 2. We tentatively interpret this finding as indirect self-advantage, which supports the idea of stronger embodiment effects for life-sized stimuli in Study 2 leading to a compensation of this disadvantage. Furthermore, one result explicitly argues for a direct advantage of self-stimuli in egocentric transformations: In Study 2, there is an advantage of self-stimuli for back views, whereas front views showed no such differences between self- and other-stimuli. As the back view showed human figures aligned with the participants' facing direction, one might argue that this predicts stronger embodiment effects resulting in a facilitation of perspective taking for back as compared to front views. Even if the self-advantage is restricted to the back view, it is the first finding, which supports the self-advantage in egocentric transformations demonstrated by Ferri et al. (2011) using photographs of hands (self vs. other). This result also provides evidence for the sub-prediction of Hypothesis 1b arguing for stronger embodiment effects of Study 2 compared to Study 1 due to the presentation of life-sized stimuli.

Concerning Hypothesis 2, results of the recognition task showed higher RTs and lower accuracy when self-related stimuli were presented compared to images of another person's body. This finding argues that resource-demanding self-awareness processes triggered by seeing images of oneself dominated over potential embodiment benefits. In the following section results will be discussed in more detail.

The role of motor expertise in object-based and egocentric transformations

Whereas the better performance of motor experts compared to non-motor experts solely emerged in egocentric transformations in Study 1, this benefit of motor expertise also occurred for object-based transformations when using life-sized figures in Study 2. This result is in line with many studies demonstrating a positive effect of motor expertise on object-based rotations (Moreau et al., 2012; Pietsch & Jansen, 2012; Tlauka, Williams, & Williamson, 2008).

According to Moreau et al. (2012), the better performance of motor experts stems from a stronger activation of motor processes when solving cognitive operations. That is, they engage motor resources to a greater extent compared to non-motor experts. Transferred to MR, Moreau suggests that using motor processes leads to a change in the reference-frame of the stimuli. That is, stimuli that were originally located relative to the surrounding environment, like it is the case in object-based transformations, are transformed into egocentric stimuli located relative to the own body. Here, are stronger involvement of motor processes is required since the own body seems to be the corresponding reference-frame resulting in a perspective transformation of the self in order to complete the task. This in turn facilitates performance (cf. Amorim et al., 2006). Moreau et al. (2012) describes this change in the reference-frame from an allocentric to an egocentric one as kind of priming that takes place. According to Moreau et al. (2012) the daily manipulation of motor representations in motor experts during training sessions might be understood as a certain priming which leads to transferring one's own body axes onto nonbody-stimuli. The notion of certain priming-processes is confirmed by functional imaging data. For example, the positron emission tomography study of Wraga, Thompson, Alpert, and Kosslyn (2003) revealed that the activation of motor areas in object-based rotation was solely present after human figures have been processed beforehand. They compared two groups: the experimental group first solved same–different judgments with hands stimuli, followed by the same task using S–M cubes. The control group performed two object-based transformations using solely S–M figures. Motor areas (M1, superior and inferior parietal lobes, frontal areas) were activated exclusively in the experimental group. The authors draw the conclusion that the use of motor processes can be transferred to nonbody-stimuli. Even if the work of Moreau differs methodologically from the present study, this notion could explain the better performance of motor experts compared to non-motor experts in object-based rotations.

Interestingly, especially object-based transformations seem to benefit from embodiment effects through stimulus size manipulation: Both the better overall performance of motor experts compared to non-motor experts in object-based transformations as well as the flatter increase of RTs in motor experts than that in non-motor experts occurred only for life-sized stimuli in Study 2 but not for smaller stimuli in Study 1. However, according to embodiment approach, the reported effects should have affected egocentric transformations to a greater extent than object-based transformations. We tentatively conclude that in egocentric transformations there has already been a kind of priming of motor simulation processes even for small stimulus sizes, whereas in object-based transformations motor processes might have been triggered only for life-sized stimuli. Even if it is very speculative at this point, there are several studies arguing for enhanced embodiment effects due to stimulus material manipulation using object-based transformations (Amorim et al., 2006; Jansen, Lehmann, & van Doren, 2012; Sack et al., 2007). It is also conceivable that potential embodiment benefits for MR of life-sized stimuli might have been counteracted by increased cognitive demands based on resource-demanding self-awareness processes, which might be more pronounced for egocentric transformation tasks compared to object-based transformations, especially given that the egocentric transformation stimuli were designed to mimic the situation of standing in front of a mirror.

Influence of self-related stimuli on object-based and egocentric transformations

Results regarding the influence of self-related stimuli support the notion of stronger embodiment effects of Study 2 when using life-sized stimuli, which in turn lead to a compensation of resource-demanding self-awareness processes. Specifically, the "stimulus type * view * study"-interaction in object-based transformations indicated that the "front-view-disadvantage of the self" of Study 1 disappears for life-sized stimuli in Study 2. Kaltner et al. (2014) concluded that this performance decrease when seeing images of oneself in Study 1 could be ascribed to resource-demanding self-awareness processes in object-based transformations. This assumption was supported by the recognition task in Study 2, where images of one's own body were in fact recognised slower and with a lower accuracy compared to other-stimuli. Since this disadvantage of self-stimuli disappeared for life-sized stimuli in Study 2, we tentatively propose that enhanced embodiment effects due to increased stimulus size might have compensated resource-demanding self-related thoughts. Even though we did not observe an explicit "self-advantage", there is a positive tendency from a self-disadvantage for small stimuli in Study 1 towards no more self-disadvantage for life-sized stimuli in Study 2. Future studies could investigate if further enhancing embodiment effects by increasing stimulus naturalism and more closely mimicking a mirror-like stimulus presentation might strengthen this trend and show an actual self-advantage.

However, it still remains unclear why the self-disadvantage solely emerged in object-based transformations. At least there is evidence from neuroscientific research that egocentric and allocentric mental transformations using whole-body photos of self and other lead to different activation in the temporoparietal junction (Ganesh, van Schie, Cross, de Lange, & Wigbolduns, 2015). One speculative conclusion on the behavioural level is that object-based transformations may require attentional demands to a greater extent due to the presentation of two stimuli compared to one stimulus in egocentric transformations (Zacks, Mires, et al., 2002). Furthermore, both egocentric and object-based tasks likely trigger self-related thoughts. Thus, the activation of self-related thoughts might compensate for the predicted embodiment benefits in egocentric transformations (cf. Ferri et al., 2011). This could explain why we did not find a self-advantage in egocentric transformations. That is, self-awareness processes lead to a self-disadvantage in object-based transformations due to the high resource-allocation of this transformation type and compensate for the embodiment benefits in egocentric transformations resulting in an absence of the predicted self-advantage.

In addition to an implicit advantage of self-stimuli in object-based transformations, results showed an explicit advantage of self-related stimuli for egocentric transformations, expressed by the "stimulus type * view * study"-interaction. Whereas in Study 1, there was no difference between self- and other-related stimuli in both front and back view, participants in Study 2 were faster in egocentric transformation tasks view when viewing pictures of themselves as compared to others, but only for back views, not frontal views. However, even if this advantage is restricted to the back view, it is noteworthy that this is the first explicit self-advantage. Two conclusions can be derived from this result: (1) Compared to object-based transformations of Study 2, where an implicit self-advantage was found, the influence of the self is more pronounced for egocentric transformations, where an explicit self-advantage emerged (cf. Ferri et al., 2011). (2) Compared to egocentric transformations of Study 1, where an implicit advantage of the self-emerged (i.e. self-disadvantage in object-based transformations disappears in egocentric ones, cf. Kaltner et al., 2014), in Study 2 an explicit self-advantage occurred.

In summary, the results of the present study suggest that the presentation of life-sized stimuli in Study 2 has enhanced embodiment effects compared to the use of small stimuli in Study 1. These embodiment effects in turn seem to compensate self-awareness processes. Regarding the role of motor expertise, there was a "rotational improvement" of motor experts compared to non-motor experts, which was more pronounced for Study 2 compared to Study 1. Results regarding the influence of self-related stimuli on the one hand showed a compensation of the self-disadvantage in object-based rotations and on the other hand an explicit "self-advantage" in egocentric transformations. Interestingly, especially object-based rotations seemed to benefit from this manipulation. Therefore, we concluded that enhanced embodiment effects could result in a transformation from abstract stimuli into body-related ones. Thus, simulative motor processes seem to be involved also in object-based transformations (cf. Moreau et al., 2012). When pursuing this thought, maybe using the term "object-based transformations" is inappropriate in the present study and should be replaced by "object-rotations" since the reference-frame is not necessarily another object but rather the own body.

Limitations and conclusions

We assessed motor experts to investigate embodiment effects. We predicted that this sample engages motor resources to a higher extent compared to non-motor experts. However, investigating the involvement of motor processes in the context of embodied MR could be more convincing. For example, an interference paradigm as conducted by Kessler and Thomson (2010) could be an interesting design when using stimuli in life size compared to small artificial stimuli.

Even if our results show that motor expertise has an influence on the MR performance, it still remains unclear, to which extent motor expertise and stimulus type interact and influence spatial transformations. A further study might be useful comparing rotational motor experts such as wrestlers or wheel gymnastics, general motor experts, and non-athletes using life-sized figures as stimulus material.

Since the present study emphasises the meaning of the stimulus material, the factor stimulus size should have been implemented as a within instead of a between-subject factor in order to avoid possible group differences confounding the findings. For a more detailed understanding of the meaning of the stimulus size, future work should investigate the influence of life-sized vs. small stimuli in a single experiment within the same group of participants. Another approach to get a deeper insight into the influence of the stimulus material should be conducted by trying to enhance embodiment effects through further stimulus material manipulation. Based on previous literature demonstrating that visuo-motor representation of one's own body is crucial for the self-advantage (Ferri et al., 2011), the presentation of moving stimulus material might be a more promising avenue for further research. We solely used static stimulus material. The presentation of moving stimulus material might be a more appropriate way to affect the senso-motor representation of the self. Since movement is a distinct signal for self-recognition (Jeannerod, 2003), this notion should be implemented in future work.

The recognition task used here to assess self-awareness processes was helpful, but it was conducted after the MR task, because this was our main issue. For an enhanced validity, the order of the presentation of both tasks should be counterbalanced.

Furthermore, differences between the experimental setup in Study 1 and 1 should be investigated in future work for a more detailed understanding whether the two positions (sitting vs. standing) induce embodiment effects differentially.

In summary, the present study was conducted to enhance the ecological validity by presenting stimuli in life size. Results underline the meaning of the stimulus size in this context. A replication of these findings would support the notion that participants tend to solve mental operations in a laboratory design more cognitive-based, whereas in real life they tend to think more "embodied". Therefore, the use of small, artificial stimuli should be considered more critically in future research.

Disclosure statement

No potential conflict of interest was reported by the authors.

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