The Psychological Reality of the Body Schema:
A Test With Normal Participants

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Neuropsychological dissociations suggest the existence of a *body schema*, a representation of the spatial relations among body parts, not used for other spatial stimuli. Four experiments verify the psychological reality of the body schema in normal participants. In Experiments 1 and 2, proprioceptive information concerning one's own body position influences visual perception of others' body positions. Contrary to expectations, facilitation is observed rather than interference in the dual-performance task. Experiment 3 eliminates the possibility that the effect is due to a particular mnemonic strategy. In Experiment 4, this effect is shown to be specific to the perception of bodies, as opposed to other complex 3-dimensional forms.

Brain damage can sometimes cause a dissociation between spatial knowledge about the human body, on the one hand, and objects in the external environment, on the other. This has led neuropsychologists to propose the existence of a *body schema*, a representation of the spatial relations among the parts of the body. In the present article, we explore the implications of neuropsychological dissociations between personal and extrapersonal space for the cognitive architecture of normal participants. Before doing so, however, we will briefly review three neurological dissociations that provide support for the concept of a body schema (see Denes, 1989, and Fredriks, 1985, for more complete reviews). These are hemispatial neglect, finger agnosia, and autotopagnosia.

The neglect syndrome involves an inability to represent or attend to the side of space contralateral to the lesion, which is usually parietal. In some cases there is a dissociation between neglect for the human body and for objects in the external environment. Case studies have shown that visual–spatial neglect for extrapersonal space can occur without personal neglect (Halligan & Marshall, 1991) and that severe unilateral personal neglect can exist in the absence of an extrapersonal space deficit (Guariglia & Antonucci, 1992). This double dissociation between personal neglect and extrapersonal neglect has also been verified in a group study of right hemisphere brain-damaged participants

(Bisiach, Perani, Vallar, & Berti, 1986) and suggests a body-specific attentional system that is separate from other attentional systems.

Further evidence for body-specific spatial cognition is found in finger agnosia, generally associated with left parietal damage. Finger agnosia is characterized as an inability to recognize, identify, differentiate, name, select, and orient the individual fingers of the patient's own hands as well as other persons' (Gerstmann, 1957). This difficulty with fingers appears disproportionate to the difficulty encountered with other complex stimuli.

The most striking evidence of a separate spatial representation of the body, distinct from the representation of external space, comes from the syndrome *autotopagnosia*.[1] Autotopagnosia is the inability to locate body parts on the body, despite relatively intact general spatial ability. The disorder is rare but shows an association with parietal lesions of the left hemisphere (De Renzi & Faglioni, 1963; De Renzi & Scotti, 1970; Ogden, 1985; Semenza, 1988). Autotopagnosic patients can recognize body parts individually, showing that the problem does not lie with knowledge of the parts themselves. In addition, they can name body parts when an experimenter points to them, showing that the problem is not linguistic. What they cannot do is locate a part in the context of a whole body, whether the part is cued by name or by picture. Although some researchers have suggested that the impairment is not body specific, but reflects a more generalized deficit in part–whole analysis (De Renzi & Faglioni, 1963; De Renzi & Scotti, 1970), in several recent cases of autotopagnosia the individuals retained the ability to locate parts of complex objects other than bodies, such as bicycles, demonstrating the specificity of the impairment for the representation of the body (e.g., Ogden, 1985).

[1] Autotopagnosia, or autotopoagnosia, is also called somatotopagnosia because it refers to an inability to locate others' as well as one's own body parts.

Although autotopagnosic patients do not have trouble localizing the parts of objects, they do have trouble locating body parts on bodies other than their own, including the examiner's body, mannequins bodies, and pictures of bodies, (De Renzi & Scotti, 1970; De Renzi & Faglioni, 1963; Ogden, 1985; Semmes, Weinstein, Ghent, & Teuber, 1963; Sauguet, Benton, & Hecaen, 1971; Sirigu, Grafman, Bressler, & Sunderland, 1991). This implies that the same body schema is used for representing the body of both the self and others. The nature of the errors made by autotopagnosic patients is also revealing of the underlying nature of the body schema. Patients are more likely to erroneously localize a body part to a nearby location than to a random location, for example, pointing to their shoulder when asked to locate their elbow (Semenza & Goodglass, 1985; Sirigu et al., 1991). This suggests a spatially organized representation for the body schema that has become less precise as a result of brain damage. The inability to localize body parts is not limited to the visual modality. For example, the patient described by Ogden (1985) made body part localization errors both when he looked for a particular body part and when he felt for a particular body part with his eyes closed. This implies that the body schema is supramodal, in the sense of representing the location of both seen and felt body parts.

The contrast between the disorder of body and external space was demonstrated clearly in a recent case study of autotopagnosia by Sirigu et al. (1991). The patient in this study was unable to point to named body parts on herself, the experimenter, or a doll, but was able to point to small toy objects that had been pinned to her clothing at various locations on her body. For example, she could not reliably point to her knee, but could reliably point to a small object pinned to her knee. Yet more surprising, after the objects were removed, she was able to point to their remembered positions.

To summarize, evidence from studies of brain-damaged individuals suggests that there is a spatial representation of the body, not used for representing other objects, that is spatially organized, supramodal, and used for representing other bodies as well as one's own. Could such a component exist in the functional architecture of spatial cognition, and not have been noticed in studies of participants without brain damage? In fact, there are hints in the literature that a body schema is engaged under certain circumstances in individuals without brain damage.

Evidence that a body image can exist independently of sensory input is found with the phantom limb phenomenon. After amputation, many individuals still experience sensations of movement, position, and pain, as if the limb still existed. Because there are no sensory receptors, any kinesthetic sensations that an amputee may associate with voluntary attempts to flex or extend a phantom joint must arise internally (Clark & Horch, 1986). In participants without amputations, Gross and Melzack (1978) found that sensation was not needed to perceive shifts in position and that those perceived shifts (e.g., the arm approached waistline) were similar for keeping the arm in place and during arm

ischemia. A phantom limb patient also reported such shifts under similar conditions.

Shontz (1969) found that individuals without brain damage perceive aspects of body size (self and others) differently than nonbody object size. In general, body size is less accurately estimated than nonbody object size, with over- and underestimatations characteristic of specific areas of the body: Upper portions of the body (head, head parts, and chest width) are overestimated and lower portions of the body (ankle to floor and knee to floor) are underestimated.

Perhaps the most striking findings of body-specific spatial representation in individuals without brain damage come from the studies of imagined and perceived motion of bodies and body parts. For example, participants spontaneously use biologically possible trajectories to mentally simulate the movement of a personal body part to match the stimulus target position (Parsons, 1987). Shiffrar and Freyd (1990) showed that similar constraints operate in determining the path of apparent motion. Anatomical constraints on body motion are also readily perceived by participants viewing dynamic light displays, who can discriminate the motion of lights attached to a moving body from other motions (Johansson, 1973) and even the motions of particular individuals (e.g., see Cutting & Proffitt, 1981, for a review).

These studies all involve judgments about spatial properties of bodies, either the participant's own or others, and they show differences between the way participants process bodies and nonbody objects. Strictly speaking, however, none show that the same representation is used for self and other bodies, and none address the issue of modality-specificity. Phantom limb and related phenomena are of course only relevant to the representation of one's own body. Constraints on the motion of viewed bodies and body parts need not derive from a representation of one's own body; they could be learned from viewing others' bodies in motion. The similarity of size estimation errors on self and others' bodies is suggestive of a common representation, but not decisive. Finally, the use of only a single modality, visual or proprioceptive, makes it impossible to know whether the body representations being used by participants in these studies are modality-specific or supramodal. In the present studies, we directly test the hypothesis that individuals without brain damage have a body schema that is supramodal and is used for processing body-related information for both the self and others.

Experiment 1

In Experiment 1, we test the hypothesis that the normal body schema is supramodal and used to encode body position information for both the self and others. We test this hypothesis using a dual-task paradigm. The primary task is a sequential same–different visual matching task for body-position memory. Participants determine whether the body position of a human model has changed or not. At the same time, participants engage in a secondary movement task: either unconstrained, nonrepetitive movement of the arms

or unconstrained, nonrepetitive movement of the legs. If there is a body schema, it should be used by the primary task to encode the model's body position and by the secondary movement task to keep track of movements to ensure that they are nonrepetitive.

Furthermore, the neuropsychological concept of body schema implies more than a body-specific representation used for visual perception of others' bodies and proprioceptive perception of one's own body. It also implies that this representation is spatially organized. To examine whether the body schema has an internal organization that is spatial in nature, we compared participants' matching ability for a model's arm and leg positions during personal movement of the same or different body parts. A spatially organized body schema hypothesis would predict an interaction between the body part being moved and the body part being matched.

Our initial prediction was that there should be selective interference between the two body-related tasks, if the same representation were used for updating of personal body position as for remembering another person's body position. Specifically, participants should be relatively impaired in their ability to discriminate arm positions of the model while moving their own arms, relative to when they are moving their own legs, and vice versa for their ability to discriminate the model's leg positions.

Method

Participants. Twenty Carnegie Mellon University undergraduates participated for partial course credit.

Stimuli. Static body positions were photographed. A human model, dressed in a blue T-shirt and pink tights, posed with her arms and legs in various novel positions. The poses selected were unusual body configurations designed to be visually distinguishable from each other but to discourage verbal labeling. The poses

were asymmetrical with respect to both vertical and lateral body axes. The complete set of trials was recorded on videotape.

In each trial, participants visually compared two poses, presented sequentially. The first pose, the memory pose, was taped from a position directly in front of the model and the second pose, the target pose, was taped from a 45° angle to the right of the model. The viewing angle was changed to prevent participants from remembering the body position as a two-dimensional image pattern. The memory and target poses were either identical or differed in terms of arm position or leg position, but not both. For the "different" target poses, position changes often involved altering the angle of the limb and keeping other body parts the same. An example of the memory pose (left) and target pose (right) is shown in Figure 1. Note that in this example the two poses are identical.

Design and procedure. We conducted the experiment using a within-subject design with the factors participant movement (arm movement and leg movement) and model position change (arm change and leg change).

Participants engaged in two tasks simultaneously. The primary task was a body position memory task in which participants viewed videotapes of a human model posed in a variety of static body positions. During each trial, the first pose was presented for 10 s, followed by a blank screen for 5 s, and then a second pose was presented. The participants' task was to determine whether the model's position in the second stimulus was different from the model's position in the first stimulus. Participants were not told which part of the model's body would change.

While viewing the videotape, participants stood directly in front of the monitor and performed one of two secondary tasks: unrestricted but nonrepetitive arm movement or unrestricted but nonrepetitive leg movement. They were instructed to start moving both arms or both legs when the first stimulus appeared and to stop moving when the second stimulus appeared. Participant movement was constrained only in that it had to be continuous and not repetitive. The experimenter monitored the participant's movement throughout, testing to ensure these criteria were met. The purpose of the nonrepetitive movement task was that it required
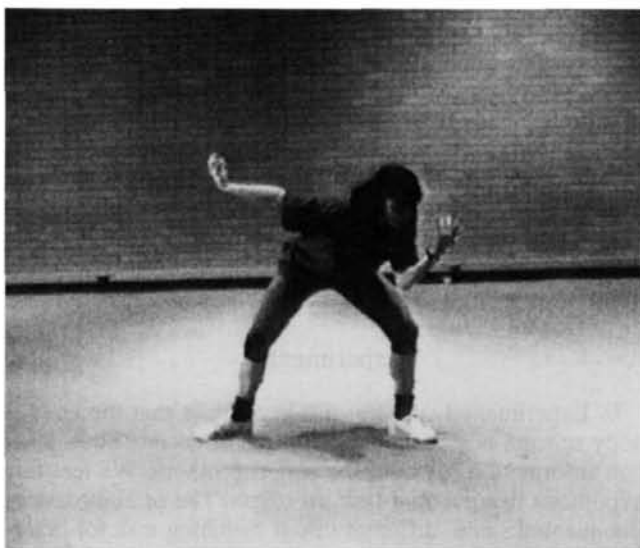

Figure 1. Examples of body position stimuli. The first pose (left) is photographed from a position directly in front of the model. The second pose (right) is photographed from a position 45° to the right of the model. Note that the two poses are identical.

participants to continuously update and encode the position of their own bodies.

Participants first received practice trials that included examples of each condition. Experiment trials followed in which there were two blocks of 20 trials each. For each block participants moved one part of the body (20 trials of arm movement and 20 trials of leg movement). Trials were blocked by movement type to reduce confusion. Within each block, half of the trials were "same" and half of the trials were "different." In half of the different trials the arm position changed and in half the trials the leg position changed. There were two different random orders of trials within each block. Trial order and movement order were rotated over participants. Response accuracy was recorded.

Results and Discussion

Overall average error rate was 13.5%. Statistical analyses were performed only on the different trials, because only these trials allowed us to examine the body-part specificity effects of the participants' movements. As can be seen in Figure 2, we obtained an interaction between participants' movements and model's position changes, but in a direction opposite to our predictions. Far from finding a selective interference effect, we found a selective facilitation effect: When participants moved their arms, they were better at noticing changes in the model's arm position than leg position, 9% versus 19% error rates, respectively. When participants moved their legs, they noticed changes in the model's arm and leg positions equally well, 12% and 14% error rates, respectively; however, compared to the errors made during arm movement, they made relatively fewer errors detecting leg position changes and relatively more errors detecting arm position changes.

A participant movement (arm movement and leg movement) and model position change (arm change and leg change) analysis of variance (ANOVA) was carried out. Although we found no main effects for participant movement, $F(1, 19) < 1.0$, we did find an effect for model position change, $F(1, 19) = 7.09, p < .02$, indicating that changes in the model's leg position were more difficult to detect than the changes in arm position. More relevant to the purpose of the experiment, the interaction between participants' movements and model's position change was significant, $F(1, 19) = 4.57, p < .05$. This interaction implies that, as predicted by the body schema hypothesis, participants without brain damage do not process their own and others' body positions independently.

However, the direction of this interaction was not as predicted. One interpretation of this selective facilitation is that participants adopted a strategy of monitoring the same part of the model's body that they were moving. Experiment 2 was undertaken to eliminate this strategy and thereby test this explanation of the selective facilitation effect.

Experiment 2

In Experiment 1 we found that participants were better able to detect changes in the model's position if the changed limb corresponded to the limbs they themselves were moving. The purpose of Experiment 2 was to rule out the relatively uninteresting explanation of the selective facilitation in terms of a strategic decision made by participants to monitor the part of the model's body corresponding to the part of one's own body being moved. In this experiment,
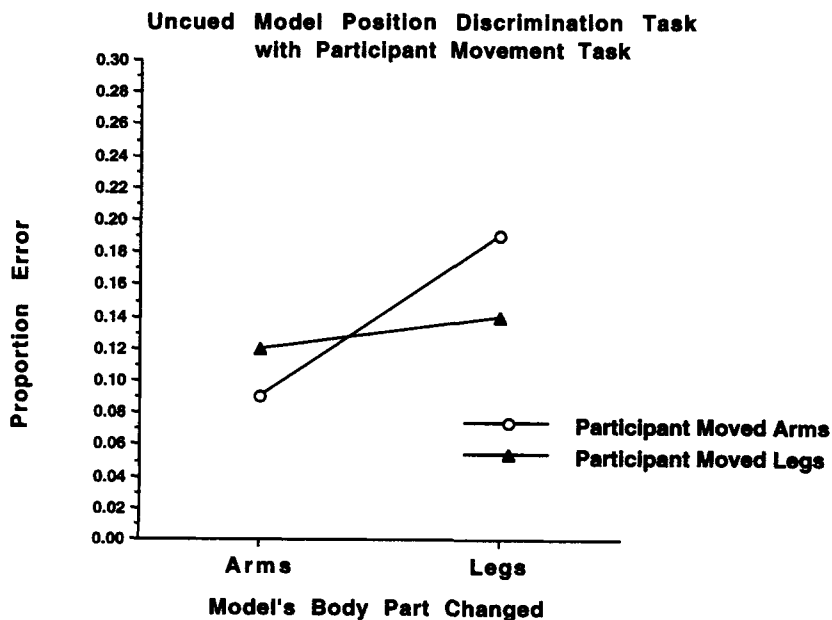

Figure 2. Results of Experiment 1. The secondary tasks of arm movement and leg movement are plotted for mean proportion error when changes in the model's arm and leg position occur.

participants were cued as to which part of the model's body might change position. The cues were 100% valid, so that if the cue were "legs," any change that might occur in the model's position would involve her legs. The rational strategy is therefore to attend to the cued part of the model's body, if such attention is under strategic control.

In addition, Experiment 2 included a body-unrelated secondary task, mental multiplication, as a baseline control condition. Mental multiplication controlled for overall processing load without engaging the body schema. The prediction was that if there is a body schema, it should be used by the primary task to encode the model's body position and by the secondary movement task to keep track of movements to ensure that they are nonrepetitive, but not by the mental multiplication task.

Method

Participants. Participants were 26 individuals from the Carnegie Mellon University community who were paid or participated for partial course credit.

Stimuli. The same stimuli used in Experiment 1 were used in Experiment 2.

Design and procedure. The experiment was conducted using a within-subject design with the factors secondary task condition (arm movement, leg movement, and mental multiplication) and cued body part (cue model's arm position and cue model's leg position).

As in Experiment 1, participants engaged in two tasks simultaneously: a primary body position memory task and a secondary movement task or a secondary nonmovement task. The primary task was a body-position memory task in which participants viewed videotapes of a human model posed in a variety of positions. Before each trial, participants were cued to focus on either the model's arm or leg positions, because if the model changed her pose, it would be by moving the cued body part. Thus, the cues were 100% valid. The first stimulus was presented for 10 s, followed by a blank screen for a 5-s interval, and then a second stimulus was presented. The participants' task was to determine whether the second stimulus was the same or different than the first stimulus.

While viewing the videotape, participants performed one of three secondary task conditions: unrestricted but nonrepetitive arm movement, nonrepetitive leg movement, and mental multiplication with no movement. Participants stood while engaging in the secondary task. They were instructed to start moving or multiplying when the first stimulus appeared and stop moving or multiplying when the second stimulus appeared. Participants moved both arms or both legs, and the experimenter watched participants closely to ensure that they were performing nonrepetitive movements that did not imitate the pose of the model.

The mental multiplication condition was included to provide a no-movement condition that preserved the dual-task requirement. Prior to the beginning of the experimental trials, participants were questioned regarding their memorization of multiplication tables. During the experiment, participants solved double-digit multiplication problems for which they did not have the answers memorized. For the mental multiplication task, a multiplication problem was selected randomly from the set and given to the participant at onset of the first stimulus. Participants then solved the multiplication problem out loud while watching the videotape.

Participants were given six practice trials in which they moved

their arms, moved their legs, and solved mental multiplication problems while they judged practice stimuli. Experimental trials followed in which there were four blocks of 20 trials each. For each block, participants either moved one part of the body or performed mental multiplication out loud; thus, there was a total of 80 trials (20 trials of arm movement, 20 trials of leg movement, and 40 mental multiplication trials). The order of body-part movement and mental multiplication was rotated over participants. Response accuracy was recorded.

At the end of the experiment, participants were asked to introspect on how they performed the body-position memory task. They were explicitly asked whether they were making a mental image of their own body or the model's body or whether they were creating a verbal label or description of the pose for comparison. Last, they were asked whether they had any dance, athletic, or martial arts training that might facilitate their ability or change their strategy for encoding the model's body position.

Results and Discussion

The proportion of error was calculated for each cued part in each secondary task. Two participants exhibited over 35% error on at least three of the four conditions and were eliminated from the analyses. The overall mean error rate was 21.5%.

An ANOVA on secondary task condition (arm movement, leg movement, and mental multiplication) and cued body part (model's arms and model's legs) was conducted for proportion error data. A significant effect was found for cued body part $F(1, 23) = 15.30$, $p < .001$, such that changes in the model's arm position were easier to detect than changes in leg position, 17.6% and 25.3% error rate, respectively. There was no significant main effect of secondary task condition, $F(2, 46) < 1$. Mean percent error for arm movement, leg movement, and mental multiplication were 21.2%, 21.5%, and 21.7%, respectively. The critical prediction of the body schema hypothesis of an interaction between secondary task condition and cued body part was significant, $F(2, 46) = 3.93$, $p < .03$ (see Figure 3).

When the secondary task was arm movement, participants detected more changes in the model's arm position than in leg position, even though whenever the model's leg position changed, the participant was cued to attend to her legs. The opposite trend was obtained when participants moved their legs. Although the latter trend was smaller, the results of the mental multiplication condition show that this was due to the generally more difficult nature of the trials on which the model's leg position was changed.

The crossover pattern of the interaction supports the hypothesis that the body schema is an articulated, spatially organized representation that distinguishes between upper and lower portions of the body. The particular portion of the participant's body being moved influenced the participant's ability to detect changes in the model's body position depending on the part of the model's body that changed position. Relative to the baseline mental multiplication condition, both movement conditions showed facilitated performance when the same body part was cued and then moved, and impaired performance when the different body part was cued and then moved. This relative facilitation and inhibi-
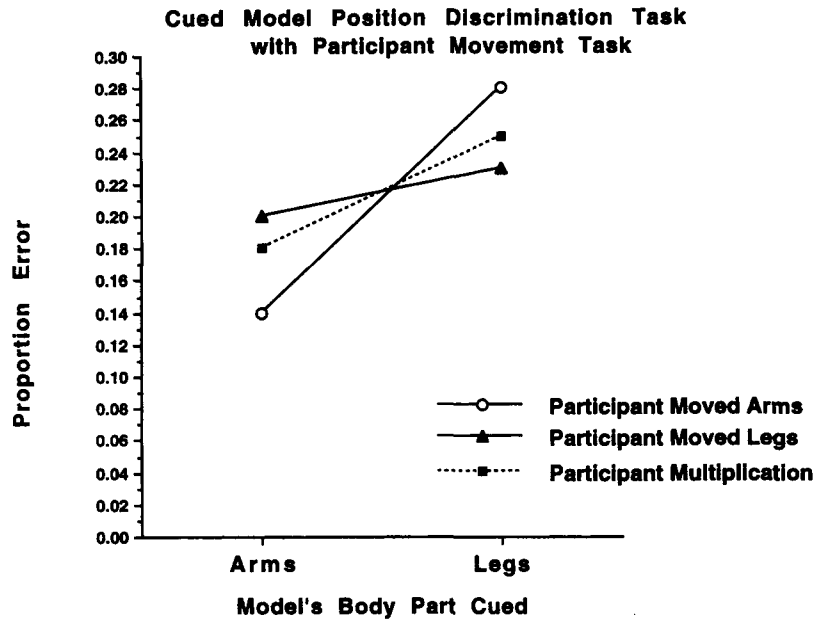
Cued Model Position Discrimination Task
with Participant Movement Task

Figure 3. Results of Experiment 2. The secondary tasks of arm movement, leg movement, and mental multiplication are plotted for mean proportion error when the model's arms and legs are cued.

tion is surprising, especially because people were explicitly told where to look for changed in the model's body position. We can therefore conclude that the results of this experiment and Experiment 1 are not due to a strategic deployment of selective attention by participants.

Participants were grouped according to their postexperimental introspections about their encoding strategies for the visual body position discrimination task. No significant group differences were found between participants using a mental image and those using a verbal description to compare the memory and target poses. Dance, athletic, or martial arts training also did not facilitate participants' ability to encode the model's body position or influence their reported encoding strategies.

These results support the hypothesis that the body schema represents people's own body positions, perceived kinesthetically or proprioceptively, and positions of other human bodies perceived visually. The body schema appears to have an internal organization, with distinct representations of different body parts, at least upper and lower body. Apparently, using one part of the body schema to monitor self-movement automatically primes, or engages attention to, the corresponding parts of other, visually encoded bodies.

In the next two experiments we tested and ruled out two additional alternative accounts of the selective facilitation effect. Experiment 3 addresses the possibility that the selective facilitation effect may arise from the use of a mnemonic strategy by which participants use their own bodies to encode the model's position. Experiment 4 investigates whether the interaction found here may be the result of a more general difference in distinguishing between the top

and bottom parts of any kind of object, including but not specific to the body.

Experiment 3

Although we have tentatively concluded that the results of Experiments 1 and 2 reflect the automatic engagement of the body schema during one's own movements, which mandatorily primes or directs attention to the corresponding parts of other, viewed bodies, it is also possible that these results can be explained by a simple mnemonic strategy, and have nothing to do with a body schema. Perhaps participants were using their own bodies to encode the model's position. The relative facilitation could then be the result of participants surreptitiously passing through the model's position as they move.

To test this explanation, we pitted it directly against in the body schema hypothesis. The experimental paradigm was the same as the previous experiments, except that before participants began moving one body part (e.g., legs), they were to explicitly match the other body part (e.g., arms) to the model's position. They were also instructed (as in Experiment 2) to avoid mimicking the model's position while they moved, and the experimenter monitored them to verify compliance. If matching the model's position is causing the facilitation effect, then the facilitation should be found for the part of the body that matches the model's position. If the use of the body schema to monitor one's own movements is causing the facilitation effect, then the facilitation should be found with the opposite limbs, those that moved nonrepeti-

tively during the trial. Thus, the two hypotheses make opposite predictions.

Method

Participants. Nineteen people from the University of Pennsylvania community were paid for their participation.

Stimuli. The same stimuli were used as in Experiments 1 and 2.

Design and procedure. Experiment 3 used a completely within-subject factorial design with the factors secondary task (match model's arm position and move legs or match model's leg position and move arms) and cued body part (model's arms or model's legs).

The same basic dual-task paradigm was used in Experiment 3 as in the previous experiments with the following exception. For the secondary task, participants were instructed to explicitly match one half of the model's body position before moving. When the first stimulus appeared, participants were instructed to match the position of either their arms or their legs to that of the model's; the other half of their body was to remain straight. After establishing the position, participants were instructed to resume a straight position and then move nonrepetitively the body part that was not matched until they made their "same" or "different" judgment. We also told them to avoid incorporating the model's position during the nonrepetitive movement, and the experimenter monitored for compliance.

Results and Discussion

The proportion of error was calculated for each cued part in each secondary task. Two participants exceeded a 35% error rate and were eliminated from the analyses. The overall mean error rate for the remaining participants was 27.6%. No participant was observed to match the model's position during nonrepetitive movement.

We conducted a secondary task (match arm and move leg or match leg and move arm) and cued body part (model's arms or model's legs) ANOVA. A significant effect of secondary task was found, $F(1, 16) = 4.627$ $p < .05$, indicating that the match arm and move leg condition was more difficult than the match leg and move arm condition. The cued body part effect did not reach significance, $F(1, 16) < 1.0$. Most important, we found a statistically significant interaction, $F(1, 16) = 25.04, p < .0001$. The pattern of means, shown in Figure 4, indicated that selective facilitation was found for the body part that was moved rather than for the body part that was matched.

These findings suggest that the selective facilitation effect results from the use of a common body schema for monitoring one's own movements and encoding and remembering the positions of other bodies. The effect of transiently matching another's position on memory for that position is negligible compared to the effect of engaging the body schema. Given this result, we now address the question of whether our findings are specific to the body.

Experiment 4

On the basis of the previous experiments, we can infer that there are some shared mechanisms for the proprioceptive representation of the self's body position and the visual perception of others' body position. However, our results may not be specific to body representations. They may be the result of a general difference in attending to the upper
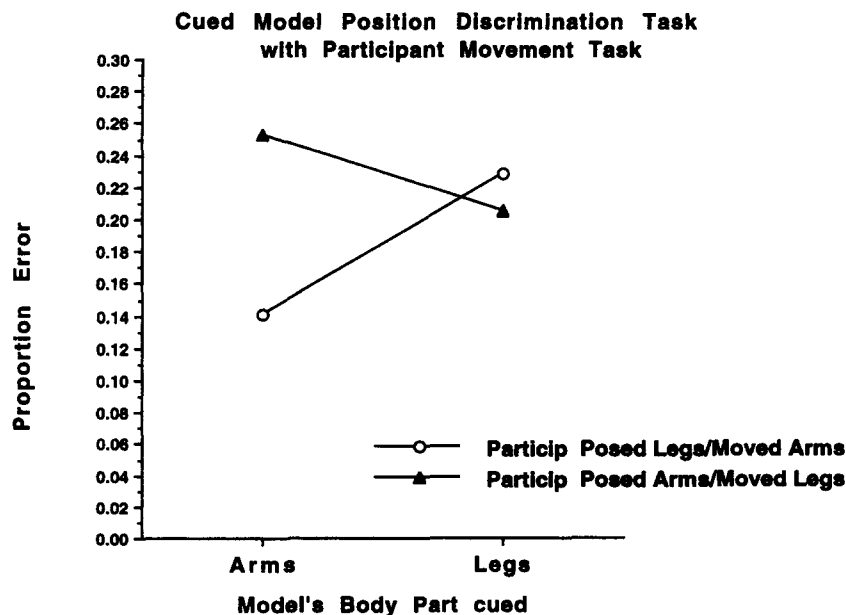

Figure 4. Results of Experiment 3. The secondary tasks of matching the model's leg position while moving arms and matching the model's arm position while moving legs are plotted for mean proportion error when the model's arms and legs are cued. Particip = participant.

parts versus the lower parts of objects. In this experiment, we again use the dual-task paradigm. We compare the accuracy of position memory in two matching task conditions (an object position memory task and a body position memory task) and two secondary tasks (arm movement and leg movement). If a common body representation is activated for body perception only, we would expect there to be an effect of body part movement for the body stimuli but not for the object stimuli. Alternatively, if the effect is due to the perception of upper and lower parts of objects, an interaction should be found for both types of stimuli.

Method

Participants. Participants were 24 individuals from the Carnegie Mellon University community who were paid or received partial course credit.

Stimuli. The stimuli used in the previous experiments were used in the body position memory task. In addition, two more videotapes of LEGO block figures were made for the object-position memory task. The block figures were constructed in a manner similar to the stimuli in the body position task. The figures were asymmetric, nonanthropomorphic configurations that were designed to be visually distinguishable from each other but to discourage verbal labeling. They were made of two different colors, with one color (white) always on the top of the configuration and one color (yellow) always on the bottom. The visual complexity of top and bottom portions was roughly equated by requiring the figure to stand unsupported on both its top or bottom sections. To increase visual discriminability, the block configurations were filmed against a black background. As for the stimuli in the body position task, "different" trials were created by altering a portion of the top or bottom section and leaving the rest of the configuration intact. Examples of the stimuli are shown in Figure 5. As in the body position videotapes, the first configuration was taped from a position directly in front of the block figure, and the second configuration was taped from a 45° angle to the right of the block figure. Also, the two block figures could be either the same

or different in terms of either the top or bottom sections, but not both. Each figure was exhibited for 10 s with a 5-s interstimulus interval.

Design and procedure. Experiment 4 used a completely within-subject factorial design. For the body position and object position memory tasks, the factors were secondary task (arm movement or leg movement) and cued part (either arms and legs or white and yellow, respectively).

The procedure was similar to that used in Experiment 2. For the primary task, participants viewed videotapes either of a human model in a variety of poses or of block figures. Before each trial for the body position task, participants were cued to attend to changes in either the model's arms or legs. For the object position task, participants were cued to attend to changes in either the white (top) or the yellow (bottom) part of the figure. While viewing the videotape, participants performed a secondary task. Participants sat and engaged in either nonrepetitive arm movements or nonrepetitive leg movements. They were instructed to stop moving after the response.

Participants were given eight practice trials, in which they moved their arms or moved their legs while they judged practice stimuli. Experimental trials followed in which there were four blocks of 20 trials each; thus, there was a total of 80 trials (20 trials of arm movement and 20 trials of leg movement with the body position stimuli and 20 trials of arm movement and 20 trials of leg movement with the object position stimuli). The order of body part movement and memory tasks was rotated over participants. Response accuracy was recorded.

As in Experiment 2, participants were asked to introspect on how they performed the two memory tasks. In addition, they were asked whether they had any dance, athletic, or martial arts training that might facilitate their ability or change their strategy for encoding the model's body position.

Results and Discussion

The proportion of error for cued parts was calculated for each condition. Four participants exhibited over 35% error rate on at least three of the four task conditions and were
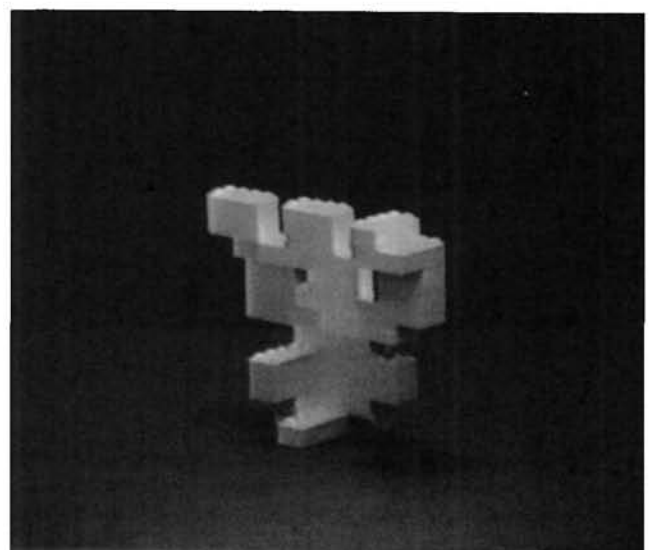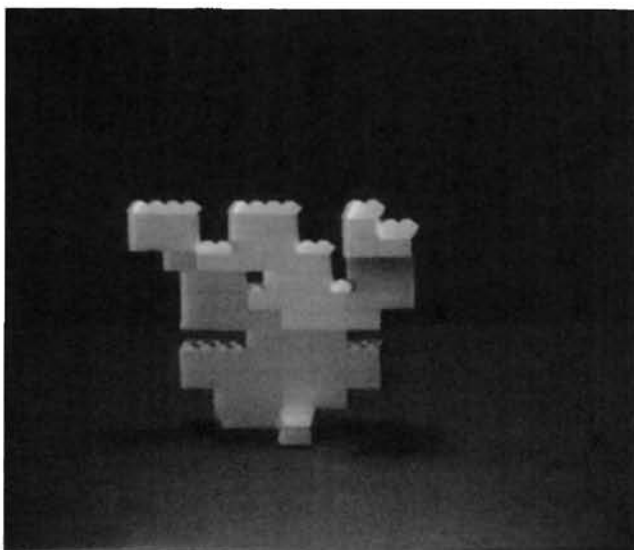

Figure 5. Examples of a "different" trial block position stimuli. The first configuration (left) is photographed from a position directly in front of the model. The second configuration (right) is photographed from a position 45° to the right of the model.

eliminated from the analyses. Mean overall error rate was 20%.

For each memory task, an ANOVA on secondary task and cued part was performed for proportion error data. The errors for the two tasks were analyzed separately because different parts of the stimuli were cued. In addition, the object stimuli were more difficult to discriminate than the body stimuli. For the body position memory task, there was no significant main effect of secondary task, $F(1, 18) = 1.96, p > .10$, or cued stimulus part, $F(1, 18) < 1.0$. As in Experiments 1 and 2, the critical prediction of the body schema hypothesis of an interaction between cued part and secondary task was significant, $F(1, 18) = 9.43, p < .007$. When the secondary task was to move their arms, participants made fewer errors detecting changes in arm position than in leg position. Again, the opposite trend was found when participants moved their legs.

In contrast, the ANOVA for the object position memory task produced no significant effects of secondary task, $F(1, 18) < 1.0$, cued part, $F(1, 18) < 1.0$, or the interaction, $F(1, 18) < 1.0$. When participants moved their arms or moved their legs, they made the same number of errors detecting changes in the white upper portions of the block figure as in the yellow lower portions of the block figure. No additional systematic effects were found for participant strategies or athletic experience in either task.

Thus, our hypothesis that the interaction between secondary task and cued part was due to attending upper and lower object parts was not upheld. The proprioceptive information from the movement of different body parts did not differentially influence the visual perception of block configurations. Figure 6 illustrates the results for both memory tasks.

These results support the hypothesis that there is a representation of the human body that is not shared by other objects.

General Discussion

The body schema, a representation devoted to the spatial relations among parts of the human body and separate from other spatial knowledge, has been invoked in the neuropsychological literature to explain a variety of spatial disorders after brain damage. The experiments in this paper tested the psychological reality of the body schema in individuals without brain damage using a dual-task procedure. These experiments demonstrated that various characteristics of the body schema inferred from neuropsychological research were true of the representations used by participants without brain damage to monitor body position. Specifically, we found evidence in participants without brain damage for a body schema that is supramodal, in that it applies to both visual and proprioceptive inputs. Our results also confirm that the body schema is used for encoding body position for both the self and others. In addition, the body schema is articulated into spatially distinguished subparts, at least to the extent that arm position is differentiated from leg position. Last, this representation of body position is separate from representations used to remember the positions of other complex objects.

Contrary to our expectations, use of one part of the body schema facilitates rather than interferes with the perception of homologous areas of other people's bodies. Moreover, the effect is a robust one in that it was not eliminated by
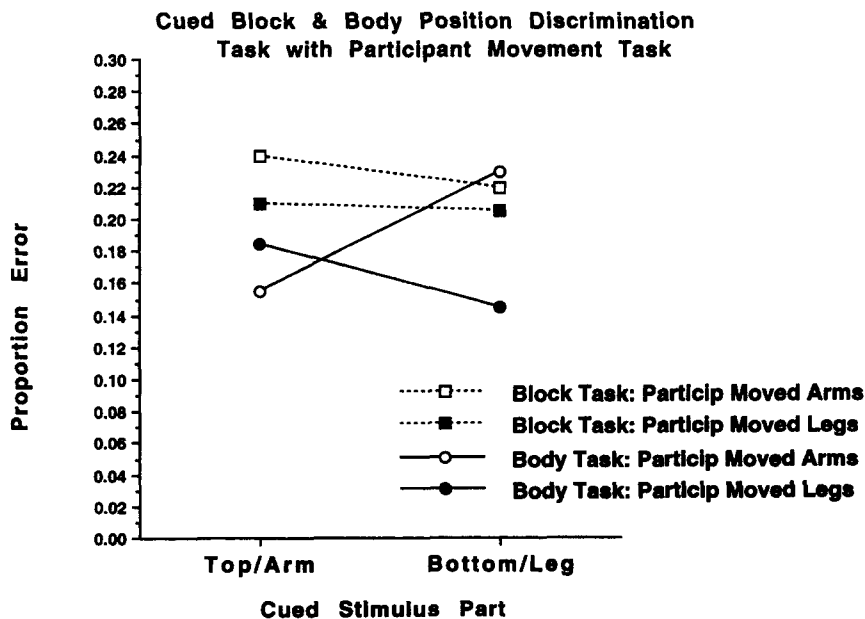

Figure 6. Results of Experiment 4 for both body and block stimuli. The secondary tasks of arm movement and leg movement are plotted for mean proportion error when the model's arms and legs are cued or the top or bottom portions of the block configuration are cued. Particip = participant.

cuing participants with completely reliable information concerning the part of the model's body that might change position. The fact that body schema effects were found even when it caused participants to attend to the noninformative part of the model's body implies that the body schema is evoked mandatorily during the perception of a human body. Thus our results reveal two ways in which the body schema meets the criteria described by Fodor (1983) for a mental system to be a module. It is both specialized for processing a particular type of content, namely the spatial characteristics of the body, and as just mentioned, it is engaged mandatorily.

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