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### Let's twist again! Embodiment effects in spatial judgments on human figures rotated along a vertical axis

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Let's twist again! Embodiment effects in spatial judgments on human figures rotated along a  
vertical axis

Mirjam Ebersbach

Universität Kassel, Kassel, Germany

Markus Krüger

Ernst-Moritz-Arndt-Universität Greifswald, Greifswald, Germany

#### Author note

Mirjam Ebersbach, Institut für Psychologie, Universität Kassel, Germany.

Markus Krüger, Institut für Psychologie, Ernst-Moritz-Arndt-Universität Greifswald,  
Germany.

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Correspondence should be sent to Mirjam Ebersbach, Universität Kassel, Institut für  
Psychologie, Holländische Str. 36-38, D-34127 Kassel, Germany. Phone: +49-561-8042036,  
fax: +49-561-8043586, e-mail: [mirjam.ebersbach@uni-kassel.de](mailto:mirjam.ebersbach@uni-kassel.de).

## SPATIAL JUDGMENTS ON HUMAN FIGURES

**Abstract**

We investigated whether individuals used mental rotation and embodiment for laterality judgments of human figures. The figures lifted their right or left arm and were stepwise rotated between  $0^\circ$  (i.e., back view) and  $180^\circ$  (i.e., front view) along a vertical axis. In Experiment 1, figures' heads were always shown in profile. Judgments were faster and more correct when figures were presented in back view compared to front view, but the relation between reaction times and rotation angles was not strictly a linear function. Judgments on figures in anatomically possible postures were better than on figures in impossible postures. In Experiment 2, figures' heads were turned together with their body. With some exceptions, reaction times and rotation angles were linearly related. These results suggest that individuals use both, mental rotation and a more direct matching between their own body and that of the figures, when making laterality judgments of human figures.

Keywords: mental rotation; spatial transformation; embodiment; embodied cognition; imagery; spatial imagery

## SPATIAL JUDGMENTS ON HUMAN FIGURES

**Let's twist again! Embodiment effects in spatial judgments on human figures rotated along a vertical axis**

Spatial judgment tasks can be solved by mental rotation, that is, participants rotate visual stimuli – in line with rotations in the real world – in their imagination in order to come to a decision. Mental rotation is reflected in linearly increasing reaction times for larger rotation angles (Shepard & Metzler, 1971). Two classes of tasks are used to examine mental rotation. In same-different judgments, two simultaneously presented stimuli are rotated against each other. The observer has to decide whether the stimuli are identical or not. It is assumed that the orientation of one of the stimuli is mentally transformed until it matches with the other one and allows for a comparison. This is also called object-based transformation. Another class of tasks involve left-right judgments, in which one stimulus is rotated and the observer has to decide whether a certain feature is located on the left or the right side from the stimulus' point of view (e.g., a lifted arm of a figure). In these laterality judgments, which are also called spatial perspective transformations, the observer mentally changes his or her own perspective to match it with the stimulus (Zacks & Tversky, 2005). This strategy is stimulated by presenting human figures as stimuli which allow a direct match of the mental representation of the observer's own body with that of the figure and to mentally reenact the position of its arm, for instance (cf. Huttenlocher & Presson, 1973; Kaltner, Riecke, & Jansen, 2014; Krüger, Amorim, & Ebersbach, 2014). Accordingly, Kessler and Thomson (2010) proposed that spatial perspective-taking can be conceived as an embodied cognitive process, which involves the emulation of body movements.

Several studies used human stimuli in spatial transformation tasks. Sayeki (1981) reported that participants were better in making same-different judgment on cube combinations with a human head on it compared to pure cube combinations. This can be taken as an indicator of facilitated embodiment processes by human stimuli (cf. Amorim, Isableu, & Jarraya, 2006). Parsons (1987) presented drawings of human figures in front and

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back view, rotated in picture plane, in laterality judgment tasks. Participants were slower and made more errors if the figures were presented in front view than in back view. These and other results (e.g., Ebersbach & Krüger, 2016; Jola & Mast, 2005; Kaltner et al., 2014; May & Wendt, 2012; Mohr, Blanke, & Brugger, 2006; Steggemann, Engbert, & Weigelt, 2011; Zacks, Mires, Tversky, & Hazeltine, 2002) suggest that judging human figures presented in front view might be aggravated because of mismatching laterality: If a figure faces the observer, its left arm – and therewith the laterality to be judged – is located on the right side from the observer's point of view and vice versa. Thus, figures presented frontally require an additional transformation: They have to be mentally turned first by 180° on a vertical axis so that their orientation matches with that of the observer. Only thereafter, mental rotation on a horizontal axis and alignment can take place (e.g., Kaltner et al. 2014). However, it is also possible that participants mentally rotate figures in front view simultaneously by multiple axes or use strategies different from mental rotation. For instance, Jola and Mast (2005) reported that there was no systematic relationship between reaction times and rotation angles for figures presented frontally and rotated along a horizontal axis. They assumed that participants may have perceived a frontal figure turned by 180° in picture plane as a figure lying on its back, whose position can be emulated by “slipping” with the feet first “into the figure”. Alternatively, participants may simply flip such a figure into an upright position rather than mentally rotate it (Murray, 1997). Figures presented in back view, in contrast, allow for a direct match, which facilitates left-right judgments (e.g., Gronholm, Flynn, Edmonds, & Gardner, 2012; Zacks & Tversky, 2005). One aim of the present study is to investigate whether human figures that are turned on a vertical axis in space are in fact mentally rotated or not.

Further evidence for embodiment effects comes from studies that used human figures in postures that could not be emulated, that is, in anatomically impossible postures. Using a same-different task, Amorim et al. (2006, Exp. 6) showed that reaction times and error rates

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were larger for figures in anatomically possible than in impossible postures (cf. Krüger et al., 2014). However, it remains an open question whether this effect emerges also in left-right judgments which are supposed to be based on different mechanisms than same-different judgments (Zacks & Tversky, 2005).

The present study examined mental rotation and embodiment effects in a spatial perspective-taking task, in which participants had to judge whether human figures that were rotated on a vertical axis raised their left or right arm. The head orientation of the figures was held constant in Experiment 1, showing the face always in profile, to ensure that figures presented in different rotations were comparable with regard to their face information. In Experiment 2, the figures' heads were turned along with their bodies in depth. In line with previous studies (e.g., Ebersbach & Krüger, 2016), we expected (1) an advantage concerning reaction times and error rates if human figures were presented in back view (i.e., 0° rotation) compared to front view (i.e., 180° rotation). (2) A linear relation between reaction times and rotation angles was expected if participants used a mental rotation strategy (Shepard & Metzler, 1971). (3) Furthermore, we explored the effect of embodiment by presenting human body stimuli in anatomically possible and impossible postures. The latter should yield larger reaction times and error rates as they hinder embodiment in left-right judgments, too (e.g., Amorim et al., 2006). (4) Finally, we tested whether men performed better than women (Voyer, Voyer, & Bryden, 1995), and whether participants were better in judging human body stimuli of their own sex compared to the opposite sex (Alexander & Evardone, 2008), which could be taken as sex-specific embodiment effect.

### Method

#### Participants

Thirty-two university students from other fields than psychology were recruited for this study. Half of the participants were females ( $n = 16$ , mean age: 24 years,  $SD = 3$ ) and half were males ( $n = 16$ , mean age: 25 years,  $SD = 3$ ). All participants were tested by the same female

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experimenter in a separate cubicle at the local university. Participation was voluntary and no compensation was offered.

**Materials**

Stimulus material consisted of the pictures of a male and female figure (Fig. 1). Both were photographed with either their left or right forearm held in a flexed position, while the respective other arm was suspended. The figures' bodies were rotated about a vertical axis in 45° steps, starting with 0° (i.e., back view). The alignment of the head was kept stable across rotations, always facing either the right or the left side in profile view. This resulted in 64 different trials: 8 angles (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) x 2 arm lateralities (left/right arm flexed) x 2 face alignments (face left/right) x 2 sexes (male/female figure). Of these trials, 40 depicted – for real humans - anatomically possible postures (Fig. 1, left side) and 24 impossible ones (Fig. 1, right side).

Stimuli were presented by means of E-prime software on a standard Acer Aspire E 17 laptop (17", HD 1920x1080), with the "a" key marked by a green sticker on and the "l" key marked by a yellow sticker.

**Procedure**

Participants were seated in a distance of about 60 cm in front of the laptop screen and were told that they would see pictures of figures. They were instructed to press the green key with their left hand, if the figure flexes its left arm and the yellow key with their right hand, if it flexes its right arm.

Participants were presented with four blocks. Each block contained all 64 trials in a random order. Each trial was preceded by a fixation cross for 1000 ms and each trial ended immediately after either the green or yellow key was pressed. Feedback was given for correct answers by presenting a smiley and a pleasant tone and for incorrect answers by a frowny and a slightly unpleasant tone. After each block participants were allowed a short break.

**Data preparation**

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Only reaction times of correct trials were analysed (Amorim et al., 2006). Trials with RTs smaller than 300 ms or larger than three standard deviations above the mean were excluded (i.e., 1.5% of the correct trials). Error rate refers to the proportion of incorrect responses.

Significance level was set at 5%.

## Results

### Error rates (ERs)

Mean error rates of the anatomically possible and impossible postures in relation to rotation angle are shown in Figure 2. First we analysed whether ERs were affected by the participants' and figures' sex, the arm of the figure that was flexed (i.e., left or right), and the alignment of the face of the figures (i.e., left or right). These analyses were conducted separately for anatomically possible and impossible postures as both conditions involved a different number of rotation angles.

For possible postures, only participants' sex had a significant but small effect on ERs, with slightly less errors among women ( $M = .01$ ,  $SD = 0.04$ ) compared to men ( $M = .03$ ,  $SD = 0.04$ ),  $F(1, 30) = 4.32$ ,  $p = .046$ ,  $\eta_p^2 = .13$ .

For impossible postures, there was a disordinal interaction between arm laterality and face alignment,  $F(1, 30) = 16.75$ ,  $p < .001$ ,  $\eta_p^2 = .36$ . Post-hoc tests (Bonferroni) showed that ERs were smaller if the figure's face was oriented to the same side as the flexed arm,  $t(31) = 2.72$  and  $t(31) = -2.69$ , for left and right face alignment, respectively,  $ps < .05$  (which meant the flexed arm was in front of the body for most trials and thus better visible for participants). In addition, there was a marginally significant interaction of the sex of the figures and of the participants,  $F(1, 30) = 3.93$ ,  $p = .057$ ,  $\eta_p^2 = .12$ , suggesting that women made slightly less errors if they were presented with anatomically impossible figures that were male ( $M = .01$ ,  $SD = 0.01$ ) compared to female ( $M = .02$ ,  $SD = 0.01$ ),  $t(15) = 2.18$ ,  $p = .046$  (uncorrected), whereas no such effect was revealed for men,  $p = .29$ . No other effects on the ERs for impossible figures were significant.



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Next, it was examined whether ERs increased with larger rotation angles. Therefore, data were accumulated across arm laterality, face alignment, and sex of the figure. In addition, trials referring to complementary rotation angles were collapsed (e.g., 45° and 315°), as participants were expected to use the shortest way to rotate the figure in the intended position (cf. Sayeki, 1981).

For possible postures, the rotation angle yielded a significant effect,  $F(2.68, 83.05^1) = 8.66, p < .001, \eta_p^2 = .22$ , which could be described best by a linear trend,  $F(1, 31) = 15.86, p < .001, \eta_p^2 = .34$ , while a quadratic trend was significant, too, but with a smaller effect size,  $F(1, 31) = 8.02, p = .008, \eta_p^2 = .21$ . In line with findings of mental rotation studies that used abstract stimuli (e.g., Shepard & Metzler, 1971), ERs increased with larger rotation angles – that is, the more the figures' positions deviated from back view. A linear regression analysis confirmed this trend,  $F(1, 159) = 15.59, p < .001$ , yielding a slope of  $\beta = 0.30$ .

For impossible postures, ERs increased with larger rotation angles, too,  $F(1.49, 46.13) = 5.92, p = .010, \eta_p^2 = .16$ , obeying a linear trend,  $F(1, 31) = 6.96, p = .013, \eta_p^2 = .18$ , which was confirmed by a linear regression analysis,  $F(1, 95) = 9.13, p = .003$ , yielding the same slope of  $\beta = 0.30$  as for possible postures.

Finally, the effect of anatomical reproducibility of the postures was analysed by comparing ERs for possible and impossible postures in relation to rotation angle. As impossible postures included only three angles (i.e., 45°, 90°, 135°), only those angles were chosen from the data of possible postures. There was only an effect of rotation angle,  $F(1.70, 52.69) = 5.23, p = .012, \eta_p^2 = .14$ , while ERs did not differ between possible and impossible postures.

### Reaction times (RTs)

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<sup>1</sup> Greenhouse-Geisser is reported if sphericity could not be assumed.

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Mean RTs for the anatomically possible and impossible postures in relation to rotation angle are shown in Figure 3. As for ERs, RTs were first analysed separately for possible and impossible postures to test for effects of participants' and figures' sex, the flexed arm, and face alignment of the figures.

For possible postures, the female figure yielded longer RTs than the male figure ( $M_{\text{fem}} = 836$  ms,  $SD_{\text{fem}} = 179$  vs.  $M_{\text{male}} = 807$  ms,  $SD_{\text{male}} = 175$ ),  $F(1, 30) = 9.71$ ,  $p = .004$ ,  $\eta_p^2 = .25$ . In addition, RTs were longer if the figures flexed their left than their right arm ( $M_{\text{left}} = 856$  ms,  $SD_{\text{left}} = 115$  vs.  $M_{\text{right}} = 787$  ms,  $SD_{\text{right}} = 162$ ),  $F(1, 30) = 24.16$ ,  $p < .001$ ,  $\eta_p^2 = .45$ , and if they looked to the left than to the right ( $M_{\text{left}} = 834$  ms,  $SD_{\text{left}} = 183$  vs.  $M_{\text{right}} = 809$  ms,  $SD_{\text{right}} = 168$ ),  $F(1, 30) = 10.54$ ,  $p = .003$ ,  $\eta_p^2 = .26$ .

For impossible postures, there were effects of arm laterality,  $F(1, 30) = 7.81$ ,  $p = .009$ ,  $\eta_p^2 = .21$ , and face alignment,  $F(1, 30) = 4.92$ ,  $p = .034$ ,  $\eta_p^2 = .14$ , too, as well as an interaction of the two variables,  $F(1, 30) = 11.31$ ,  $p = .002$ ,  $\eta_p^2 = .27$ . In addition, sex of the figure and face alignment interacted,  $F(1, 30) = 8.67$ ,  $p = .006$ ,  $\eta_p^2 = .22$ . Post-hoc tests (Bonferroni) revealed that RTs were in particular longer if figures flexed their left than their right arm when they were looking to the right,  $t(31) = 3.48$ ,  $p < .05$ , while no such difference occurred when they were looking to the left. This could be assigned to the partial occlusion of the arm if the figures looked to the right (cf. ERs). In addition, RTs were longer, if the female figure was looking to the right than to the left,  $t(31) = 3.55$ ,  $p < .05$ , while no such effect emerged for the male figure.

Next, the effect of rotation angle on RTs was analysed separately for possible and impossible postures. For possible postures, rotation angle yielded a significant effect,  $F(1.41, 43.54) = 54.22$ ,  $p < .001$ ,  $\eta_p^2 = .68$ , which could be described best by a quadratic trend,  $F(1, 31) = 66.55$ ,  $p < .001$ ,  $\eta_p^2 = .68$ , and somewhat poorer by a linear trend,  $F(1, 31) = 56.33$ ,  $p < .001$ ,  $\eta_p^2 = .65$ . A linear regression analysis confirmed this linear trend,  $F(1, 159) = 39.58$ ,  $p < .001$ , revealing a slope of  $\beta = 0.45$ . Repeated contrasts, comparing RTs for subsequent

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rotation angles, however, indicated a significant decrease of RTs between figures shown in  $0^\circ$  and  $45^\circ$  rotations,  $p < .001$ , a marginally significant increase of RTs between  $45^\circ$  and  $90^\circ$ ,  $p = .056$ , and significant increases for the two larger angles,  $ps < .001$ .

For impossible postures, RTs increased with larger rotation angles, too,  $F(2, 62) = 33.47$ ,  $p < .001$ ,  $\eta_p^2 = .52$ , obeying a significant linear trend,  $F(1, 31) = 51.96$ ,  $p < .001$ ,  $\eta_p^2 = .63$ . A linear regression analysis confirmed this trend,  $F(1, 95) = 8.73$ ,  $p = .004$ , revealing a slope of  $\beta = 0.29$ , which was smaller than the slope for possible postures. Repeated contrasts revealed significantly larger RTs for impossible figures that were rotated by  $135^\circ$  compared to  $90^\circ$ ,  $p = .005$ , which were in turn larger than for figures rotated by  $45^\circ$ ,  $p < .001$ .

Finally, the effect of anatomical reproducibility of the postures on RTs was analysed in relation to the rotation angles. Reproducibility yielded a significant main effect with longer RTs for impossible postures ( $806$  ms,  $SD = 174$  ms) than for possible postures ( $M = 753$  ms,  $SD = 148$  ms),  $F(1, 31) = 33.25$ ,  $p < .001$ ,  $\eta_p^2 = .52$ . In addition, there was a main effect of rotation angle,  $F(1.50, 46.56) = 39.93$ ,  $p < .001$ ,  $\eta_p^2 = .56$ , and an interaction of the two variables,  $F(1.94, 60.01) = 16.16$ ,  $p < .001$ ,  $\eta_p^2 = .34$ . Post-hoc tests (Bonferroni) revealed that RTs were significantly longer for impossible compared to possible postures for the rotation angles  $45^\circ$ ,  $t(31) = 3.92$  and  $90^\circ$ ,  $t(31) = 6.79$ ,  $ps < .01$ , while they did not significantly differ for a rotation angle of  $135^\circ$ .

### Discussion

In Experiment 1, the performance of individuals making left-right judgments on anatomically possible and impossible human figures that were rotated on a vertical axis was examined. The advantage of figures presented in back view in terms of smaller ERs and RTs compared to figures presented in front view was replicated (e.g., Ebersbach & Krüger, 2016). In addition, RTs were smaller for figures with anatomically possible than with impossible postures. These results underline the important role of embodiment in spatial transformation tasks that involve human stimuli: Participants try to align the mental representation of their own body onto the

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human figure to come to left-right judgments. However, this projection is aggravated when figures are presented from the front as this requires an additional step (i.e., turning the image of one's own body or of the figure by  $180^\circ$  to come to an alignment in which one's own left arm is on the same position as the figure's left arm; Kaltner et al., 2014). The projection is also aggravated or even made impossible if the figures are presented with anatomical postures that cannot be emulated (Amorim et al., 2006; Krüger et al., 2014), yielding a poorer performance in both cases. No embodiment effects emerged concerning the correspondence of the figures' and participants' sex – on the contrary: Women tended to make somewhat less errors if they were presented with male than with female figures. However, overall men and women performed similarly well and almost accurately, except for a slight disadvantage of men if they were presented with anatomically possible figures.

Another central question of this experiment was whether participants used mental rotation at all to make laterality judgments on human figures that were rotated on a vertical axis. ERs increased linearly with larger rotation angles, that is, the farther figures were rotated from back view. The relationship between rotation angles and RTs for anatomically possible and impossible figures RTs could appropriately be described by a linear model. Nevertheless, RTs for possible figures were better fitted by a quadratic model, describing decreasing RTs between  $0^\circ$  and  $45^\circ$ , followed by rather constant RTs between rotations of  $45^\circ$  and  $90^\circ$  and increasing RTs between  $90^\circ$  and  $180^\circ$ . This unexpected first decrease might be explained by the fact that the alignment of the figures' faces was held constant, being oriented either  $90^\circ$  to the left or right side. With a rotation of  $0^\circ$ , figures were presented with their back to the observer while their heads were turned by  $90^\circ$  to one side. This posture might appear anatomically inconvenient to be emulated by the participants. Thus, embodiment might have been impeded, yielding longer RTs for figures presented in a  $0^\circ$  rotation compared to  $45^\circ$ . In addition, in this rotation condition the figure's head and body were strongly twisted against each other, with the body facing forward and the head facing to the left (or right). This twisted

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posture deviated maximally from the participant's posture, who was facing forward with both the body and the head. It has been shown that the compatibility between the posture of participants and the stimulus material in mental rotation tasks affects performance (e.g., Ionta, Fourkas, Fiorio, & Aglioti, 2007). Thus, trying to align one's own body with the figure would be most effortful in this condition due to the twist of the head and body, which might explain longer RTs, too. The same effect would emerge for figures in the 180° condition, but RTs here were long anyway, due to the large rotation angle. To test these explanations for the unexpected non-linear relation between rotation angle and RTs, Experiment 2 was conducted with anatomically possible figures only, whose faces were rotated in line with the orientation of the figures and whose head-to-body orientations were the same as those of the participants.

A last remark refers to lacking interactions of the figures' and participants' sex. From an embodied perspective, judging figures of the same sex as the observer might facilitate performance. However, this effect was not found in this experiment, which might be due to the stimulus material. The dolls that served as stimuli have no realistic proportions and might appear quite artificial, which might have hindered the projection of one's own body onto the stimuli. Alternatively, it is also possible that figures' sex is no relevant factor for embodiment, and that body postures are much more important. Testing both hypotheses against each other remains an aim of future studies.

### Experiment 2

The main difference between Experiment 1 and 2 was the alignment of the figures' faces. Furthermore, a few minor changes were implemented in Experiment 2: In order to test whether participants in fact used the shortest rotation path between their own body representation and the rotated figure (Sayeki, 1981), stimuli were rotated about an additional 5° if presented in front view. Thus, figures presented in front view were rotated by 175°, 180°, and 185°, whereas figures in back view were presented with a rotation of 5° and 355° instead of 0°. Furthermore, the figures in Experiment 1 had their arms flexed, because a raised

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arm would have concealed their faces. This was of no concern in Experiment 2 as face information was not held constant, so the figures' complete arms were lifted for better visibility.

### Method

#### Participants

Thirty-two university students were recruited for this study, who had not taken part in Experiment 1. Half of the participants were females ( $n = 16$ , mean age: 22 years,  $SD = 7$ ) and half were males ( $n = 16$ , mean age: 23 years,  $SD = 5$ ). Three females were left handed. All participants were tested by the same male experimenter in a separate cubicle at the local university. Participants received course credit.

#### Materials

Stimulus material consisted of pictures of the same male and female figure as in Experiment 1. However, in contrast to Experiment 1, their left or right arm was lifted with a slight backwards tilt to enhance visibility in  $90^\circ$  and  $270^\circ$  rotations. Furthermore, to test our hypothesis, the heads were always oriented straight forward (centred on the figures' bodies, Fig. 4). The figures' bodies were rotated about a vertical axis in 11 steps. This resulted in 44 different trials: 11 angles ( $5^\circ$ ,  $45^\circ$ ,  $90^\circ$ ,  $135^\circ$ ,  $175^\circ$ ,  $180^\circ$ ,  $185^\circ$ ,  $225^\circ$ ,  $270^\circ$ ,  $315^\circ$ , and  $355^\circ$ ) x 2 postures (left/right arm lifted) x 2 sexes (male/female figure). No impossible postures were included in Experiment 2. Stimuli were presented by means of E-prime software on a standard DELL laptop (17", HD 1920x1080), with a green sticker on the "a" key and a yellow sticker on the "l" key.

#### Procedure

The procedure was the same as in Experiment 1, but each of the 4 blocks contained 44 trials (more angles, but the face was always directed straight ahead), resulting in a total of 176 trials.

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**Results**

Data were prepared as in Experiment 1. As a result of the outlier analysis, 4.2% of the RTs were missing.

**Error rates (ERs)**

It was tested first whether ERs differed for figures presented frontally by 175°, 180°, and 185°. An ANOVA with repeated measures on ERs revealed no significant effect of rotation angle,  $p = .53$ . Therefore, the rotation angle of 180° representing front view was used for further analyses.

We examined in a preliminary ANOVA whether ERs were affected by the participants' and figures' sex, and the arm of the figure that was lifted (i.e., left or right). There were neither significant main effects nor interactions. Accordingly, ERs were accumulated across these variables and the effect of rotation angle was analysed. The ANOVA yielded only a marginally significant effect of rotation angle,  $F(2.05, 63.66) = 2.75$ ,  $p = .070$ ,  $\eta_p^2 = .08$ , suggesting a tendency of increasing ERs with larger angles. However, ERs were in general very small,  $M = 0.03$ ,  $SD = .16$ , and repeated contrasts yielded no significant differences concerning ERs between subsequent angles.

**Reaction times (RTs)**

As for ERs, it was analysed first whether RTs differed for figures presented frontally by 175°, 180°, and 185°. Again, an ANOVA with repeated measures on ERs revealed no significant effect of rotation angle,  $p = .64$ . Therefore, the rotation angle of 180° representing front view was used for further analyses.

Next, a preliminary ANOVA on RTs was computed, with sex of the figures and of the participants and arm lifted as independent variables. It yielded a main effect of the figures' sex,  $F(1, 30) = 11.78$ ,  $p = .002$ ,  $\eta_p^2 = .28$ , with longer RTs for the female figure,  $M = 763$  ms,  $SD = 128$  ms, than for the male figure,  $M = 730$  ms,  $SD = 108$  ms. In addition, there was a main effect of arm,  $F(1, 30) = 8.30$ ,  $p = .007$ ,  $\eta_p^2 = .22$ , with longer RTs for the left arm,  $M =$

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763 ms,  $SD = 120$  ms, than for the right arm,  $M = 731$  ms,  $SD = 120$  ms. No other effects or interactions were significant.

To account for these main effects, the effect of rotation angle was analysed separately for the male and female figure, lifting its left or right arm. Rotation angle had a significant effect in all four cases: male figure, left arm:  $F(2.52, 78.01) = 22.13$ ,  $\eta_p^2 = .42$ ; male figure, right arm:  $F(2.73, 84.61) = 23.76$ ,  $\eta_p^2 = .43$ ; female figure, left arm:  $F(2.33, 72.12) = 19.02$ ,  $\eta_p^2 = .38$ ; female figure, right arm:  $F(2.46, 76.19) = 33.26$ ,  $\eta_p^2 = .52$ ; all  $ps < .01$  (Bonferroni). Repeated contrasts, comparing RTs for subsequent rotation angles are shown in Table 1, line A (Appendix). They confirm a general increase of RTs for larger angles with some exceptions: First, RTs for  $5^\circ$  and  $45^\circ$  rotations were similar in some cases. Second, there was no significant increase between  $135^\circ$  and  $180^\circ$  - instead even a significant decrease for the female figure that lifted its right arm.

Nevertheless, a linear trend yielded significant and larger fits in all cases – as indicated by larger partial eta squares – than a quadratic, cubic, or fourth order trend: male figure, left arm:  $F(1, 31) = 49.67$ ,  $\eta_p^2 = .62$ ; male figure, right arm:  $F(1, 31) = 51.10$ ,  $\eta_p^2 = .62$ ; female figure, left arm:  $F(1, 31) = 35.93$ ,  $\eta_p^2 = .54$ ; female figure, right arm:  $F(1, 31) = 61.19$ ,  $\eta_p^2 = .66$ ; all  $ps < .01$  (Bonferroni).

To ensure that RTs and rotation angles were linearly related, given that not all rotation angles in Experiment 2 were equidistant to each other (i.e.,  $5^\circ$  instead of  $0^\circ$ ), linear regression analyses were additionally conducted. They yielded a significant model fit in each condition (all  $ps < .01$ , Bonferroni): male figure, left arm:  $F(1, 158) = 38.03$ ,  $R^2 = .19$ ,  $\beta = .44$ ; male figure, right arm:  $F(1, 158) = 27.68$ ,  $R^2 = .15$ ,  $\beta = .39$ ; female figure, left arm:  $F(1, 158) = 32.97$ ,  $R^2 = .17$ ,  $\beta = .42$ ; female figure, right arm:  $F(1, 158) = 28.05$ ,  $R^2 = .15$ ,  $\beta = .39$ .

The finding that RTs for figures rotated by  $135^\circ$  and  $180^\circ$  hardly differed, or even decreased between  $135^\circ$  and  $180^\circ$  (see Fig. 5) might be due to the fact that the visibility of the lifted arm was reduced as it was partly covered by the head if figures were presented at  $135^\circ$



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and lifted their right arm and if figures were presented at 225° and lifted their left arm (cf. Exp. 1 for similar effects of visibility). As data were merged across both rotation angles, this effect might have aggravated participants' performance in 135° rotations in contrast to the 180° rotations, where the arm was fully visible. To test this explanation, new variables for RTs in 135° rotations were computed, including in the left arm condition only figures rotated by 135° (but not 225°) and in the right arm condition only figures rotated by 225° (but not 135°). ANOVAs for each condition (figures' sex and arm) yielded similar patterns as the initial analyses, but repeated contrasts comparing RTs of figures rotated by 135° and 180° changed (see Table 1, line B, Appendix): The increase of RTs between both angles became marginally significant for the male figure lifting its right arm and for the female figure lifting its left arm and the unexpected decrease of RTs for the female figure lifting its right arm was levelled, at least indicating no longer a significant difference.

### Discussion

Aim of Experiment 2 was to check whether the non-linear relation between rotation angle and RTs for anatomically possible figures in Experiment 1 could be explained by the fact that the figures' face orientation was held constant throughout the rotations. In Experiment 2, the figures' face was rotated together with the figures' body so that the face was no longer visible when the figure was presented with its back to the observer. This yielded in fact in a linear relation between rotation angle and RTs, suggesting that figures were mentally rotated. Nevertheless, RTs of figures presented from the back (i.e., 5°) and slightly rotated (i.e., 45° or 315°) were quite similar, as were RTs of figures presented from the front (i.e., 180°) and those that were slightly rotated (i.e., 135° or 225°). The first finding could be explained by the fact that laterality judgments on figures presented from the back or slightly rotated but still from the back could be solved without mental rotation. For instance, the left lifted arm is still unambiguously on the left side from the observer's point of view for figures presented by 5° and 45°. The second finding of a lacking increase of RTs between 135° and 180° could partly

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be explained by a reduced visibility of the lifted arm in half of the trials included in the 135° condition, as confirmed by additional analyses. ERs were in general small and hardly affected by the rotation angle.

### General discussion

The present study examined the role of embodiment and mental rotation in spatial perspective taking tasks that involved human figures rotated in depth as stimuli. Participants' reaction times (RTs) and error rates (ERs) when judging the laterality of human figures were affected by rotation angles: The more the figures were turned away from frontal view and the more they turned towards back view, the less errors participants made and the faster their judgments were. This replicates the effect that spatial judgments for human figures are better when presented in back view compared to front view (e.g., Ebersbach & Krüger, 2016). This effect can be explained by strategies that are based on embodiment and that are evoked by spatial perspective taking tasks (e.g., Kessler & Thomson, 2010): In order to judge whether the human figures raised their left or right arm, participants appear to align the mental representation of their own body with the figure, which facilitates their decisions. This alignment is easier when the figure is presented in back view, as it allows a direct match, while it is more effortful when the figure is presented in front view, as this requires an additional step, that is, first adapting the orientation of oneself or of the figure before matching one's own body with the figure (e.g. Kaltner et al., 2014).

Further evidence for the embodiment approach comes from the comparison of participants' performance with anatomically possible and impossible human figures. While ERs did not differ between both types of figures, RTs were larger for impossible than for possible figures. This effect can be explained by the fact that figures with anatomically impossible postures prevent the alignment with one's own body and therewith hinder embodiment (e.g., Krüger, et al., 2014). However, the effects of embodiment did not expand to sex: Participants' performance was not better with figures of their own sex. On the

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contrary: presented with impossible figures, women made marginally less errors when they judged the male than the female figure. A main effect of sex on ERs concerning possible figures was revealed in women who were slightly more accurate than men in these trials.

We furthermore investigated whether participants in fact mentally rotated the figures (or the image of their own body) – which should be reflected in a linear relationship between RTs and rotation angles (Shepard & Metzler, 1971) – or used other strategies. Results were not fully conclusive. Overall, there was a linear relationship between rotation angles and RTs for anatomically impossible figures in Exp. 1 and for anatomically possible figures in Exp. 2: Participants needed proportionally more time, the more the figures' orientation deviated from back view. However, RTs for anatomically possible figures in Exp. 1 were non-linearly related to rotation angles. In this condition, RTs for figures presented in full back view ( $0^\circ$ ) were larger than for figures shown laterally from the back, rotated by  $45^\circ$ . In Exp. 2, we tested whether this effect was due to the inconvenient posture of figures presented in full back view ( $0^\circ$ ), whose head was turned by  $90^\circ$  to one side. Accordingly, in Exp. 2 the figures' head was turned along with their body, which in fact levelled RTs for figures presented by  $0^\circ$  and  $45^\circ$ . Nevertheless, the increase of RTs between  $0^\circ$  and  $45^\circ$  was not significant in all stimulus conditions. More strikingly, the increase of RTs between  $135^\circ$  and  $180^\circ$  disappeared in Exp. 2. Additional analyses confirmed that the latter finding could partly be explained by a reduced visibility of the lifted arm in half of the trials.

More generally, it can be concluded that laterality judgments on human figures rotated on a vertical axis involve several processes. Often, participants use mental rotation, bringing the figures and the mental representation of their own body into alignment. Accordingly, it takes longer (and produces more errors) the stronger the figures' body orientation is turned away from that of the participants. However, if the orientation of the figures deviates only slightly from back view (i.e.,  $45^\circ$  rotation), mental rotation is not required because it is still easy to judge whether the figure lifts its left or right arm as it is visible on the left or right side

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from the observer's point of view. This might explain why RTs hardly differed for figures presented from the back at  $0^\circ$  and turned by  $45^\circ$ . A second factor that affects laterality judgments is the visibility of the target feature. In both experiments, RTs and in part also ERs were larger if the lifted arm was not fully visible but partly covered by the figure's body. In these cases, the performance did not solely depend on rotation angles but was even poorer for smaller (i.e.,  $135^\circ$ ) than for larger rotations (i.e.,  $180^\circ$ ) or at least similar. This suggests that participants do not have a full 3D mental representation of the figure in their mind, which they simply rotate. Instead, they might reconstruct the partly invisible arm or infer the lifted but partly covered arm by deciding first, which is the visible, not lifted arm. This takes time and is more error prone than just using mental rotation, and might therefore impair performance in  $135^\circ$  rotations in which arms were partly covered compared to  $180^\circ$  rotations, where arms were fully visible.

Taken together, the results of this study highlight the role of embodiment in spatial perspective taking tasks. The presentation of human body stimuli seems to automatically evoke attempts to align the image of one's own body with that of the human figures. These attempts can improve performance, as it was the case in our study concerning anatomically possible figures – but it can also result in a declined performance, as shown with anatomically impossible figures (cf. Krüger et al., 2014). Moreover, people appear to solve spatial transformation tasks quite flexibly by not only using mental rotation but also other strategies, too - which depends on task simplicity and feature visibility.

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**Figure Captions**

*Figure 1.* (A) Male figure at  $0^\circ$  (back view), right arm flexed and face aligned to the right (possible posture). (B) Female figure at  $180^\circ$  (front view), left arm flexed and face aligned to the left (possible posture). (C) Female figure at  $45^\circ$ , left arm flexed and face aligned to the left (possible posture). (D) Male figure at  $270^\circ$ , right arm flexed and face aligned to the left (impossible posture).

*Figure 2.* Mean error rates (ERs) for possible and impossible postures as a function of rotation angle. *Note.* A rotation angle of  $0^\circ$  indicates back view.

*Figure 3.* Mean reaction times (RTs) for possible and impossible postures as a function of rotation angle. *Note.* A rotation angle of  $0^\circ$  corresponds to back view.

*Figure 4.* (A) Male figure at  $180^\circ$  (front view) with left arm lifted. (B) Female figure at  $90^\circ$  with left arm lifted. Note that the face is always in an eyes front position.

*Figure 5.* Effects of rotation angle on RTs, separately for figures' sex and arm laterality.



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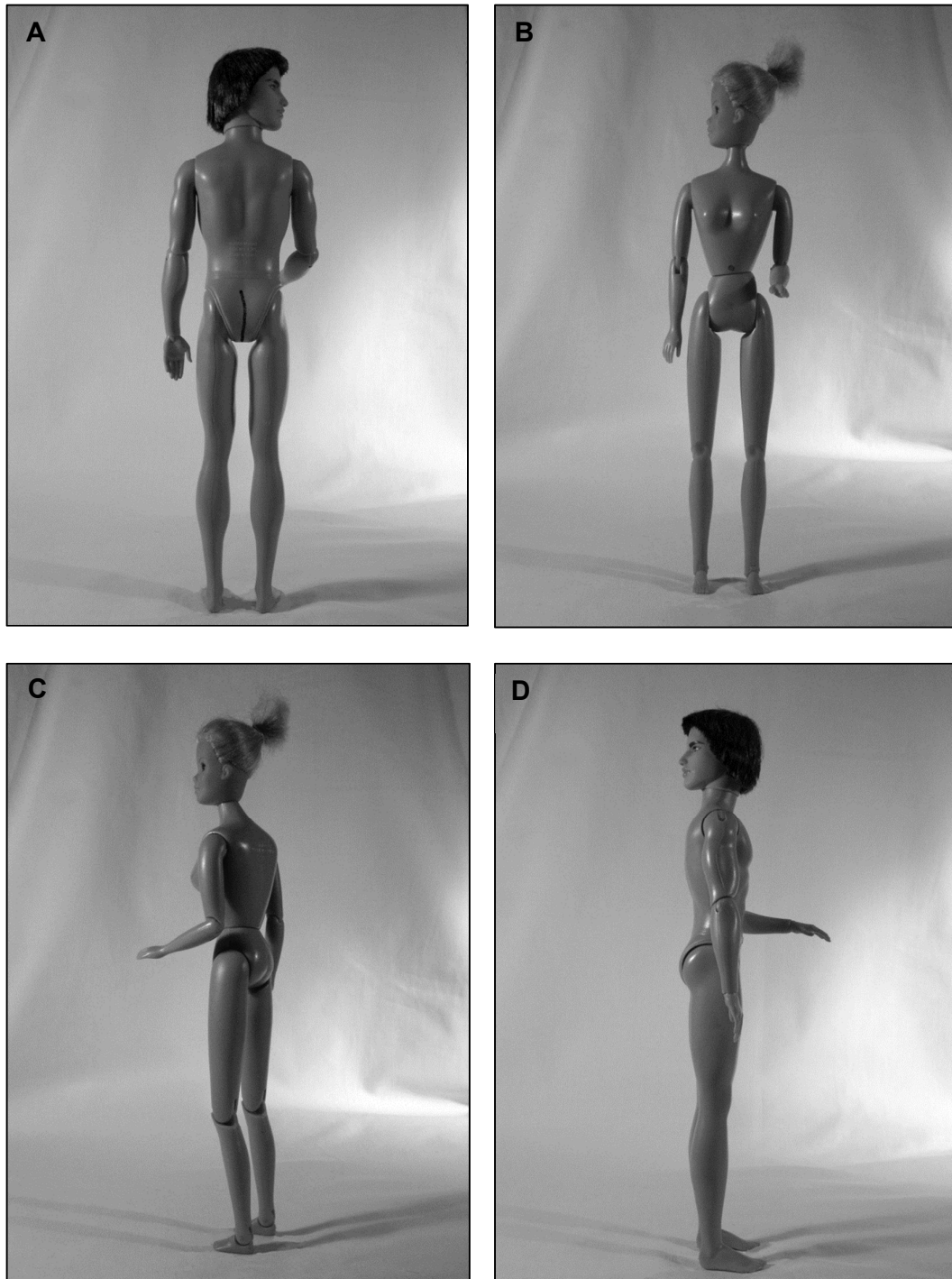


Figure 1.

SPATIAL JUDGMENTS ON HUMAN FIGURES

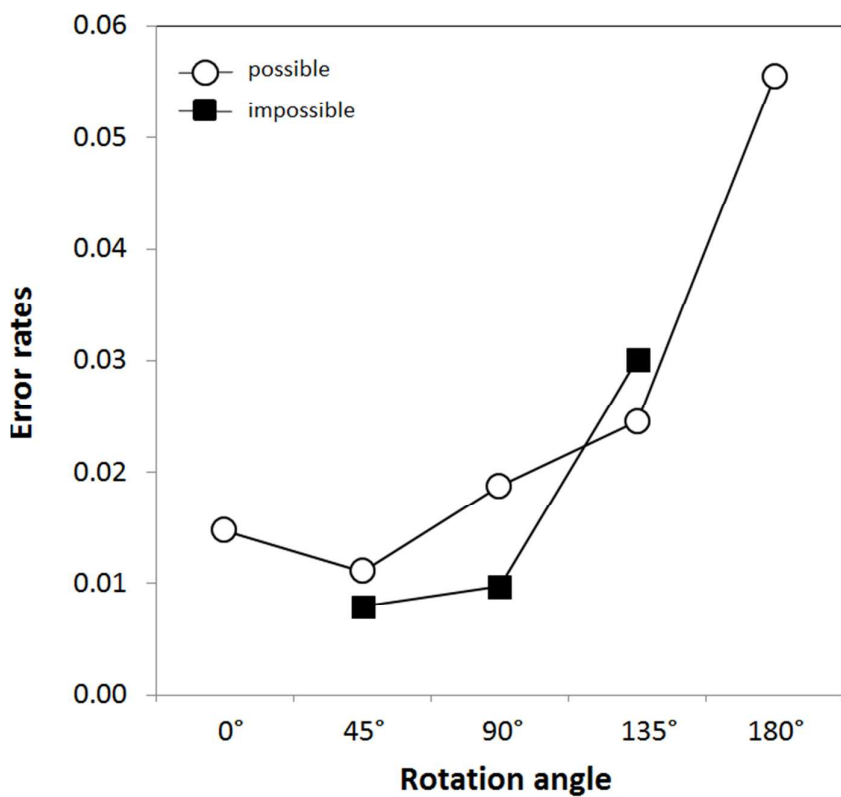


Figure 2.

## SPATIAL JUDGMENTS ON HUMAN FIGURES

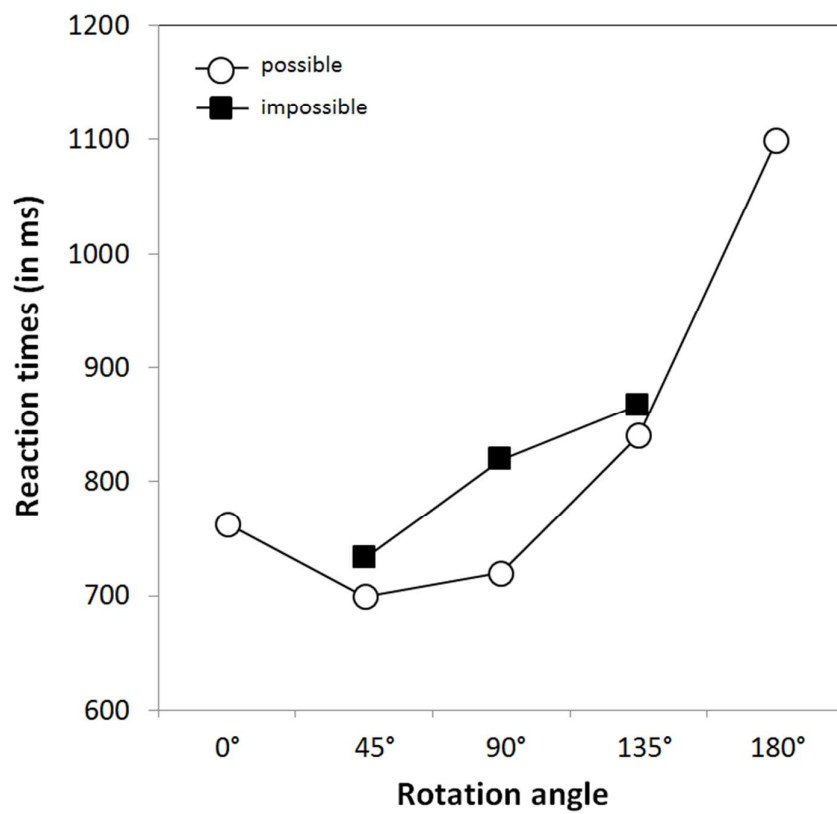


Figure 3.

SPATIAL JUDGMENTS ON HUMAN FIGURES

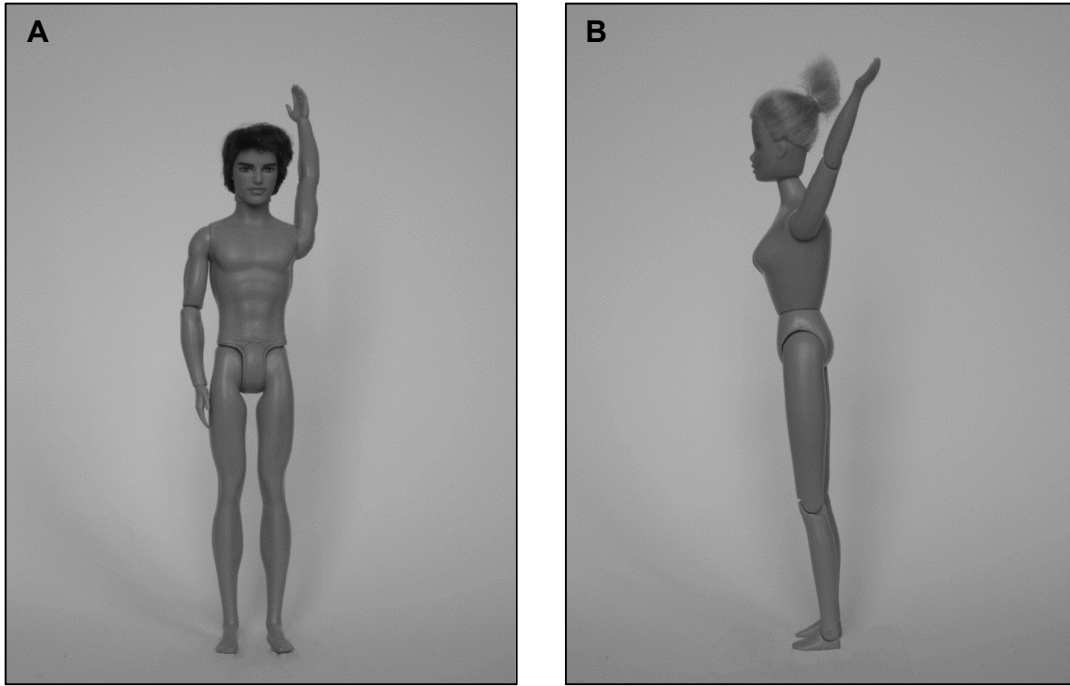


Figure 4.

## SPATIAL JUDGMENTS ON HUMAN FIGURES

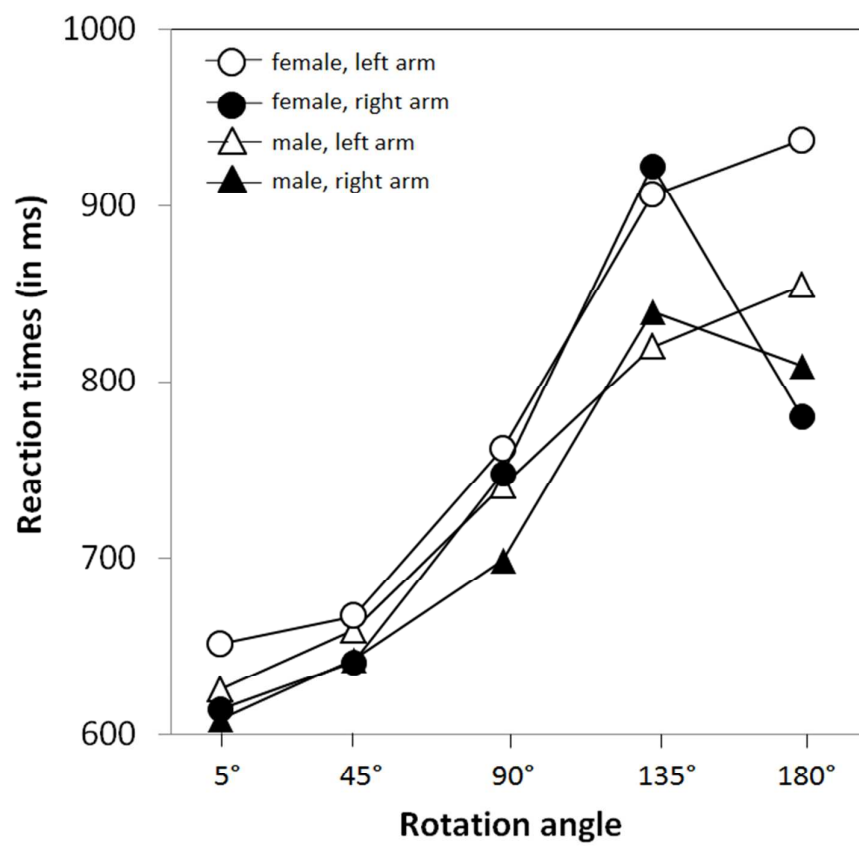


Figure 5.

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## Appendix

Table 1

Results of repeated contrasts ( $p$ -values) comparing RTs of subsequent rotation angles separately for the figures' sex and lifted arm.

Contrasts	Sex of the figure															
	male								female							
	left arm				right arm				left arm				right arm			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
(A)	<b>.062</b>	<b>&lt;.001</b>	<b>.009</b>	.36	<b>.036</b>	<b>.013</b>	<b>&lt;.001</b>	.37	.31	<b>&lt;.001</b>	<b>.003</b>	.55	.20	<b>&lt;.001</b>	<b>&lt;.001</b>	<b>.001</b>
(B)	“	“	“	.46	“	“	“	<b>.075</b>	“	“	“	<b>.030</b>	“	“	“	.16

Notes. (1): 5° vs. 45°; (2): 45° vs. 90°; (3): 90° vs. 135°; (4): 135° vs. 180°. Bold: significant on 5%-level or marginally significant on 10%-level.

(A) RTs for 135° rotations including RTs on figures rotated by 135° and 225°. (B) RTs for 135° rotations including for the right arm only RTs on figures rotated by 225° and for the left arm only RTs on figures rotated by 135°.