Body Schemas

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Abstract

Two studies investigated the existence and properties of the body schema, people's mental representation of the space of their bodies. Participants verified whether a named and a depicted body part were the same or different either when presented a picture of a whole body or when presented the body part alone. Part significance accounted for verification times better than part size or part discontinuity, suggesting that mental representations of the body reflect proprioceptive as well as visual knowledge.

Introduction

In 1935 in *Image and Appearance of the Human Body*, Schilder wrote that "The image of the human body means the picture of our own body which we form in our mind, that is to say the way in which the body appears to ourselves" (p. 11). Although researchers have long been interested in what comprises the body schema, many questions remain unanswered. What characterizes mental representations of the body? Like objects, bodies are visual stimuli. Unlike objects, bodies are also experienced proprioceptively from within as people act on the world. Body schemas, then, should reflect sensorimotor knowledge in addition to visual knowledge.

Several lines of evidence indicate that body kinematics affect mental representations of bodies. Parsons (1994) put forth that the body schema is based on both perception and action and represents the spatial orientation of the body and its parts. He found that the time to judge whether a depicted hand was a right or a left hand correlated with the time to move one's hand into the depicted position. This suggests that people perform mental kinematic transformations in order to make the judgments. PET images from such a task yielded activation in the posterior and inferior parietal cortex (Parsons *et al.*, 1995), areas know to be involved in planning body action (R.A. Anderson, 1995; Stein, 1991; Stein, 1992).

Reed and Farah (1995) hypothesized that body movement would engage the body schema when judging whether pairs of photos of complex body positions taken from different angles were of the same pose or of different poses. They found that upper body movement facilitated detecting upper body differences and lower body movements facilitated detecting lower body differences. No analogous effects were found for detecting differences in Lego structures. In a task requiring participants to shift their attention from one stimulated body part to another, Lakatos and Shepard (1997) also found faster responses to the upper body than to the lower body. In addition, Lakatos and Shepard found that responses were faster when body parts were closer in real space suggesting that the body schema is keeping track of current spatial positions.

Some neuropsychological research also supports the existence of a separate body schema. Guariglia and Antonucci (1992) studied the body schema of a man with an internal capsular lesion in the right hemisphere which involved the basal nuclei. This patient suffered from severe personal neglect of the left side of his body. His schema of the space beyond his body was unimpaired, implying that only the body schema was damaged by the lesion.

There is evidence, then, that mental representations of the body may include proprioceptive knowledge of the body in tasks where information about position and orientation of body parts is needed or where there is actual movement or stimulation. Would proprioceptive knowledge be reflected in a purely visual task, such as verifying whether a named body part is the part cued in a picture of the body? There are two theories from the object recognition literature that make predictions about which body parts will be most rapidly verified. According to the *image size theory*, larger body parts should be verified faster than smaller ones. Kosslyn (1976) reported that when asked to verify whether an imaged animal, such as a rabbit, had a named part, such as a back or ears, participants were faster to verify large parts when they verified from their images. On the basis of the image size theory, parts like back and leg should be verified more quickly than parts like hand and foot. According to the *part discontinuity theory*, parts that have greater discontinuity from the object contour should be verified more quickly. Several theorists have proposed that objects are recognized when we decompose them into their parts and recognize their parts (Hoffman & Richards, 1984; Biederman, 1987). These theories propose that part decomposition occurs at inflection points or points of greater discontinuity along the object contour. On the basis of the part discontinuity theory, parts like head and foot should be verified faster than parts like chest and back.

A third theory, the *part significance theory*, incorporates knowledge about behavior and function as well as knowledge about appearance. Tversky and Hemenway (1984) found that when participants rated the "goodness" of various parts of objects, animate and inanimate, those parts with the highest ratings had both functional significance and perceptual salience. Part significance would predict that those body parts that are the highest in these two qualities, functional significance and perceptual salience, would be responded to more rapidly than those with less functional significance and perceptual salience. More significant body parts, then, would be expected to have greater sensory and motor enervation underlying greater motor agility and greater sensory sensitivity. The index of part significance we adopted was relative size in the sensorimotor cortical map and cutaneous sensitivity, which are correlated. The often depicted "homunculi" in the postcentral gyrus for somatosensory information and in the precentral gyrus for motor information show some relatively smaller body parts, such as hand, with relatively larger cortical representation than some larger parts, such as back (Penfield & Rasmussen, 1950). These findings correspond with findings on two-point skin thresholds which are much lower for body parts like head, hand, and foot than for relatively larger parts like leg and back (Weinstein, 1968). On the basis of the part significance theory, highly significant parts like head and hand should have faster verification times than less significant parts like back and leg. Note that because part significance is also affected by perceptual salience, the three theories may make similar predictions. However, the theories differ in predicting verification times among specific combinations of parts. For example, hand is smaller than foot but is more significant, and chest has less contour discontinuity than leg or foot but has greater significance.

Experiment 1: Whole Body Part Verification

In this experiment, participants saw the name of a body part followed by a picture of a body with a part cued. Their task was to respond "same" if the named and cued body parts were the same, and to respond "different" otherwise. The body parts selected were those that are most commonly named across cultures (E.S. Andersen, 1978; Brown, 1976; Burton & Kirk, 1979) and those that are more or less in the same size scale.

Method

Participants. Twenty-four Stanford University undergraduates participated for course credit. The data from four participants were discarded; one due to a computer error during testing, and three due to error rates greater than 10%. The results from 11 women and 9 men were analyzed.

Stimuli. Twelve different poses of realistic-looking human bodies were created using the software Fractal Design Poser (1995), two for training and ten for testing (See Figure 1). Poses were selected to represent a broad set of human postures. All poses were in profile to eliminate left/right judgments, with direction the body was facing counterbalanced across poses. The poses were created to maximize the amount and types of body part comparisons as well as to maximize the possible distance between various body parts. Each body was shown in three orientations: 0°, 90°, and 180°. Seven body parts were highlighted on each body using a uniform sized white dot placed approximately in the center of the body part. The seven highlighted parts were the head, arm, hand, chest, back, leg, and foot.

Figure 1: Four Testing Poses

Design. Fourteen questions were asked of each body at each orientation, seven "same" questions and seven "different." Four random orders of the testing stimuli were created with the constraint that the same pose, the same named part, or the same highlighted part could not appear more than three times in a row. No orientation appeared more than four consecutive times. There was a training block of 20 trials followed by 10 blocks of test trials with 42 trials per block yielding 420 trials per participant.

Equipment. This study was run on the Apple Power Macintosh 7200/75 using PsyScope (1994) software. Reactions times were measured using the PsyScope "Button Box" to millisecond accuracy.

Procedure. Participants sat before the Apple Macintosh computer and they were told that they would see a series of trials; first the name of a body part for one second, then an asterisk fixation point for half a second, then an image of a body with a part cued. Their task was to respond as quickly and as accurately as possible to whether the named body part was the same as or different from the cued body part by pressing the appropriate keys on the button box. The image would remain on the screen until the participant responded. To initiate a new trial, the participant was instructed to press the third key on the button box. Once the instructions were given, the participants completed the twenty-trial training session after which they were informed that the testing would begin. Following the training, participants completed the experiment at their own pace.

Results and Discussion

Errors and reaction times greater than two standard deviations from the participant's mean were removed from the data.

All Responses. An alpha level of .05 was used for the remaining statistical analyses. Due to limitations imposed by the coding of the data, four one-way analyses of variance (ANOVAs) were employed in the analysis of the following independent variables: answer, sex, testing version, and pose. Participants were faster to correctly respond "same" ($\underline{M}$ = 797 ms) than "different" ($\underline{M}$ = 863 ms; $\underline{F}$ (1,19) = 22.68, $\underline{p}$ < .001), suggesting that an extra verification process is performed before responding "different." This process most likely includes checking both the named position on the body and looking to see where the dot actually is located before responding. Neither sex, $\underline{F}$ (1,18) = 0.046, n.s., nor testing version, $\underline{F}$ (3,36) = 0.096, n.s., differentially affected the results. The body pose factor was significant ($\underline{F}$ (9,171) = 2.84, $\underline{p}$ =.004) indicating that some poses were responded to faster than others. The ordering was uninterpretable as other respondents' groupings of the poses did not correlate with the reaction time ordering. The body pose factor was not included in further analyses since including it had no differential effects on the outcome of the other analyses.

The next two sets of analyses were conducted on "same" and "different" responses separately because the theoretical questions of interest differed.

Same Responses. The effects of orientation (0°, 90°, 180°) and named body part (arm, back, chest, foot, hand, head, leg) were investigated in a two-way ANOVA. Participants responded most quickly to the 0° orientation ($\underline{M}$ = 776 ms) followed by the 90° orientation ($\underline{M}$ = 806 ms) and the 180° orientation ($\underline{M}$ = 810 ms; $\underline{F}$ (2,38) = 9.07, $\underline{p}$ <.001). Unlike earlier studies, this study did not use small increments of rotation (Cooper, 1975; Cooper & Shepard, 1973) and the poses were repeatedly shown which could account for the lack of meaningful orientation effects in both the same and different conditions.

Figure 2 depicts participants' significantly faster responses to some body parts as compared to others ($\underline{F}$ (6,114) = 10.21, $\underline{p}$ < .001). Tukey's W Procedure revealed two points where one body part significantly differed from the next in terms of reaction time ordering: between head and chest and between arm and leg. The orientation x named body part interaction was not significant, $\underline{F}$ (12,228) = 1.11, n.s.

Table 1 portrays the actual ranking of body parts by reaction times and the predictions from each of the three theories. For the data, the seven parts were divided at the points where two sequential body parts differed significantly. For image size, the largest body parts, chest, back, leg, and arm, were grouped separately from the smallest parts, head, hand, and foot. For contour discontinuity, those parts with

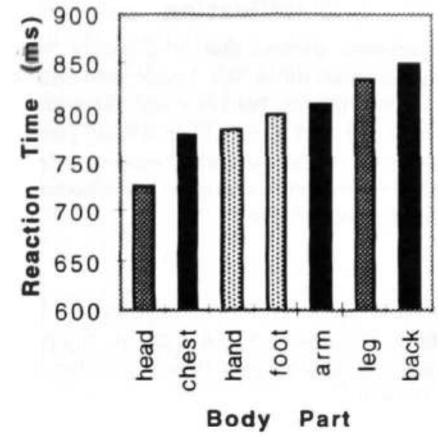

Figure 2: Body Part Verification Times

a similar degree of discontinuity were grouped together. Thus, head, hand, and foot were placed in Group 1, arm and leg in Group 2, and chest and back in Group 3. For the part significance groupings, using as an index relative size in the sensorimotor cortical map and cutaneous sensitivity, Group 1 consisted of head, hand, and foot, Group 2 of chest, and Group 3 of arm, leg, and back.

Body Part	Data	Image Size	Contour Discontinuity	Part Significance
Head	1	2	1	1
Chest	2	1	3	2
Hand	2	2	1	1
Foot	2	2	1	1
Arm	2	1	2	3
Leg	3	1	2	3
Back	3	1	3	3

Table 1: Data Rankings and Theoretical Rankings for Body Part Verification

When the Spearman Rank-Order Correlation was conducted on these rankings of body part, the data correlated most highly with part significance ($\underline{r}$ = .732, $\underline{p}$ < .09). The data did not significantly correlate with contour discontinuity ($\underline{r}$ = .590, n.s.). A negative correlation was found between the data and image size ($\underline{r}$ = -.644, n.s.); yet, this correlation did not reach significance. It is important to keep in mind that having only seven body parts, and thus only seven data points, creates difficulty when trying to find significance through correlational analysis. However, the correlational evidence does suggest that the body schema differs in terms of part significance, rather than by contour discontinuity or by image size.

Different Responses. Orientation did not have a significant effect on different responses, $\underline{F}$ (2,38) = 0.34, n.s.

Experiment 2: Disembodied Part Verification

The first experiment showed that in a purely visual task body part verification times are better predicted by part significance, which reflects behavior and function, than by part discontinuity or part size, which reflects purely visual factors. Perhaps this is due to configurational effects of the body. In this experiment, we present disembodied parts to remove configurational effects.

Method

Participants. Twenty-six Stanford University undergraduates participated for course credit. Six participants were removed for error rates over 10% leaving the data of 10 women and 10 men.

Stimuli. The 12 poses used in Experiment 1 were modified to include the presentation of a single body part at a time (See Figure 3). Each of the 12 poses was divided into its component parts (head, hand, arm, foot, and leg) preserving the location and position of each individual part. Chest and back were eliminated due to the difficulties of recognizing them in isolation.

Figure 3: Disembodied Parts

Design. The design was identical to that of the first experiment except that ten questions were asked about each set of body parts, participants only performed one block of fifteen trials for training, and only performed ten blocks of 25 trials each for the testing session.

Equipment and Procedure. The equipment and procedure were identical to that used in Experiment 1.

Results and Discussion

Errors and reaction times greater than two standard deviations from the participant's mean were removed prior to data analysis as they were in Experiment 1.

All Responses. An alpha level of .05 was used during the following analyses. Similar to Experiment 1, participants responded more quickly to "same" ($\underline{M}$ = 768 ms) than to "different" ($\underline{M}$ = 857 ms; $\underline{F}$ (1,19) = 55.36, $\underline{p}$ < .001). Women were faster ($\underline{M}$ = 727 ms) than men ($\underline{M}$ = 877 ms; $\underline{F}$ (1,18) = 5.23, $\underline{p}$ < .035). Testing version, $\underline{F}$ (3,16) = 1.32, n.s., was not significant.

Since orientation differences did not yield interesting results in Experiment 1 and since it was difficult to ascribe orientation to the body parts alone, the effect of orientation was not analyzed for either the same responses or the different responses.

Same Responses. A one-way ANOVA was used to investigate the effects of named body part (arm, foot, hand, head, leg). Reaction times to identify body parts significantly differed ($\underline{F}$ (4,76) = 17.85, $\underline{p}$ < .001) and the ordering nearly replicated that found in the first experiment (see Figure 4). Tukey's W Procedure showed significant differences between the grouping of head and hand and the grouping of arm, foot, and leg. These data support the earlier conclusion that the body schema is structured in terms of part significance, rather than by size of body parts or contour discontinuity. Error rates for the various parts were ordered almost the same as the RTs and ranged from 2.0% for head to 6.5% for arm.

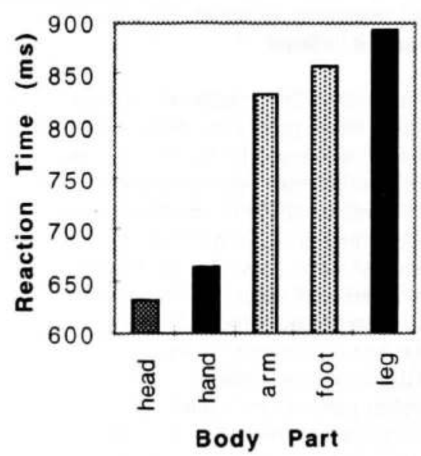

Figure 4: Disembodied Part Verification Times

General Discussion

People experience the human body both from the inside and from the outside. Previous research, both behavioral and neuropsychological, has suggested that mental representations of the body reflect both the outsides, that is the appearance, and the insides, that is, proprioceptive knowledge, of the body. The prior research derived from tasks that specifically invoked proprioceptive knowledge. Here, we investigated mental representations of the body in a purely visual task, one in which participants were asked to verify whether a named body part was the same as a depicted one. The body parts probed were those that are most commonly named across languages.

Three theories making different predictions about verification times for the various body parts were presented. According to the image size theory, larger parts should be more readily detected than smaller ones. According to the contour discontinuity theory, parts with greater contour discontinuity should be detected faster. Both these theories rely only on visual information. The third theory, the part significance theory, also takes into account the behavior or function of body parts. An index to part significance is the relative area of projection in sensorimotor cortex or the correlated cutaneous sensitivity of the various parts.

Of the three theories investigated, the part significance theory best predicted the speed of verifying body parts. Verification times were also positively (but insignificantly) related to part discontinuity, but negatively (and insignificantly) related to part size. Though the ordering of verification times was consistent with the part significance theory, with so few data points the correlation did not reach significance. Qualitatively, the results are consistent only with the part significance theory. The facts that hand was significantly faster than leg and back, arm was significantly faster than leg, and foot was significantly faster than leg and back refute the image size theory. The contour discontinuity theory cannot account for the finding that chest had faster verification times than arm, foot, and leg, all parts with greater discontinuities of contour.

Part significance accounted for part verification times both for body parts presented in the context of a body and for disembodied body parts, indicating that the configurational information provided by the body is not essential. People's knowledge about function and behavior of body parts seems to be invoked in verifying body parts in a purely visual task, suggesting that sensorimotor knowledge as well as visual knowledge is inherent in mental representations of the body.

There remains the intriguing possibility that part significance would predict part verification times in objects as well as in bodies, a possibility we are currently investigating. For most common objects, part significance and part size are correlated (Tversky & Hemenway, 1984) so only highly selected objects can be studied. Nevertheless, if part significance dominates size and discontinuity in objects as well as bodies our account may need to be modified.

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