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Embodied representation of the body contains veridical spatial information

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In two experiments, the extent to which mental body representations contain spatial information was examined. Participants were asked to compare distances between various body parts. Similar to what happens when people compare distances on a real visual stimulus, they were faster as the distance differences between body parts became larger (Experiment 1), and this effect could not (only) be explained by the crossing of major bodily categories (umbilicus to knee vs. knee to ankle; Experiment 2). In addition, participants also performed simple animate/inanimate verification on a set of nouns. The nouns describing animate items were names of body parts. A spatial priming effect was found: Verification was faster for body part items preceded by body parts in close spatial proximity. This suggests automatic activation of spatial body information. Taken together, results from the distance comparison task and the property verification task showed that mental body representations contain both categorical and more metric spatial information. These findings are further discussed in terms of recent embodied cognition theories.

Keywords: Body image; Spatial priming effect; Distance comparison effect; Auditory; Veridical metric distances.

When asked to estimate whether a new pair of jeans will fit we need to judge size and distance information of our own body. An interesting question is how well we are able to do this purely based on memory (i.e., without looking at or touching our own body). This task draws on a mental representation of the body, without perceptual input, referred to as either a somatorepresentation (Longo, Azañón, & Haggard, 2009) or a body image (e.g., Dijkerman & De Haan, 2007; Head & Holmes, 1912). It includes lexical–semantic knowledge about body parts and structural knowledge about the topology of the body (De Vignemont, 2009; Longo et al., 2009; Schwoebel & Coslett, 2005). Although the topological map contains visuospatial relationships between body parts, there remains a close link to language (Longo et al., 2009; Semenza & Goodglass, 1985). Most likely, the visuospatial relationships are stored in categorical relations such as "on top of" and "right side connected" (Laeng, Chabris, & Kosslyn, 2003). It remains to be seen, though, whether a spatial organization with veridical distance information is maintained. The present

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study aimed to explore this possibility as well as to what extent this organization is automatically accessed.

Recently, Smeets, Klugkist, Van Rooden, Anema, and Postma (2009) examined, as one of the first, whether distance information is actually preserved in our mental body representation. They used a so-called distance comparison task (Moyer & Bayer, 1976) and compared females with high and low body shape concern. Participants were required to make a forced choice about which distance between body pairs was the longest (e.g., hip–hip vs. ear–ear). Smeets et al. found evidence for a symbolic distance effect—that is, reaction time decreases, and accuracy increases, with increasing (physical) distance difference. For example, participants responded faster and more accurately in the case of a hip–hip versus ear–ear comparison than when contrasting hip–hip against shoulder–shoulder. This symbolic distance effect strongly suggests that participants used spatial information to solve the task. It remains to be seen whether this spatial information is really metric. It should be mentioned that Denis and Zimmer (1992) in their original paper on the distance comparison task argued that their participants were able to convert verbal descriptions of environments into mental representations that contained reliable metric properties similar (isomorphic) to the representations derived from visual experience with an actual map.

A point of criticism on the study by Smeets et al. (2009) regards their stimulus set. They included a range of horizontal distance pairs that were emotionally sensitive to females with high body shape concern, such as hip and thigh. They contrasted these items to emotionally insensitive items, such as eye and ankle. Smeets et al. found that emotionally sensitive pairs, where at least one distance was emotionally sensitive, were judged faster than insensitive pairs, especially in the shorter distance difference spectrum. As such, the symbolic distance effect was less pronounced for emotionally sensitive pairs than for emotionally insensitive pairs. This effect was similar in high and low body shape concern groups. The authors provide an explanation for this odd finding: Perhaps female participants visualized the emotionally sensitive body parts more often, which speeds up access to these representations. Since no differences between high and low body shape concern participants were found, an alternative explanation could be that spatial knowledge about body parts is represented not only in a spatial manner but also in a semantic factual way (e.g., your conviction that "your hips are huge" makes you always judge the hips as the largest distance). As such, the symbolic distance effect obtained by Smeets et al. does not provide conclusive evidence for the presence of a spatial representation of the body. Therefore, in a first experiment we designed a distance comparison task without focusing on emotionally sensitive body parts but instead focusing on three different scanning orientations in order to disentangle a spatial representation and a semantic representation: (a) horizontal distances, (b) vertical distances, and (c) mixed horizontal and vertical distances. It might be argued that for comparisons along the horizontal or vertical orientation we cannot rule out the possibility that they are solved on the basis of semantic factual knowledge rather than by mental scanning of spatial distance properties. That is, we might simply know which widths or heights between body parts are the largest without needing to scan a particular mental distance (e.g., you know that your hips are wider than your ears). For a mixed orientation trial, comparing horizontal and vertical distances, we assume it is highly unlikely that the ranking of differently oriented distances is stored as a semantic fact. We rarely have to contrast a horizontal body distance (e.g., the width of your hips) to a vertical one (e.g., the length of your arm) in daily life. Consequently, the only way to achieve accurate performance in the mixed condition would be to really mentally scan the distance from one body part to the other. Thus the strongest evidence for a spatially organized mental body representation would follow from a symbolic distance effect in the mixed condition. Furthermore, if participants use semantic knowledge to solve the horizontal and vertical conditions, but need to perform an additional computation to solve the mixed condition, this would result in generally faster responses for the horizontal and vertical conditions, which do not require any computations, than for the mixed condition.

The body distance comparison task requires active deliberation on body size information. However, theories on embodied cognition and perceptual simulations argue that language comprehension involves linguistic processing as well as automatic simulation of referents such as multimodal percepts, beliefs, and actions (Barsalou, 1999; Barsalou, Santos, Simmons, & Wilson, 2008; Zwaan, 1999). In line with these theories, recent neuroimaging studies have demonstrated motor resonance when processing action-related verbs—for example, reading the word "kick" activated the leg-area in the motor cortex (for a review, see Willems & Hagoort, 2007). Similarly, evaluating body parts could result in automatic activation of a mental body representation. Therefore, we added a second task (a property verification task) assessing the possibility of automatic activation of the underlying mental body representation. In the property verification task, no conscious decision is required on any form of spatial information (Denis & Zimmer, 1992; Noordzij & Postma, 2005). Participants simply have to judge whether or not an item falls in a certain semantic class. In this case, the criterion property was animate versus inanimate, and all the animate items were body parts. By comparing the intertrial relations, however, the presence of a so-called spatial priming effect can be established: Faster responses to target items (e.g., nose) when preceded by another target item close in space (e.g., chin) than when preceded by a target item far in space (e.g., knee). Importantly, these effects occur unconsciously and are less sensitive to strategies (McNamara, 1986) than, for example, image-scanning tasks (Kosslyn, Ball, & Reiser, 1978).

Property verification requires participants to use deeper processing, which could result in situated simulations with access to spatial information, instead of relying on superficial word-level representations as in lexical decision tasks (Barsalou et al., 2008; Glaser, 1992). We expected that if the mental body representation is immediately accessed, a spatial priming effect should occur, signified by faster reaction times for target body parts when primed by another body part near in space than when primed by a body part far in space. However, if the spatial information is unavailable or inaccessible, participants can only rely on semantic information, resulting in similar reaction times for near and far primed target body parts.

We describe the results from two experiments. The first experiment consisted of a distance comparison task and a property verification task to examine the spatial organization of the mental body representation. However, this organization could involve strong metric information or depend on more coarse spatial categories. In the second experiment, the paradigm was adapted to test whether the crossing of major bodily categories could better explain the distance comparison and spatial priming effects.

EXPERIMENT 1

In the first experiment, participants performed a distance comparison task and a property verification task. Both tasks provide information about the organization of body parts. The distance comparison task explicitly instructs participants to use their mental representation about their own body. The property verification task, on the other hand, measures the mental body representation in an implicit manner, through possible priming effects. Participants started with the property verification task to ensure that they had not consciously activated their body image. Together these tasks may shed light on the hypothesized spatial organization of the mental body representation. In order for participants to focus on their own mental body representation, they were blindfolded, and the stimuli were presented auditorily.

Method

Participants

A total of 28 Utrecht University students participated for course credits or monetary compensation.

Two participants had misunderstood the instructions in one of the tasks as demonstrated by performance far below chance level and were excluded from the analysis, which resulted in a group of 26 participants (13 male; age $M = 21.69$ years, $SD = 1.72$). Prior to the experiment, all participants signed an informed consent, which was approved by the local ethics committee.

Design

All participants were blindfolded during the auditory experiment. Participants were led into the experiment room by the experiment leader and were seated in front of a table with a computer with two external loudspeakers.

Participants started with the property verification task. The task was to judge whether an item was animate or inanimate. Half of the participants pressed the left button on a response box for animate items, and the other half pressed the right button for animate items. Participants were instructed to respond as quickly as possible without compromising accuracy. After the instruction, participants received 12 practice trials, where animate items were animal parts (e.g., wing). Participants received feedback about their performance. During the task the animate items were body parts.

Subsequently, participants performed the distance comparison task in which they were asked to compare two distances between pairs of body parts and to judge which pair contained the largest distance. When the first pair was the largest distance, participants had to press the left key on the response box; when the second pair was the largest distance they had to press the right key. Again, participants were instructed to respond as quickly as possible without compromising accuracy.

Prior to the distance comparison task, participants were instructed to imagine their own body as if they were watching a picture of themselves, standing upright with their arms hanging down and their feet together. This instruction was repeated three times during the experiment. After the instruction, participants received 10 practice trials with feedback about their performance. During the actual task, no feedback was provided.

Stimulus material and procedure

Although the participants first performed the property verification task, we start with discussing the distance comparison task because of theoretical relevance following the line of arguments from the introduction.

Distance comparison task. The task consisted of 92 trials divided over three orientations: horizontal, vertical, and mix (see Table 1, for examples). Nested within the orientations was the distance difference: small, medium, and large distance differences, based on the ratios between the two body distance pairs within a trial. The ratios were computed using a standard body and by dividing the smallest by the largest distance and sorted into small, medium, and large distance differences (see Table 1). In a pilot experiment, 25 participants were photographed standing in an upright position in accordance with the instruction. For each participant, the individual ratios were computed and compared against the ratios from the standard body. The pilot experiment showed that, in general, individual ratios provided the same categories as did the standard body ratios; therefore the standard body ratios are reported in Table 1.

There were four sessions in which trials were presented randomly. The sessions were separated by a reminder of the imagery instruction. A single trial started at 0 ms with a short beep (100 ms); at 1,100 ms the first word of Pair 1 was presented (700 ms), followed by a short interval (300 ms); at 2,100 ms the second word of Pair 1 was presented (700 ms), followed by a short interval (800 ms); at 3,600 ms the first word of Pair 2 was presented (700 ms), followed by a short interval (300 ms); at 4,600 ms the second word of Pair 2 was presented (700 ms), followed by a response interval. Participants had 4,000 ms to respond. The next trial started 500 ms after the response, or after the response interval when no response was given. The words were recorded with Audacity (Mazzoni, 2006) and presented

Table 1. Examples of trials with different orientations and different distance differences and the ratio bins determining the different categories for each orientation

Orientation	*Distance difference*	*Example trial*		*Range*
Horizontal	Small	hip–hip	elbow–elbow	.69–1.00
	Medium	shoulder–shoulder	elbow–elbow	.50–.69
	Large	shoulder–shoulder	ear–ear	.30–.50
Vertical	Small	nose–navel	hip–knee	.62–1.00
	Medium	hip–knee	forehead–chin	.37–.62
	Large	nose–navel	forehead–chin	.25–.37
Mix	Small	elbow–wrist	knee–knee	.76–1.00
	Medium	elbow–wrist	ankle–ankle	.57–.76
	Large	ankle–ankle	nose–navel	.14–.57

auditorily through external loudspeakers with Presentation software 11.0 (Neurobehavioral Systems, 2007).

Property verification task. For the auditory property verification task, a list of 72 objects (body parts or nonliving objects) was created. Each object required a response. The trials were presented in a fixed order, which determined the prime–target relation. There were two types of prime–target relations: near (shoulder–ear) and far (wrist–ankle). In total there were eight prime–target pairs for each spatial distance. The words were presented with the same set-up as that used in the distance comparison task. A single trial consisted of the presentation of a word, followed by a response interval of 4,000 ms maximum. The next trial started 1,000 ms after the response, or at the end of the response interval in the case of no response.

Data analysis

For the distance comparison task, we analysed two behavioural measures: performance measured by the proportion of correct trials and mean response times to correct verifications. Behavioural data were analysed using SPSS (SPSS for Windows, Rel. 16.0.2 2008. Chicago: SPSS Inc.) with a 3 × 3 repeated measures analysis of variance (ANOVA). The within-participant factors were orientation (horizontal, vertical, or mix) and distance (small, medium, or large difference). Further analysis by means of pairwise comparisons used a significance level corrected for multiple comparisons with the Bonferroni method. SPSS multiplies the p value with the Bonferroni multiplier instead of dividing α by the Bonferroni multiplier. The results are, however, equal, and this method corrects for multiple comparisons. We denote the Bonferroni corrected p values by p_B.

For the spatial property verification task we also analysed two behavioural measures: performance measured by the proportion of correct trials and mean response times to correct targets. Behavioural data were analysed with a one-way repeated measures ANOVA. The within-participant factor was distance (near: target is close to the prime; far: target is far from the prime). The results are reported using the same procedure as that in the distance comparison task.

Results

Distance comparison task

Performance. The overall proportion of correct trials was high ($M = .816$, $SE = .012$), but differed slightly for the three orientations. The 3(orientation) × 3(distance) repeated measures ANOVA on the proportion of correct answers revealed a main effect of orientation, $F(2, 50) = 11.22$, $p < .001$. Pairwise comparisons showed that performance was slightly lower on horizontal trials ($M = .783$, $SE = .018$) than on vertical trials ($M = .863$, $SE = .011$), $t(25) = -4.16$, $p_{\mathrm{B}} = .001$. Performance on vertical trials was slightly higher than that on mix trials ($M = .801$, $SE = .016$), $t(25) = 4.07$, $p_{\mathrm{B}} = .001$. There was also a main effect of distance, $F(2, 50) = 86.06$, $p < .001$. Pairwise comparisons revealed that performance was higher for large distance differences ($M = .918$, $SE = .013$) than for medium distance differences ($M = .846$, $SE = .015$), $t(25) = 4.00$, $p_{\mathrm{B}} = .001$, and higher for medium distance differences than for small distance differences ($M = .684$, $SE = .018$), $t(25) = 10.19$, $p_{\mathrm{B}} < .001$. Furthermore, the interaction between orientation and distance was significant, $F(4, 100) = 5.13$, $p = .001$, and was also further analysed by means of pairwise comparisons between distance differences for each orientation. These showed that performance increased with distance difference (see Figure 1). For all orientations, participants performed significantly better on medium than on small distance differences (all $p_{\mathrm{B}} < .010$). For mix trials, performance was significantly better on the large distance differences than on the medium ($p_{\mathrm{B}} = .002$), which can be summarized as a symbolic distance effect. For horizontal and vertical trials, the difference between medium and large distance differences was not significant ($p_{\mathrm{B}} = .321$, and $p_{\mathrm{B}} = .165$, respectively), but pointed in the predicted direction; see Figure 1.

Response times. Another 3 (orientation) × 3(distance) repeated measures ANOVA was performed to analyse the mean response times to correct verifications. Again a main effect of orientation, $F(2, 50) = 5.84$, $p = .005$, was found. Participants responded faster on horizontal trials ($M =$ 1,389.54 ms, $SE = 71.09$) than on vertical trials ($M =$ 1,523.69 ms, $SE = 66.84$), $t(25) = -2.58$, $p_{\mathrm{B}} = .048$, and mix trials ($M =$ 1,505.08 ms, $SE = 68.78$), $t(25) = -3.85$, $p_{\mathrm{B}} = .025$. The faster responses and lower accuracy on the horizontal trials might suggest a speed−accuracy trade-off. However, closer inspection of the distance differences revealed that the fastest responses were given to the large distance differences, while the accuracy was highest in this condition. This pattern argues against a speed−accuracy trade-off. The main effect of distance was also significant, $F(2, 50) = 31.22$, $p < .001$. Pairwise comparisons showed that participants responded faster to large distance differences ($M =$ 1,314.21 ms, $SE = 61.32$) than to medium ($M =$ 1,477.34 ms, $SE = 65.29$), $t(25) = -4.17$, $p_{\mathrm{B}} = .001$, and faster to medium distance differences than to small distance differences ($M =$ 1,626.77 ms, $SE = 77.38$), $t(25) = -3.50$, $p_{\mathrm{B}} = .005$. The interaction between orientation and distance was not significant, $F(4, 100) = 1.62$, $p = .176$. All results are summarized in Figure 2.

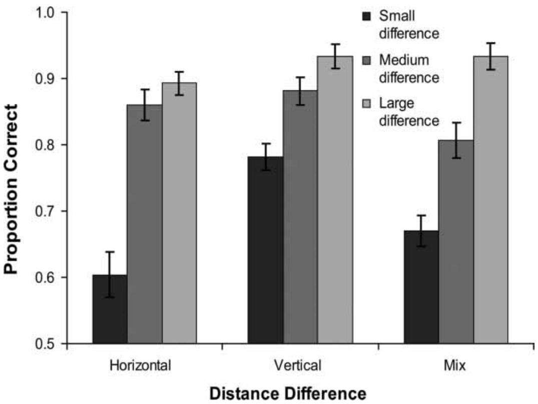

Figure 1. *Mean proportion of correct responses on the distance comparison task, split up for three orientations. Chance level is .5. Error bars indicate standard error of the mean.*

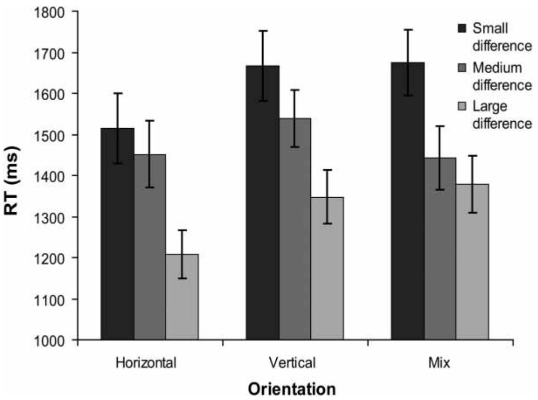

Figure 2. *Mean reaction times (RTs) on the distance comparison task, split up for three orientations. Error bars indicate standard error of the mean.*

Property verification task

Performance and response times. The overall proportion of correct trials was very high ($M = .98$, $SE = .01$). The one-way repeated measures ANOVA on the proportion of correct trials did not reveal an effect of distance, $F(1, 25) = 0.14$, $p = .713$.

The analysis of the mean response times to correct body parts revealed an effect of distance, $F(1, 25) = 7.71$, $p = .010$. Participants responded significantly faster to near targets ($M = 772.37$ ms, $SE = 25.60$) than to far targets ($M = 835.03$ ms, $SE = 38.91$).

Discussion

The purpose of this study was to determine whether the mental representation of the body is spatially organized. In the body distance comparison task, we found a symbolic distance effect where responses were faster and more accurate with increasing distance difference. This effect indicates that participants found it easier to compare large distance differences between pairs of body parts, and it is in line with previously obtained results when participants compared actual metric distances on a visual map (Denis & Zimmer, 1992). The fact that the symbolic distance effect emerged especially in the mix condition, where participants had to compare a horizontal and vertical distance, suggests that participants could no longer rely on semantic knowledge to solve the task, since different postures might alter the ranking of distance differences. Instead they used spatial information and needed to actively manipulate two differently oriented distances. The active manipulation strategy seems to have been reflected on the vertical orientations, as demonstrated by the presence of the symbolic distance effect in this condition as well. There was also a symbolic distance effect in the horizontal orientation. Additionally, responses in the horizontal orientation were faster than those in the other two orientations. As we hypothesized, this could be due to a semantic strategy. Certainly the presence of the symbolic distance effect rules out a complete semantic strategy, but, like the results reported by Smeets et al. (2009), there might have been some semantic influence. Overall, the presence of the symbolic distance effect in all three conditions suggests that our body knowledge is spatially organized.

In order to assess the possibility of automatic activation of the underlying mental body representation, we included the property verification task for which we found that participants responded significantly faster to targets close in space than to targets far in space. This spatial priming effect provides converging evidence that participants use a mental representation of the body with preserved spatial information. Moreover, even without being aware, participants activate spatial information about the body in line with theories on embodied cognition.

The results of both the distance comparison task and the property verification task suggest that body information is spatially organized. However, they do not inform us whether a strong, exact metric is employed or rather coarser categorical spatial information is used.[1] In parallel to the levels of taxonomy based on the principles of categorization by Rosch, Mervis, Gray, Johnson, and Boyes-Braem (1976), Andersen suggested a partonomy: A division of the body into four categories: head, trunk, arm, and leg (Andersen, 1978). Partonomy represents a hierarchical categorical ordering of body parts. For example, the basic concept “knee” has “leg” as its superordinate concept, “patella” as its subordinate concept, and “ankle” as its coordinate concept. When we apply this framework to our property verification task, it could be that the near distances were all within a superordinate category, while the far distances were across superordinate categories. Notice that we assume that a categorical organization is not merely semantic, but rather is spatial at a coarse-grained level—that is, body parts within the same category are spatially equivalent, though relative distance differences emerge when crossing one or more categories. The use of categorical spatial

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[1] We would like to thank an anonymous reviewer for this suggestion.

information could also have been present in the distance comparison task. Experiment 1 was not designed to distinguish between these two spatial alternatives. In order to further examine the categorical spatial possibility, we therefore performed a second experiment in which we included two factors: distance (near, far) and category (within, across).

EXPERIMENT 2

In the first experiment, we have shown that information about the spatial organization of the body is automatically available in the property verification task and deliberately accessed in the distance comparison task. However, this organization could either involve strong metric information or depend on more coarse spatial categories, or even a mix of the two. Adding a factor category could provide additional information about the underlying characteristics of the spatial organization of the body.

For the distance comparison task, new pairs of distances were constructed such that the factor category could be added. We only used the vertical condition since it offered the most suitable combinations of body parts. The factor distance again had three levels: small, medium, and large distance differences. These three levels were realized for pairs within a category (within) and pairs across a category (across). We used the partonomy by Andersen (1978) with four body categories: head, trunk, arm, and leg. In Experiment 1, we have argued that it is unlikely that participants used semantic information in the mixed condition. Indeed the results support this idea. However, in the vertical condition, participants could still rely on a strategy other than a metric one. In this adapted experiment, we manipulated the influence of categorical information. We may conjecture four possible response patterns. If participants indeed based their response on categorical information, then we would expect to find no symbolic distance effect and an advantage for within trials compared to across trials. On the other hand, the use of metric information predicts a symbolic distance effect for both within and across trials. Alternatively, both metric and categorical information could be available, yielding a symbolic distance effect but easier (i.e., faster and more accurate) for within trials than for across trials, as demonstrated by a significant interaction. A pure semantic strategy would yield no symbolic distance effect and no categorical effect, which seems unlikely given the results of Experiment 1.

Experiment 2 also included the property verification task with the manipulation of the factor category. For both near and far trials, the combination of body parts was chosen either from within a body category or from across body categories. The same rationale as that for the distance comparison task holds here, yielding four predictions: categorical, metric, a combination of categorical and metric, or semantic information. Furthermore, to make sure that participants did not activate their body image, we also included animal part names, which were also animate.

Method

Participants

A total of 28 Utrecht University students participated for course credits or monetary compensation. None of the participants had participated in Experiment 1. One participant misunderstood the instructions in one of the tasks, resulting in performance below chance level, and was excluded from the analysis, which resulted in a group of 27 participants (11 male; age $M = 23.56$ years, $SD = 2.69$). Prior to the experiment, all participants signed an informed consent, which was approved by the local ethics committee.

Design

The distance comparison task from Experiment 1 was adapted. The task only consisted of vertical trials in which distance and category were manipulated. The procedure of administering the tasks was identical to that of Experiment 1.

Stimulus material and procedure

Distance comparison task. Participants received the same instruction as given in Experiment 1. The task consisted of 48 trials divided over two categories: within (pairs were within the same body category) and across (pairs were from different body categories). Nested within the categories was the distance difference: small, medium, and large, based on the ratios between the two body distance pairs within a trial. The boundaries for the ratio bins that determined the three distance differences were the same for within and across trials. There were three sessions in which trials were presented randomly; the sessions were separated by a reminder of the imagery instruction. The presentation of the trials was identical to that in Experiment 1.

Property verification task. For the auditory property verification task, a list of 138 objects (body parts, animal parts, or nonliving objects) was created. There were two categories: within (prime–target pairs were within the same body category) and across (prime–target pairs were from different body categories). Nested within the categories were two distances: near and far. In total there were six prime–target pairs for each condition. In addition to the body parts there were 24 animal parts that also required a yes response. The numbers of yes and no responses were equal. The trial presentation was identical to that in Experiment 1.

Data analysis

For the distance comparison task we analysed two behavioural measures: performance measured by the proportion of correct trials and mean response times to correct verifications. Behavioural data were analysed with a 2 × 3 repeated measures ANOVA. The within-participant factors were category (within or across) and distance (small, medium, or large difference). The results are reported in the same way as in Experiment 1.

For the spatial property verification task, we analysed performance measured by the proportion of correct trials and mean response times to correct body part targets. Behavioural data were analysed with a 2 × 2 repeated measures ANOVA. The within-participant factors were category (within or across) and distance (near or far). The results are reported in the same way as in Experiment 1.

Results

Distance comparison task

Performance. The 2 × 3 repeated measures ANOVA for the proportion of correct trials revealed significant main effects of category, $F(1, 26) = 14.63$, $p = .001$, and distance, $F(2, 52) = 43.76$, $p < .001$, as well as an interaction, $F(2, 52) = 8.94$, $p < .001$ (see Figure 3). Performance within categories ($M = .775$, $SE = .013$) was better than that across categories ($M = .698$, $SE = .022$). Pairwise comparisons for the various distance differences revealed that performance increased with distance difference. Performance was better for large distance differences ($M = .866$, $SE = .022$) than for medium distance differences ($M = .759$, $SE = .024$), $t(25) = 4.28$, $p_B = .001$, which in turn was better than small distance differences ($M = .584$, $SE = .023$), $t(25) = 5.30$, $p_B < .001$.

In order to assess the presence of a symbolic distance effect, pairwise comparisons between the three distance differences within each category were performed. The pairwise comparisons revealed that in within trials performance was

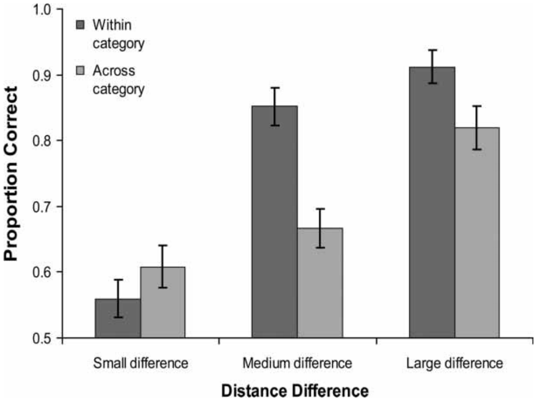

Figure 3. *Mean proportion of correct responses on the distance comparison task, with factors category and distance displayed for three distance differences (small, medium, and large). Chance level is .5. Error bars indicate standard error of the mean.*

equal for large and medium distance differences, $t(25) = 1.58$, $p_B = .375$ (see Figure 3), but better than that for small distance differences, $t(25) = 6.95$, $p_B < .001$. In the across trials, performance was better for large than for medium distance differences, $t(25) = 5.28$, $p_B < .001$, and equal to that for small distance differences, $t(25) = 1.26$, $p_B = .659$.

Response times. Another 2 × 3 repeated measures ANOVA on the mean response times for correct verifications revealed only a significant main effect for distance difference, $F(2, 52) = 18.74$, $p < .001$, all other Fs < 1.00. Pairwise comparisons showed that responses were slower for small distance differences ($M = 1{,}943.77$ ms, $SE = 80.67$) than for medium distance differences ($M = 1{,}805.44$ ms, $SE = 71.22$), $t(25) = 2.94$, $p_B = .021$ (see Figure 4). Furthermore, medium distance differences were responded to slower than large distance differences ($M = 1{,}676.09$ ms, $SE = 61.07$, $t(25) = 3.72$, $p_B = .003$).

Property verification task

Performance. The overall proportion of correct trials was again very high ($M = .97$, $SE = .008$). The 2 × 2 repeated measures ANOVA on the proportion of correct body part targets did not reveal any main effects (Fs ≤ 1.00); however the interaction between category and distance was significant, $F(1, 26) = 6.57$, $p = .017$. Pairwise comparisons revealed that for the near pairs, the within trials were judged better ($M = .99$, $SE = .006$) than the across trials ($M = .97$, $SE = .013$), $t(25) = 2.08$, $p_B = .043$. Performance on the far pairs did not differ (within: $M = .96$, $SE = .017$; across: $M = .98$, $SE = .015$), $t(25) = -1.19$, $p_B = .265$.

Response times. The 2 × 2 repeated measures ANOVA on the mean response times for correct body part targets showed significant main effects for category, $F(1, 26) = 5.42$, $p = .028$, and distance, $F(1, 26) = 11.05$, $p = .003$, as well as an interaction, $F(1, 26) = 8.00$, $p = .009$. Pairwise comparisons for the interaction showed that for the near trials, response times were equal for the within trials and the across trials, $t(25) = 0.53$, $p_B = .598$ (see Figure 5). However, for the far trials, responses were faster for within trials than for across trials, $t(25) = -3.33$, $p_B = .003$ (see Figure 5).

Discussion

The aim of Experiment 2 was to disentangle the underlying characteristics of the spatial organization of the body. A factor category was composed

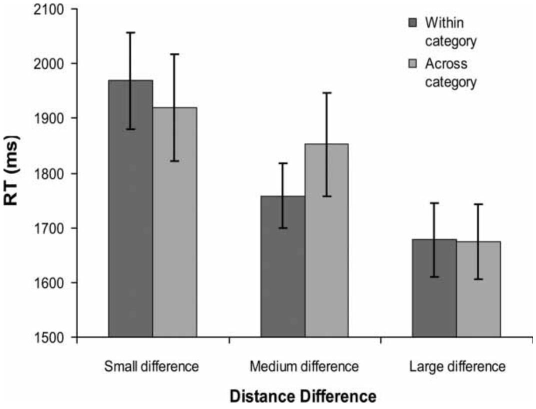

Figure 4. *Mean reaction times (RTs) on the distance comparison task, with factors category and metric displayed for three distance differences (small, medium, and large). Error bars indicate standard error of the mean.*

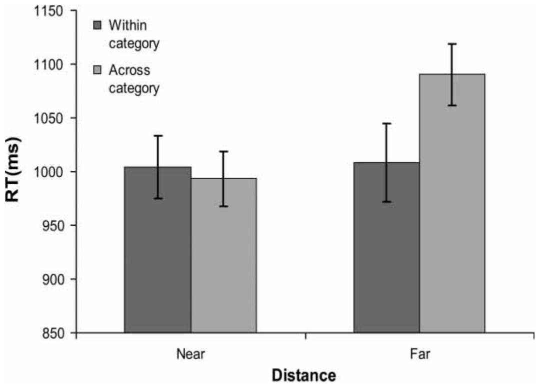

Figure 5. *Mean reaction time (RT) on the property verification task, with factors category and metric displayed for two distances (near and far). Error bars indicate standard error of the mean.*

including distance relations that crossed major body categories and distance relations that resided within a single body category. The vertical orientation from the distance comparison task of Experiment 1 was adapted in order to comprise both within category trials and across category trials. We hypothesized that if participants used categorical spatial information, responses would be faster for within category trials than for across category trials. Moreover, the symbolic distance effect would then be absent. On the contrary, the results showed the presence of a symbolic distance effect in the response times for both within and across category trials. This effect was supported by the symbolic distance effect in the proportion of correct trials, although the symbolic distance effect was more pronounced for within than across category trials. The emergence of these effects, especially in the response times, strongly suggests that participants indeed used spatial metric information to solve the task and did not resort to semantic strategies, although a mild influence of categorical information was observed in the proportion of correct trials.

The distance comparison task is an explicit task in which participants were instructed to use their own body image during the task. Following this instruction, participants were able to use spatial metric information to perform well on the task. However, in the property verification task, which preceded the distance comparison task, participants were unaware of the fact that the underlying body image might be activated. In Experiment 2, this was more strongly controlled for by including animal part names that also required a yes response. This implicit task showed that besides metric spatial influences, categorical spatial influences might emerge when processing body part names. The results from the property verification task of Experiment 2 depict a combination of our metric and categorical hypothesized response patterns. Since performance was at ceiling level, this interaction should not be overemphasized. However, the results from the response times show an interesting pattern. The response times on the near distances followed the metric hypothesis in that there were no differences between within and across category trials. On the other hand, the far distances followed the categorical/topological pattern, with slower response times to across category trials than to within category trials. Or to put it differently, for the within category trials we did not find a spatial priming effect, but for the across category trials we did find a spatial priming effect. This mixed pattern of results indicates that both a categorical/topological and a more metric representation might play a role, though they are not fully independent.

GENERAL DISCUSSION

The present set of experiments was designed to elucidate whether the mental representation of the body contains spatial information. More specifically, the spatial organization could be fully metric, fully categorical/topological, or a mix of both. In two experiments we addressed these questions. In both experiments we found a symbolic distance effect in the distance comparison task, indicating that the spatial information available about our body is isomorphic (Denis & Zimmer, 1992). This effect emerged in both experiments in the response times, demonstrated by an inverse linear relationship between response time and distance difference. The performances in Experiment 1 demonstrated a linear relationship between proportion of correct trials and distance difference, and this general pattern was also present in Experiment 2. However, in Experiment 2 there was also a moderate influence of categorical information, which resulted in a more pronounced symbolic distance effect for within category trials than for across category trials. The distance comparison results indicate that metric distance was the predominant source of information when participants were explicitly instructed to use this information, and the categorical/topological manipulation only affected the proportion of correct trials. Moreover, the spatial organization of our body appears quite compelling and may be accessed automatically and obligatorily as indicated by the priming results of Experiments 1 and 2. Reactions were faster to body parts when preceded by body parts in the vicinity. Experiment 2 addressed the nature of the spatial organization in more detail. The response times in the property verification task gave a mixed pattern of results with signs both of a metric organization and of a categorical one.

Hierarchical theories claim that spatial mental representations contain hierarchies of categorical information together with more detailed information (Huttenlocher, Hedges, & Duncan, 1991; Maki, 1981; McNamara, 1986; Stevens & Coupe, 1978). Besides Euclidean distance between items, mental representations can also contain different clusters of items grouped into global spatial categories. Research on object location memory has shown that categories can be determined by a variety of sources, such as geographical boundaries (Friedman, 2009; Maki, 1981), functional clusters (Stevens & Coupe, 1978), artificial boundaries (McNamara, 1986), vertical and horizontal axes (Huttenlocher et al., 1991; Postma, Huntjens, Meuwissen, & Laeng, 2006), colour clusters (Hommel, Gehrke, & Knuf, 2000), or spatial proximity (De Lillo, 2004). With regard to the body, "geographical" boundaries or spatial proximity could be important to determine the body categories. Interestingly, the present results indicate that hierarchical coding in combination with detailed information might also characterize the mental body representation, which contains metric spatial information, as well as categorical spatial information based on the partonomy division (basic concept: "knee"; superordinate concept: "leg").

Which type of information we can access depends on the task at hand. The two tasks used in our experiments had different sensitivity to the categorical spatial information. In the implicit property verification task, both types of spatial information appear to affect response times. In the distance comparison task, participants were explicitly instructed to use metric distance information to solve the task. Although categorical information influenced the proportion of correct trials, there was no influence found in the response times. Given the explicit instruction, participants were able to focus mainly on the metric distance information as demonstrated by the symbolic distance effect in the response times.

The present results are in line with embodied cognition theories of knowledge representations (Barsalou, 1999, 2008; Zwaan, 1999; Zwaan & Radvansky, 1998). According to these theories, the meaning of words is obtained through situated simulations—reenactments of modal states captured during perception (Barsalou, 2008). Hearing body part names starts simulations of the mental body representation where metric and categorical spatial information seem to be available in parallel. The extent of simulation varies with the depth of processing; first, superficial processing activates linguistic information, and, subsequently, deeper processing activates associated simulations (Barsalou et al., 2008). We would like to speculate that the semantic decision in the property verification tasks evoked relatively deep semantic processing, resulting in situated simulations with access to categorical and metric spatial information. In order to test this idea, future research might use a more superficial task—for example, judging whether the letter "a" was present in the word. If our assumption is correct, then we should observe a lower or even absent spatial priming effect under those circumstances, since superficial tasks do not engage in situated simulations and hence do not give access to spatial information.

Recent neuroimaging studies have provided further evidence supporting embodied cognition theories. These studies have shown that activation in the motor cortex occurs when processing action-related words—for example, reading the word "kick" activated the leg area in the motor cortex (for a review, see Willems & Hagoort, 2007). A point of criticism raised by Willems and Hagoort is that the reported motor cortex activity might also result from deliberate motor imagery. It seems unlikely that the present spatial priming results are based on motor imagery, since there is no reference to action nor does it impose active spatial body scanning. As such, it might be relevant to study the neural activation of processing of body parts. According to embodied cognition, one might expect body parts to generate simulations of these body parts, which might result in additional motor resonance while not explicitly involved in action. In addition, two areas have been identified that selectively respond to images of human bodies and body parts: the fusiform body area (FBA) in the ventral surface and the extrastriate body area (EBA) on the lateral surface (Downing, Jiang, Shuman, & Kanwisher, 2001; Schwarzlose, Baker, & Kanwisher, 2005; Schwarzlose, Swisher, Dang, & Kanwisher, 2008). While both areas responded to images of human bodies, the EBA also coded the location of the stimulus. Although this location information referred to the position of the stimulus, rather than the position of the body parts within the body, it might be a possible candidate for coding position information of body parts and might be involved in our set of tasks.

In conclusion, the body image incorporates veridical metric spatial information about distances between body parts. When asked to judge distances on the body, participants are able to use this veridical spatial information. In addition, this spatial information is also accessed in a more implicit, automatic manner during a property verification task, in which participants do not consciously attend to the spatial layout of their body. Coupled to this automatic activation, we also found that an influence of spatial body categories emerged. In line with recent theories on embodied cognition (Barsalou, 1999, 2008; Barsalou et al., 2008; Zwaan, 1999; Zwaan & Radvansky, 1998), these results show that hearing a verbal referent to a body part automatically evokes a mental simulation of the body containing categorical and more metric spatial information similar to how our physical body is composed.

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