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Perceived Spatial Organization of Cutaneous Patterns on Surfaces of the Human Body in Various Positions

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The perceived spatial organization of cutaneous patterns was examined in three experiments. People identified letters or numbers traced on surfaces of their body when the relative spatial orientations and positions of the body surfaces and of the stimuli were varied. Stimuli on the front or back of the head were perceived with respect to a frame of reference positioned behind those surfaces, independent of the surfaces' position and orientation. This independence may relate to the way in which the sensory apparatus on the front of the head is used in planning action. Stimuli on other surfaces of the head and body were perceived in relation to the position and orientation of the surface with respect to the whole body or trunk (most of which was usually upright). Stimuli on all transverse/horizontal surfaces were perceived with respect to frames of reference associated with the head/upper chest area. These frames were also used for stimuli on frontoparallel surfaces in front of the upper body. These observations may result from the use of "central" frames of reference that are independent of the head and are associated with the upper body. Stimuli on surfaces in other positions and orientations (with two exceptions) were perceived "externally"—that is, in frames of reference directly facing the stimulated surface. The spatial information processing we found may be fairly general because several of our main findings were also observed in very young children and blind adults and in paradigms studying perception by "active touch" and the spatial organization of the motor production of patterns.

In 1977, Corcoran reported intriguing demonstrations of the perception of cutaneous patterns on surfaces of the hand, head, and thigh. An upright *2* traced on a backward-facing back of a subject's hand or the back of the head was perceived as a normally oriented *2,* whereas an upright *2* traced on a forward-facing palm or on the forehead was perceived as its upright mirror image. This pattern of perceptions on forward- and backward-facing body surfaces was also observed when the hand's orientation was reversed. An upright *2* traced on a backward-facing palm was perceived as an upright *2,* whereas an upright *2* traced on the forward-facing back of the hand was perceived as its upright mirror image. However, not all forward-facing body surfaces showed this tendency for stimuli to be perceived as their mirror images. An upright *2* traced on a standing individual's thigh was perceived as an upright *2*. All of these observations were collected from standing, blindfolded individuals, with their hand in front of their upper chest and head and their head upright and facing in the same direction as the front of the body; other investigators obtained similar results (Allen & Rudy, 1970; Duke, 1966; Krech & Crutchfield, 1958; Natsoulas, 1966; Natsoulas & Dubanoski, 1964; Pedrow & Busse, 1970; Podell, 1966).

These findings are of general interest because they may reveal how the parts, surfaces, and surrounding space of the body are represented for purposes of perception, action, and cognition. There have been recent advances in our understanding of spatial information processing associated with the production of movement (Arbib & Amari, 1985; Pellionisz & Llinas, 1980, 1982; Robinson, 1982; Soechting, 1982; Soechting, Lacquaniti, & Terzuolo, 1986; Soechting & Ross, 1984), and in our understanding of the tactile information transmitted to, and represented in, the cortex (Dellon, 1981; Johannson & Vallbo, 1979, 1983; Johnson, 1983; Johnson & Lamb, 1981; Phillips & Johnson, 1981a, 1981b). However, there have been few studies on how the perceptual system integrates and processes information from tactile receptors.

Perception of Spatial Organization and Frames of Reference

In three-dimensional space, a bidimensionally asymmetric pattern such as a letter or number is intrinsically ambiguous because it can be described within more than one frame of reference. For example, it can be described with respect to an *intrinsic* (or object-centered) frame of reference, as shown in Figure 1 (Hinton & Parsons, 1981; Marr & Nishihara, 1978). It can also be described with respect to an *extrinsic* frame of refer-

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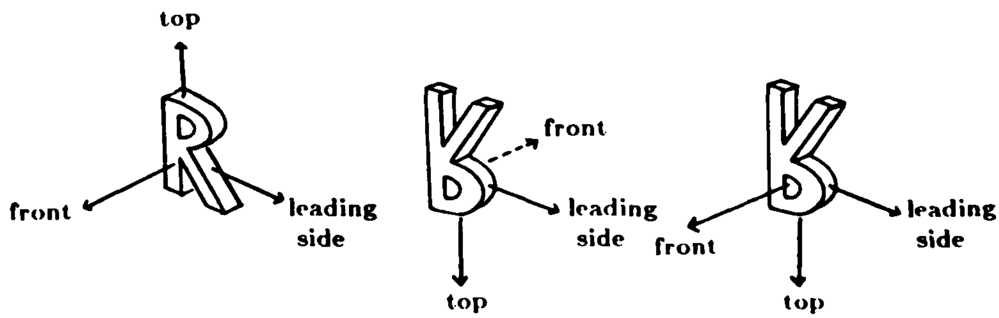

Figure 1. Intrinsic, object-centered frames of reference: An upright and upside-down *R* described in an intrinsic frame and shown from the front and back. (The far right figure is an upside-down, mirror-reversed *R* shown from the front. The difference between the descriptions of two upside-down letters is that the middle one is described in a left-handed frame and the right one is described in a right-handed frame.)

ence—that is, one centered at some location other than on the object, as shown in Figure 2.

Researchers recognize the role of three frames of reference in the perception of shape and spatial relations (Figure 3): that of the perceiver, the perceived object, and the (local) environment containing them (Clowes, 1969; Hinton, 1981; Hinton & Parsons, 1987; Palmer, 1977; Pinker, 1985; Rock, 1973; Sedgwick, 1983; Shepard & Hurwitz, 1984). These three frames of reference are also useful in analyzing the perceived spatial organization of cutaneous patterns on surfaces of the body. However, the situation is complicated because parts and surfaces of the body can adopt many different configurations (cf. Committee for the Study of Joint Motion, American Academy of Orthopaedic Surgeons, 1965).

Generally, the perceptual system must determine the mapping among the possible K orientations (with respect to the environment) of a sensory surface, L configurations of the body, M orientations of the body as a whole with respect to the environment, and N frames of reference that may describe a stimulus. A system could be effective while using only limited regions of this $K \times L \times M \times N$ space of possible mappings if it followed a few principles. Findings like Corcoran's (1977) suggest that this is what people do.

There are three kinds of interpretative systems, each with many possible variants. In an *environment-based* system, cutaneous stimuli are referred to a coordinate system organized either universally (e.g., in directions implied by gravity and a compass) or locally (implied by local landmarks). (This system is not investigated here but in Parsons & Shimojo, 1987.) In a *local surface-based* system, a stimulus is referred to intrinsic features of the stimulated surface (its frame of reference) without regard for the surface's orientation and position (Figure 4A and 4B). (A local surface-based system is embodied in neurological exams, in which the patient is expected to report the identity of cutaneous stimuli from the point of view of an examiner who directly faces the stimulated surface.) In a *whole body-based* system, a stimulus is described in a frame of reference assigned to the trunk or whole body. This frame of reference may be positioned, oriented, and organized in various ways (i.e., using one of the many possible coordinate systems and metrics—see, e.g., Morse & Feshbach, 1953, p. 655 ff.). A surface's position and orientation with respect to the trunk or whole body determines the perceived spatial organization of cutaneous stimuli (Figure 4C and 4D).

Assuming that there is a frame for each principal surface of each body part, a local surface-based system requires about 56 local frames of reference. A whole body-based system requires only a single frame of reference. However, this latter system needs sensorimotor information (cf. Clark & Horch, 1986) about the configuration of the relevant body parts in order to "compute" the coordinates of cutaneous stimulation with respect to this frame of reference. Computing this relation directly or initially facilitates later comparisons of the spatial properties of cutaneous stimulation received at different surfaces or at the same surface but at different times (i.e., with the body, its parts, and the stimulus in different configurations). The information perceived serially from partial cutaneous stimuli could be used to build a representation of the whole object. (This is similar to integrating information gathered from successive glances at an object or scene—see, e.g., Hochberg, 1968; Turvey, 1977.)

The comparison of stimulation received at different moments or at different skin surfaces is likely to be more difficult in a system that uses only local frames of reference because it requires access to representations of configurations of the body, its parts, and the stimulus at arbitrary moments in the past. If the perceptual system requires frequent comparison or integration of spatial information received at different instants or different surfaces, a whole body-based system is more efficient than a local surface-based one.

The topology of surfaces containing an organism's sensory and motor processes, as well as functions of the perceptual system other than those just discussed, may also determine the optimal interpretative system.[1] If peripheral components of the sensory or motor systems are concentrated on some surfaces, those surface might be "privileged," because action and perception are organized or coordinated with respect to those surfaces. Local or special frames of reference might be used for such privileged surfaces, whereas (for the reason described earlier) a whole body-based system might be used for other surfaces.

[1] See, for example, Hecaen and Albert (1978, p. 292 ff.) and Ratcliff (1982) for reviews of solutions to the problem of reorganizing such a system after injury to the nervous system or body.

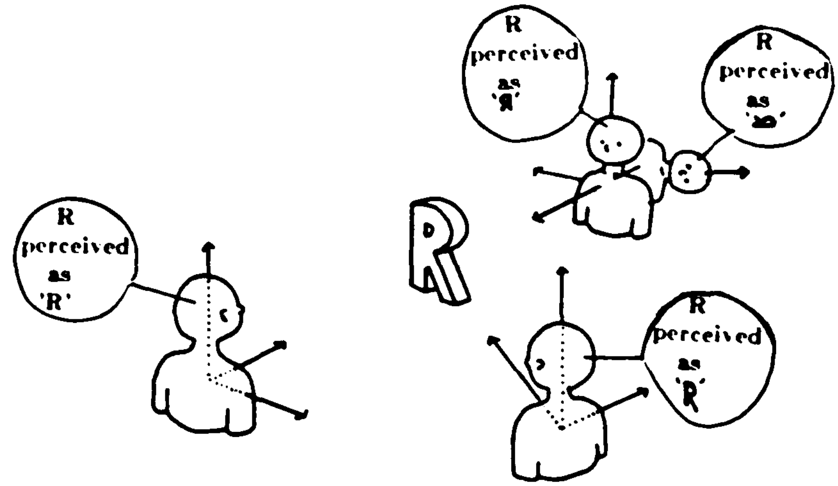

Figure 2. Letter *R* with respect to frames of reference centered at positions other than on the *R*.

Experimental Paradigms and Findings

The position and orientation of the reference frame used to interpret a stimulus on a surface may be revealed by examining how that interpretation is affected by changes in the disposition of a stimulus on a surface and in the disposition of a stimulated surface relative to the whole body (Figure 4). Such methods could signal use of a local surface-based or whole body-based system.

The latter method has been used with limited effectiveness. Results from such studies suggest that only the head's surfaces are described in local frames of reference, whereas other surfaces are described in one or another frame dependent on the body's intrinsic frame (or on a frame that is a compromise among intrinsic frames of the head, trunk, lower limbs, and local environment). Egocentric and environmental frames have been confounded in nearly all preceding work, so it is not known in which of the two frames such stimuli are described: See Oldfield and Phillips (1983) and the General Discussion section.

Previous findings, though useful, are insufficient or too ambiguous to support a full and detailed description of this system. Changes in position have often been confounded with changes in orientation, body part, or body surface; furthermore, few surfaces, orientations, and positions have been examined.

The purpose of the studies we report is to provide a systematic empirical basis for understanding individuals' systems of interpretation for cutaneous stimuli. We first compare perception of cutaneous stimuli at many surfaces of the body in a natural standing position. Then we examine how the perception of cutaneous stimuli on a body surface is influenced by the orientation and position of the surface. (We do not investigate whether for a given spatial relation of the stimulated surface to the whole body or trunk, perception is affected by the configuration of the unstimulated body parts.) We also examine the perceptual system's preference for interpreting stimuli that are multiply ambiguous. A stimulus in Experiments 2 and 3 is ambiguous not only with respect to its "handedness" (whether it is a mirror reversed or normal form of the experimenter-defined stimulus) but also with respect to the orientation of its top–bottom axis.

For brevity, we refer to the experimenter-defined handedness of a stimulus as *external handedness;* we call the opposite-handed version of a stimulus *mirror reversed.*

Experiment 1: Stimuli on Body Surfaces in a Natural Standing Position

In Experiment 1 we surveyed cutaneous pattern perception on many body surfaces of a standing, blindfolded individual. A normal or mirror-reversed *2, h,* or *L* was traced on the surfaces shown in Figure 5. These surfaces were meant to be representative of the whole body. We assumed, as did others, that the perception of spatial organization of cutaneous stimuli on body parts of the left half of the body was indistinguishable from that on body parts of the right half, and therefore we did not com-

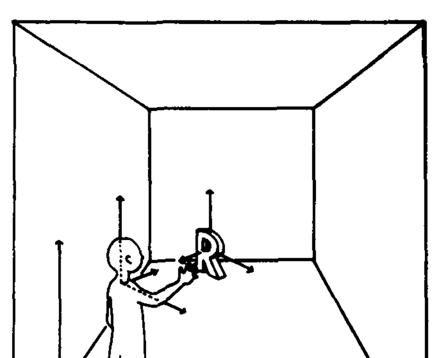

Figure 3. Examples of frames of reference for the perceiver, perceived object, and local environment.

pare the left and right halves.[2] All but four stimulated surfaces were vertical; the others—the top of the tongue and head, and the front and back surfaces of the top of the shoulder—were nearly horizontal. On vertical surfaces, a letter or number was traced with its top oriented upward (toward the top of the body). Stimuli on the top of head and the back of the top of shoulder were traced with their tops pointing forward (facing in the same direction as the front of the body and head). Stimuli on the top of tongue and the frontal surface of the top of the shoulder were traced with their tops pointing backward (facing in the opposite direction that the front of the body and head). The subjects were instructed to report their very first perception of the identity and handedness of the stimulus.

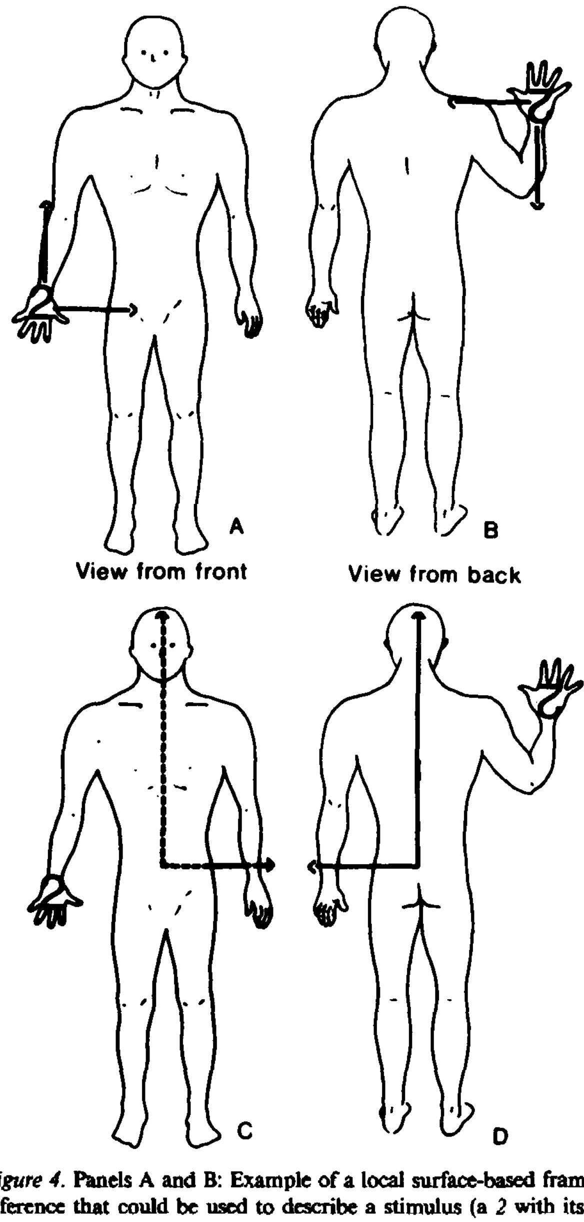

Figure 4. Panels A and B: Example of a local surface-based frame of reference that could be used to describe a stimulus (a *2* with its top toward the wrist) traced on the back of the hand in two different positions and orientations. (In both cases, the stimulus is described as an upright normal version of a *2*.) Panels C and D: A whole body-based frame of reference used to describe a *2* (with its top toward the wrist) traced on the back of the hand in two different positions/orientations in front of the body. (The frame is positioned with its top–bottom axis along the spine. In Case C, the stimulus is described as an upright mirror-reversed *2*; in Case D, it is described as an upside-down normal 2.)

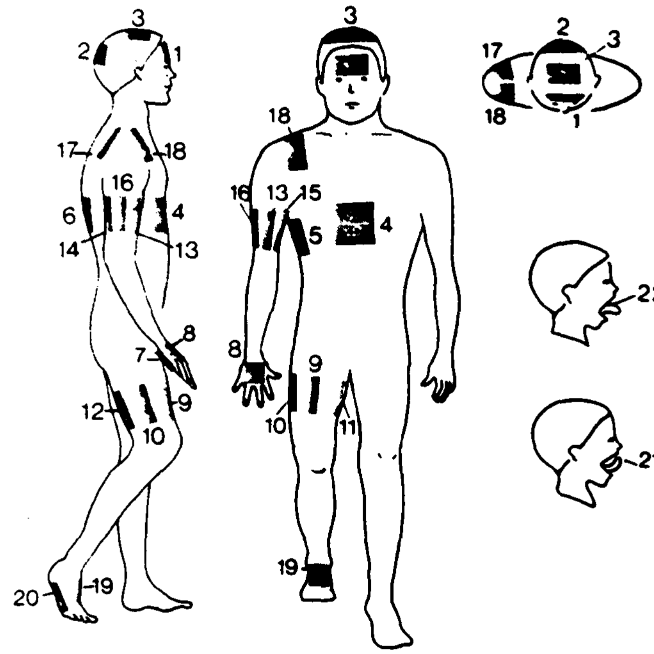

Figure 5. The position and orientation of the body and the surfaces stimulated in Experiment 1.

Method

Subjects. Eighteen male undergraduates at the Massachusetts Institute of Technology, who had not been in any related experiments, received $5.25 per hour for participating in this study.

Stimuli. The characters *2, h, L,* or their mirror reversals were traced with a soft, plastic-tipped stylus either on the skin or on the overlying clothes (Figure 5). Stimuli were as close as possible to 7 × 7 cm in size, and on every trial they were traced with identical strokes, moving from the top of the character downward. The duration and force of the strokes were uniform across characters, surfaces, and trials. The same experimenter traced the characters for all subjects in all the experiments reported here.

Design. Two sets of 66 trials were used, with half of the subjects randomly assigned to perform each set. In each set, half of the characters were mirror reversed and half were normal, and one or the other version of a *2, h,* or *L* was traced on each of 22 body surfaces. A surface never received either all mirror reversed or all normal characters, and it was never stimulated on consecutive trials. The two sets of trials exhausted (without duplication) all possible combinations of body surface, stimulus identity, and stimulus handedness. The order of trials was random and unique for each subject.

Procedure. Subjects first visually inspected ink-drawn versions of six stimuli. Then they stood with eyes covered and performed six practice

[2] However, for evidence that some aspects of the information processing in tactile–spatial tasks differ with respect to the left and right sides of the body, see, for example, DeRenzi, 1982; Hermelin and O'Connor, 1971; Rudel, Denckla, and Hirsh, 1977; Rudel, Denckla, and Spalten, 1974; Smith, Chu, and Edmonston, 1977.

trials with each stimulus drawn on the back of their head and then on their forehead. They were told to report their very first impression of the identity and handedness of each character. It was emphasized that there was no single correct answer, that the experimenter's point of view was not pertinent in any way, and that they need not be consistent across trials but should simply report their spontaneous interpretation of each stimulus as quickly as possible. Then two sets of 33 test trials were performed, with an intervening 5-min break. A trial began with the experimenter's indicating where a stimulus would be traced, and the trial ended with the subject's making a verbal report (e.g., "*L*, normal"). Subjects could request repeated presentations of a stimulus, but this occurred on less than 15% of trials.

Results

There was no significant difference between the responses of the two groups of subjects, as determined by a chi-square test of the responses for each surface at each orientation and position; therefore, groups were combined in all further analyses. Subjects reported perceptions that did not always match the external handedness of the stimulus but that nearly always matched its identity.[3] On all surfaces except the forehead, tongue, and top of the foot, subjects reported perceiving stimuli as matching the external handedness. (For each surface at each orientation and position, the chi-square test against chance performance ranged from 24.0 to 4.16, with $df = 1$, $N = 54$, $p < .05$.) Stimuli on the top of the foot were also reported to have the external handedness more frequently than the reverse, but only marginally so. Table 1 summarizes the responses of 16 subjects and shows the responses of 2 other subjects, which were markedly different from the majority and are discussed separately.

Forehead and tongue. Subjects consistently perceived mirror reversals of stimuli traced on the forehead, whereas they perceived stimuli traced on the back and top of the head as having external handedness. Subjects were less consistent in their responses to stimuli on the tongue: They mostly perceived stimuli on the underside of the tongue as mirror reversals, but this tendency was not reliable. Subjects were also inconsistent in their responses to stimuli on the top of the tongue. Some of their variability for the tongue (and foot) may be due to differences in the ability to place the tongue (and foot) in positions described by the experimenter.

Two deviant performances. Two subjects produced patterns of responses that markedly differed from those of the majority (Table 1). These individuals reported mirror reversals 2.7 times more often overall, and they consistently reported mirror reversals on seven surfaces on which the others had consistently reported perceptions matching external handedness.

Table 1
Experiment 1: Handedness of Perceived Character on Various Surfaces of Body in a Natural Standing Position (N = 18)

Surface	Percentage of responses matching experimenter-defined handedness: 16 subjects	2 deviant subjects
Head		
Forehead	20.8**	50.0
Back	100.0***	83.3
Top	95.8***	66.6
Trunk		
Front	70.8	16.6
Right side	91.6***	16.6
Back	95.8***	83.3
Right hand		
Palm	75.0*	66.6
Back	75.0*	16.6
Right thigh		
Front	85.4***	50.0
Back	83.3**	66.6
Inside	89.5***	100.0
Outside	93.7***	33.3
Right upper arm		
Front	83.3**	33.3
Back	91.6***	83.3
Outside	81.2**	16.6
Inside	77.0**	66.6
Top of right shoulder		
Backward	93.7***	83.3
Forward	79.1**	33.3
Right foot		
Top	64.5	33.3
Sole	72.9*	66.6
Tongue		
Underside	37.5	0
Top	58.3	0

* Reliably different from that expected by chance (as tested by a chi-square, $df = 1$, $N = 54$ $p < .05$). ** Reliable to .01 (chi-square, 1 *df*, $N = 54$). *** Reliable to .001 (chi-square, 1 *df*, $N = 54$).

Experiment 2: Stimuli on a Body Surface Placed at Different Orientations and Positions

The findings in Experiment 1—that different surfaces produce different perceptions—seem to support the notion that different surfaces have different perceptual "rules." However, because the position and orientation of surfaces (relative to the body or trunk) were not controlled independently, we do not know whether perceptual interpretation was influenced by the factor of surface per se or by its position and orientation. Experiments 2 and 3 addressed this issue.

In Experiment 2, we used a paradigm like that of Experiment 1 to examine two aspects of cutaneous pattern perception. First, we examined the effect of changes in the surface's orientation and position relative to the body on the perception of stimuli on a surface. In Experiment 2 and Part A of Experiment 3 we examined all physically possible combinations of the six principal egocentric directions that a surface can face (forward, backward, upward, downward, laterally, and medially), the six principal regions of space around the body on which a surface can be located, and the two principal surfaces of the hand that can be stimulated. These orientations and positions in body space are illustrated in Figure 6. We traced *p, d, b,* or *q* on the back or palm of the subject's right hand when it was in an orientation and position like that shown in Figure 7. The stimuli were drawn oriented upward when the hand was vertical and toward the thumb edge of the hand when the hand was horizontal. The contours of strokes composing different letters were identical.

[3] In the exceptional misidentifications (all of them on top of shoulder), 4 subjects perceived an *h* as a *2* with its top pointed toward or away from the sagittal plane. They identified it correctly when reminded that top of stimulus pointed either forward or backward.

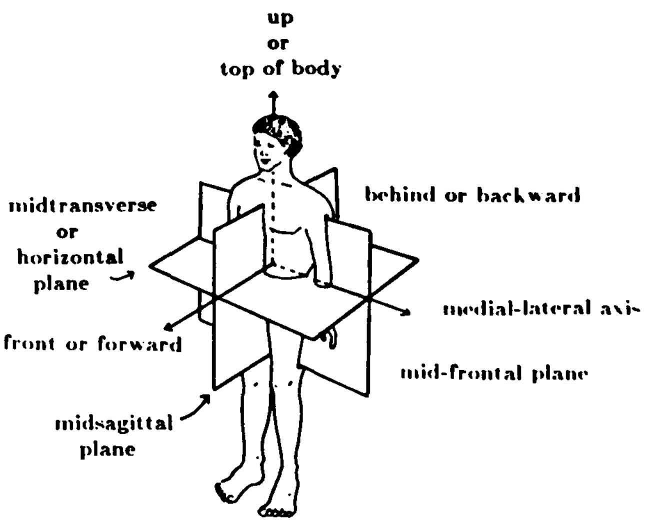

Figure 6. Key to the terms in the text describing the positions and orientations of a surface about the body (cf. Howard, 1982). (In ipsilateral positions, a surface has a medial orientation when it faces the midsagittal plane; it has a lateral orientation when it faces away from the midsagittal plane.)

The stimuli in Experiments 2 and 3 were more ambiguous than those in Experiment 1. In Experiment 1, the stimuli were asymmetric about their transverse axis, and subjects knew in advance in which direction the top–bottom axis of the character was aligned. Under those conditions, the stimuli were insensitive to differences between the actual orientation of the stimulus' top–botom axis and the preferred (or standard) orientation of the stimulus' top–bottom axis at a surface. In visual information processing, we prefer to see letters upright (Corballis, Zbrodoff, & Roldan, 1976). Analogously, subjects in Experiment 1 may have found it necessary in some cases to apply a corrective process such as "mental rotation" (Shepard & Metzler, 1971) to perceive the external stimulus. By contrast, in Experiments 2 and 3, the subjects were not told in which direction the top–bottom axis of a stimulus was aligned, and stimuli were multiply ambiguous. Suppose that a *b* is traced on the back of the hand, with the letter's top oriented toward the fingers. The stimulus is ambiguous with respect to its handedness because it can be perceived as either a *b* or a *d*, both of which have stems pointing in the same direction but are mirror reversals of one another (about a top–bottom axis). In addition, the stimulus is ambiguous with respect to its top–bottom orientation, because a *p* or *q* could also be perceived, and their stems point in the opposite direction of the stems of the *b* and *d*. So, if subjects perceive *p* or *q* on a surface, it implies that they prefer to interpret the top–bottom axis of the stimulus as oriented in the direction that the top of the *p* and *q* points. If they perceive a *b* or *d* on a surface, it implies that they prefer to interpret the top–bottom axis of the stimulus as oriented in the direction to which the top of the *b* and *d* points.

The principal directions that a surface of an upright body can face in this experiment (Figure 6) are described as follows. For brevity, *up* and *down* refer both to gravitational vertical directions and the directions toward the top and bottom of the body. *Forward* and *backward* describe directions that the front and back of the body face. *Medial* or *lateral* describe directions toward or away from the body's midsagittal plane.[4] We refer to the experimenter-defined top of the letter as the *external* top.

Methods

Subjects. Seven male and 7 female undergraduates from the Massachusetts Institute of Technology received $5.25 per hour for participating in this study.

Stimuli and design. A *p, d, b,* or *q* was presented in the same manner as in Experiment 1. The letter was traced (starting at the free end) on the palm or back of the right hand while it was in one of the positions and orientations shown in Figure 7. The 216 trials were produced by combining seven arm positions, four palm orientations, four stimuli, and two hand surfaces for receiving stimuli, minus one position that was too awkward to perform (i.e., behind the back on the contralateral side with the palm facing forward). All trials were performed in a random order that was unique for each subject; consecutive trials never used the same combinations of hand orientation and position.

Procedure. Subjects were given the same instructions as in Experiment 1 but were to report only the perceived identity of the pattern (not whether it was a mirror reversal). They visually inspected ink-drawn versions of the stimuli. Then they performed (blindfolded) the eight practice trials in which each stimulus was traced on the forehead and back of the body. Finally, they performed the test trials, in a procedure identical to that in Experiment 1.

Results

There were no reliable differences in the performances of male and female subjects (tested with chi-square on responses for each surface at each position and orientation. The subject's sex was not used in any other analyses.

Perceived identity of the stimulus. For each position and orientation of the hand, we compared the number of trials (Figure 7) on which subjects reported identical and mirror-reversed perceptions to chance performance, using a chi-square test. Except for cases noted in the next section or in Table 2, the values were reliably different from chance (chi-square values ranged from 28.0 to 4.32, with $df = 1$, $N = 56$, $p < .05$).

For a horizontal surface in all positions, a stimulus on an upper face of the surface was perceived to match the external identity, and a stimulus on the lower face of the surface was perceived as a mirror reversal. Stimuli on forward-facing surfaces were perceived as mirror reversals when in front of the body, whereas stimuli on backward-facing surfaces were perceived to have external handedness. However, when the surface faced forward or backward—in the down, contralateral behind, and ipsilateral positions—stimuli on both the palm and back of the hand were perceived as matching the external handedness.

The interpretation of stimuli on the lateral- or medial-facing surfaces depended on the orientation of the surface and on which body part was stimulated. These data fall into two groups. In both forward and upward positions, when the palm faced laterally, stimuli on the back of the hand were perceived

[4] Contralateral positions of the hand occur when it crosses the midsagittal plane to the other side of the body (when the left hand is in the space in front of, or behind, the right half of the body). Ispilateral positions of the hand occur when the hand remains in the space on the side of body to which it belongs (when the left hand is in the space in front of, or behind, the left half of the body).

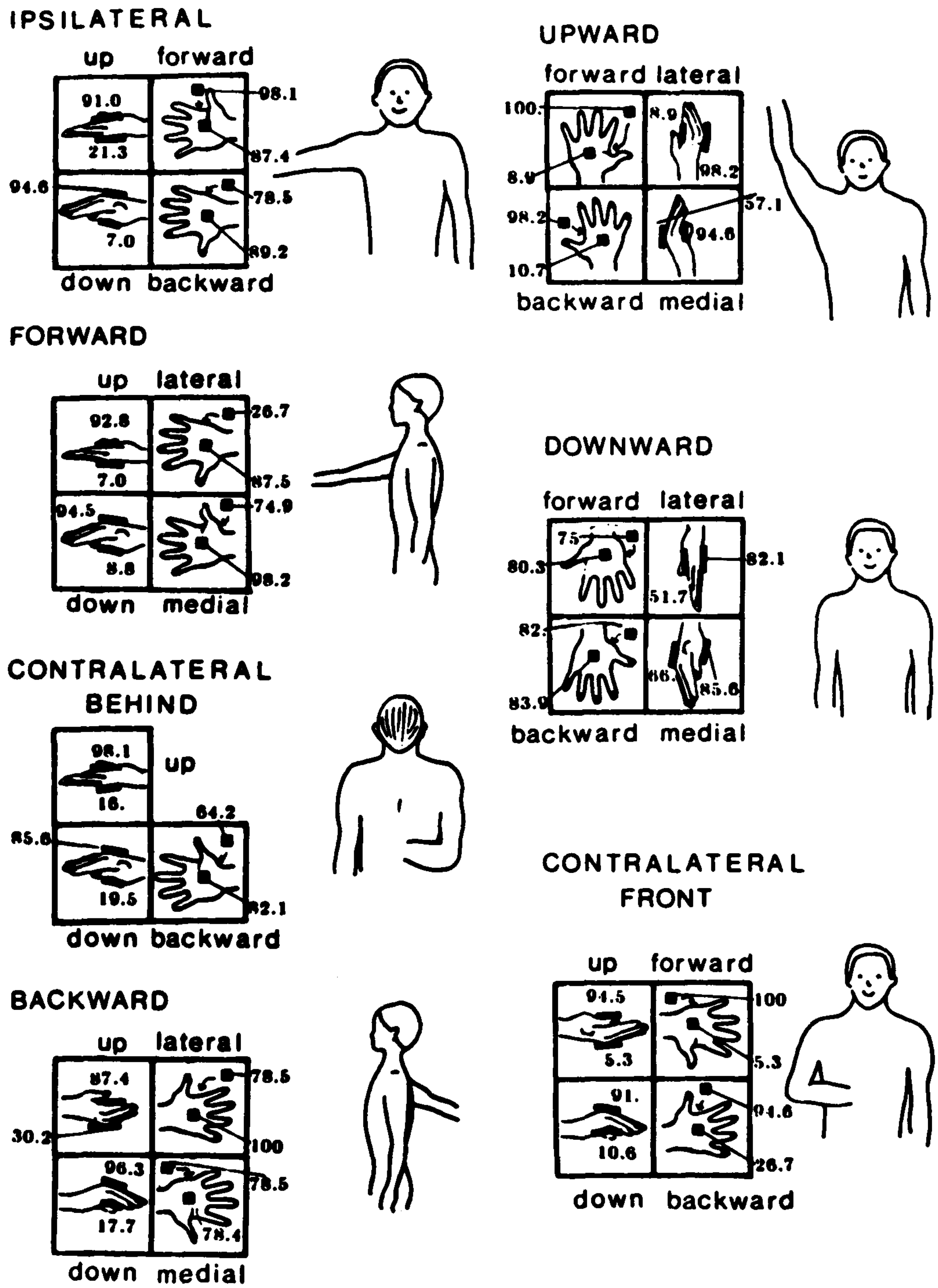

Figure 7. The position and orientation of the palm and back of right hand in Experiment 2: Percentages of trials on which the handedness of subjects' responses matched the handedness of the experimenter-defined (external) stimulus. (Squares shown outside the hand indicate stimulated surfaces on the side of hand opposite that shown. The percentages were tested against chance with a chi-square, $df = 1$: Those greater than .821 or less than .179 are reliable at .001; those greater than .75 or less than .25 are reliable at .01; those greater than .696 or less than .304 are reliable at .05.)

to have external handedness, whereas those on the palm were perceived as mirror reversals. However, when the palm faced medially and was in the forward position, stimuli on both the back and palm of the hand were perceived as having external handedness. This was also true for the upward position with the palm facing medially. However, when the hand was behind the back or down at the side, stimuli on the back and palm were mostly perceived to have external handedness.

Perceived orientation of the stimulus. For each position and orientation of the hand, we compared the number of trials on which the perceived top of the letter pointed in the same direction as the top of the externally defined stimulus (rather than being oppositely oriented) with chance performance, using a chi-square (Table 2); except for those cases noted in the next section, the values were reliably different from chance (chi-square values ranged from 28.0 to 4.32, with $df = 1$, $N = 56$, $p < .05$).

When the back of the hand and palm were vertical, the perceived top of the letter pointed upward. Responses on trials when the back and palm of the hand were in a horizontal plane can be summarized as follows. With four exceptions, if the hand's thumb edge was oriented forward or backward, the perceived top of the letter pointed forward. In the four exceptions, the results were mixed, with trends approaching statistical reliability (Table 2).

Experiment 3

The results of Experiment 2 showed that the orientation and position of a skin surface can strongly influence the perception of cutaneous stimuli. Further, these results showed that the perceived orientation of a cutaneous pattern can be influenced by principal directions in either the egocentric frame of reference (forward, lateral, or toward the head) or the environmental frame of reference (gravitational vertical).

In Experiment 3, we investigated the generality of the hypothesis that cutaneous pattern perception depends on the position and orientation of the skin surface. We also tested the complementary hypothesis that perceptual interpretation of stimuli on a surface at a particular orientation and position is not influenced by which surface is stimulated. In Part A of this experiment, cutaneous pattern perception on the hand was examined in the positions shown in Figure 8. These conditions complement those in Experiment 2, to test all available combinations of principal hand surface, orientation, and position of the surface in the space about the body.

In Part B, we examined whether pattern perception on the surface of the head had a privileged status (as suggested by results of Natsoulas & Dobanoski, 1964) and was not influenced by changes in the position and orientation of its surface or whether, like pattern perception on the hand, it was influenced by these changes. The perception of cutaneous patterns was observed on surfaces of the head when it was turned 90° to the left, inclined forward or backward 90° relative to its upright position, or inclined forward or backward 180° relative to the nearly upright lower body (Figure 9).

In Part B, the relation between the body's orientation and the environment was more complicated (Figure 9), so we adopted the following conventions. When the body was bending far forward or backward, we used the term *forward* to refer to the direction that the lower body faces and the term *backward* to refer to the opposite direction. The terms *up* and *down* refer to the gravitational vertical directions (which in part B are often decoupled from the direction in which the front of the body pointed).[5]

In Part C we tested whether findings for cutaneous pattern perception on the hand can be generalized to other body parts or to surfaces at as yet unexamined (vertical) distances from the upper trunk. Surfaces of different body parts were placed in approximately the same position relative to the body (Figure 10), and individuals' perceptions of stimuli on these surfaces of the different body parts were compared.

Method

Subjects. Twelve male undergraduates at the Massachusetts Institute of Technology who had not been in any related experiments, were paid $5.25 per hour for participating in this study.

Stimuli. A *p, d, b,* or *q* was presented exactly as in Experiment 2. In Part A, a letter was traced on the palm or back of the right hand in the position and orientation shown in Figure 8. When the hand was horizontal, a letter was traced with its top pointed toward the thumb edge; when vertical, the top of a stimulus letter was pointed upward. In Part B, a letter was traced on the surfaces shown in Figure 9. In Part C, the letters were traced on the body surfaces shown in Figure 10. In Parts B and C, when the stimulated surface was vertical, a letter was traced with its top pointed upward. When the surface was horizontal, a letter was traced with its top pointed forward.

Design and procedure. In Part A, 104 trials were generated by combining seven arm positions, two hand orientations, two hand surfaces, and four letters, minus one hand position and orientation that was too awkward to perform (i.e., putting the palm above the left shoulder with the palm pointing backward). We generated 64 trials for Part B from the combination of four positions, four stimuli, and three head surfaces, and the combination of four stimuli and four surfaces in one other position. In Part C, we produced 60 trials by combining four letters and 15 stimulated surface-and-position pairs. Two subjects were randomly selected to perform Parts A, B, and C in each of the six possible orders. A subject performed Parts A, B, and C in three short sessions, some on separate days. All other aspects of the design and procedure were identical to those used in Experiment 2.

Results

There were no reliable differences in the responses of subjects performing Parts A, B, and C in different orders (in each case, determined by chi-square test). The subjects' responses, summarized in Tables 3–5 and Figures 8–10, were analyzed exactly as in Experiment 2 (significant chi-square values ranged from 24.0 to 4.16, $df = 1$, $N = 48$).

Surfaces of the hand. One especially interesting finding is that when the hand was horizontal and held above the head, if the palm faced up, stimuli on the palm were perceived as mirror

[5] Studying the perception of tactile stimuli via "active touch," Oldfield and Phillips (1983) examined the effect of changing the orientation of the perceiver's *whole* body with respect to the environment and stimulus. Their results suggest that tactile stimuli on surfaces in at least some configurations are perceived as if described with respect to the environmental frame (gravitational vertical), not the egocentric frame. However, other results of Oldfield and Phillips (1983) and our results suggest that in other cases the orientation and position of surfaces with respect to the body (i.e., the egocentric frame) are more important than gravitational vertical in determining the perceived spatial organization of stimuli (Parsons & Shimojo, 1987). Additional work is necessary to determine how the perceived spatial organization of stimuli is influenced by the relation between the "physical" and "perceived" egocentric orientation, which are likely to differ when the different parts of the body are in different (nonstandard) orientations with respect to the environment.

Table 2
Experiment 2: Orientation of Perceived Letter on the Hand in Various Orientations and Positions

Palm orientation & stimulated surface	% responses	Letter orient.[a]	Palm orientation & stimulated surface	% responses	Letter orient.[a]
Hand position: backward			**Hand position: backward**		
Up			Lateral		
Palm	62.4	Lateral	Palm	100.0***	Up
Back	76.7**		Back	96.4***	
Down			Medial		
Palm	90.9***	Lateral	Palm	92.7***	Up
Back	69.5*		Back	76.7**	
Hand position: contralateral behind			**Hand position: contralateral behind**		
Up			Backward		
Palm	98.1***	Forward	Palm	92.8***	Up
Back	83.8***		Back	67.8	
Down					
Palm	62.4	Forward			
Back	94.6***				
Hand position: contralateral front			**Hand position: contralateral front**		
Up			Forward		
Palm	96.3***	Forward	Palm	100.0***	Up
Back	94.5***		Back	98.2***	
Down			Backward		
Palm	83.8***	Forward	Palm	98.1***	Up
Back	58.8***		Back	87.4***	
Hand position: downward			**Hand position: downward**		
Forward			Lateral		
Palm	64.2	Up	Palm	89.2***	Up
Back	85.7***		Back	91.0***	
Back			Medial		
Palm	83.8***	Up	Palm	97.9***	Up
Back	66.0		Back	71.4*	
Hand position: forward			**Hand position: forward**		
Up			Lateral		
Palm	89.2***	Lateral	Palm	96.3***	Up
Back	76.7**		Back	98.2***	
Down			Medial		
Palm	55.2	Lateral	Palm	100.0***	Up
Back	57.0		Back	98.2***	
Hand position: ipsilateral			**Hand position: ipsilateral**		
Up			Forward		
Palm	37.5	Forward	Palm	98.2***	Up
Back	37.5		Back	98.1***	
Down			Backward		
Palm	76.7**	Forward	Palm	100.0***	Up
Back	74.9**		Back	92.8***	
Hand position: upward			**Hand position: upward**		
Forward			Lateral		
Palm	100.0***		Palm	100.0***	Up
Back	100.0***		Back	100.0***	
Backward			Medial		
Palm	100.0***		Palm	100.0***	Up
Back	100.0***		Back	100.0***	

Note. Letter orient. = orientation of top of perceived letter. This orientation is described in terms of environmental or egocentric directions: up and toward the direction the head points; forward or toward the direction the front of the body faces (see Figure 7).
[a] The orientation designations (lateral, up, forward) "float" in the table because they are independent of hand position, palm orientation, and stimulus surface.
* Observed more reliably than expected by chance (as tested by chi-square, 1 *df*, $N = 56$, $p < .05$). ** Reliable to .01 (chi-square, 1 *df*, $N = 56$).
*** Reliable to .001 (chi-square, 1 *df*, $N = 56$).

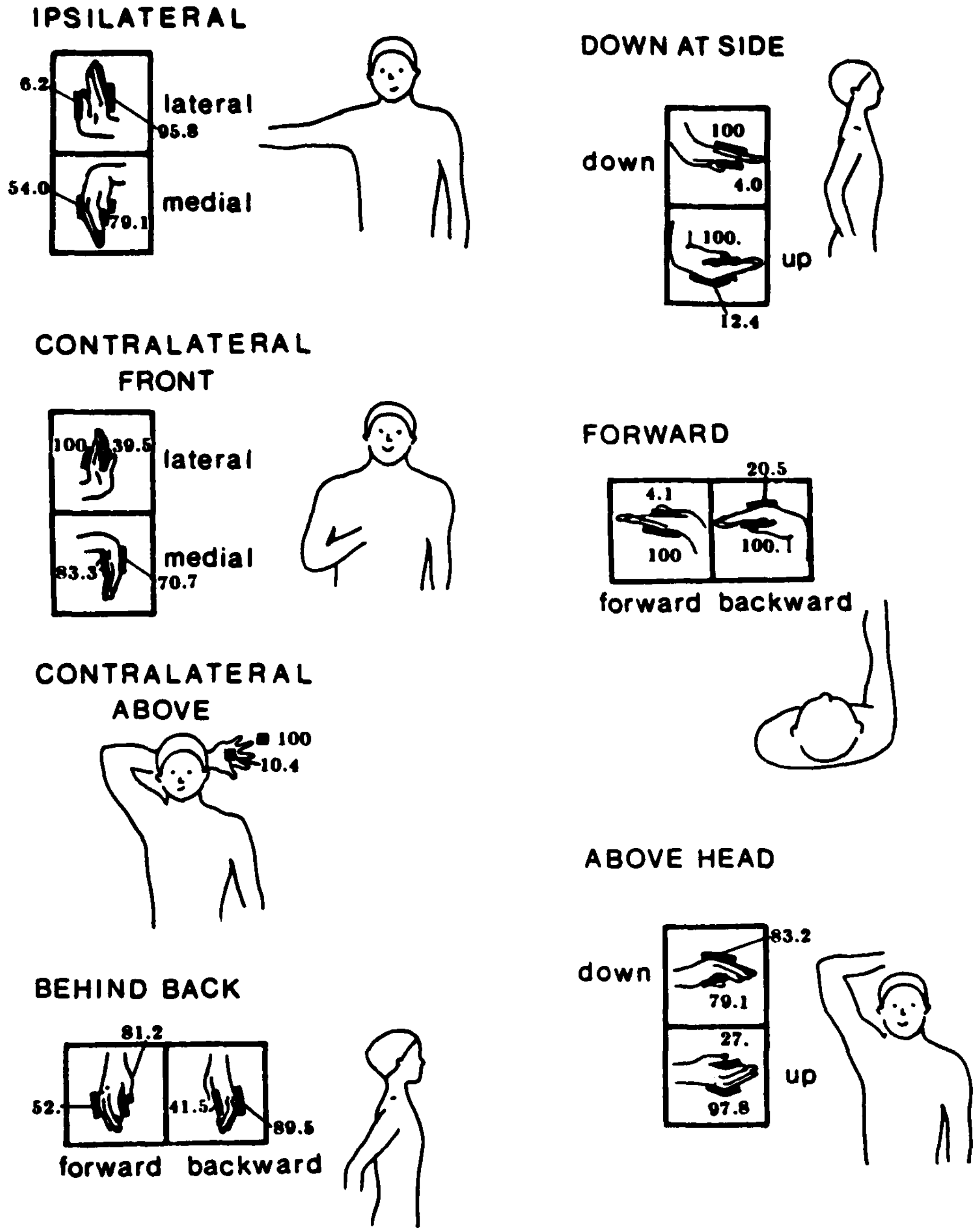

Figure 8. The position and orientation of the palm and back of right hand in Part A of Experiment 3: Percentages of trials on which the handedness of subjects' responses matches the experimenter-defined handedness. (The percentages were tested against chance with a chi-square, $df = 1$, $N = 48$: Those greater than .85 or less than .15 are reliable at .001; those greater than .77 or less than .23 are reliable at .01; those greater than .708 or less than .291 are reliable at .05.)

reversals, and stimuli on the back were perceived to have external handedness; if the palm was facing down, stimuli on both the palm and the back of the hand were perceived to have external handedness. The remainder of the results in Part A fits the patterns noted in Experiment 2.

Surfaces of the head. The perception of stimuli on the front and back of the head was not influenced by changes in the orientation and position of the head. However, the perception of stimuli on the top and right side of the head was influenced by such changes. With one exception, the results for the top and sides of the head resembled those for other surfaces in comparable orientations and positions. In the exceptional case, when the head was inclined backward 180°, the spatial manipulation may not have been effective because most of the body was essentially horizontal, with the head leaning backward 90° relative to the horizontal body. (Accordingly, the results observed in this con-

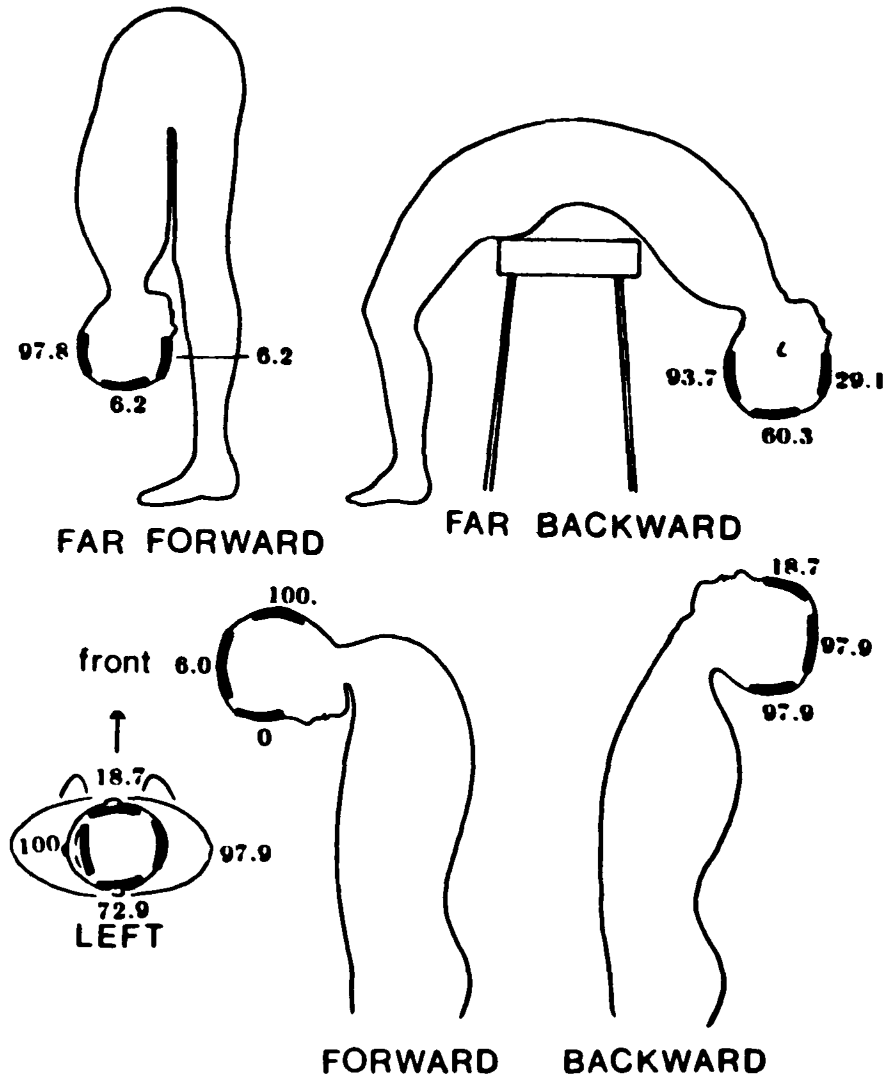

Figure 9. The position and orientation of the head and stimulated surfaces in Part B of Experiment 3: Percentages of trials on which the handedness of subjects' responses matches the experimenter-defined handedness. (The percentages were tested against chance with a chi-square, $df = 1$, $N = 48$: Those greater than .85 or less than .15 are reliable at .001; those greater than .77 or less than .23 are reliable at .01; those greater than .708 or less than .291 are reliable at .05.)

dition were identical to those in the backward position in this experiment and in upright positions in Experiment 1.)

Different surfaces at the same orientation and position. When a surface (of the foot, hand, or thigh) was horizontal, stimuli on the upward-facing surface were perceived to have external handedness, and stimuli on the downward facing surface were perceived as mirror reversals. This suggests that the perception is based on the orientation and position of a surface, not on which body part the surface is on. By contrast, data in the hand-on-chest condition show that stimuli on comparably oriented surfaces of two different body parts placed in the same position can be perceived differently. Stimuli on the chest were perceived to have external handedness in Experiment 1, whereas stimuli on the palm were perceived as mirror reversed. The perception of stimuli on the forward- or backward-facing forearm and upper arm was like that for the hand. The top–bottom axis of the perceived letter was oriented upward for vertical surfaces and forward for horizontal surfaces.

Discussion of Results in Experiments 1–3

Use of Local-Surface and Whole Body-Based Systems

The mapping from the earliest, and likely local surface-based, representation of a pattern to an object-based description was underdetermined in this study because a pattern could be sensibly interpreted in several ways, depending on the reference frame imposed on it. Our results show that this mapping is influenced in a complicated way by spatial relations among the stimulus, surface, and whole body. The perceptual system does not minimize the number of principles used in mapping between points in this space of possible frames and spatial relations.

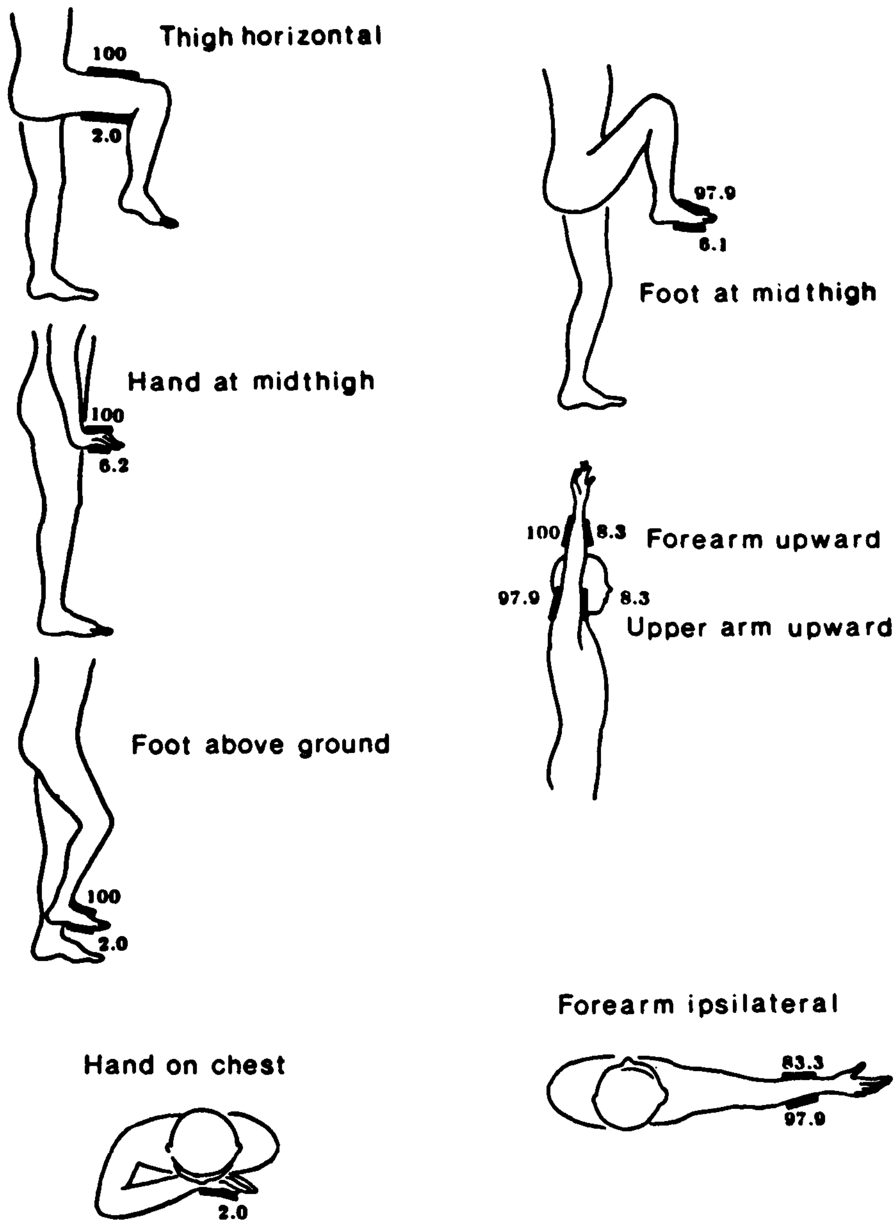

Figure 10. The position and orientation of right thigh, hand, foot, upper arm, and forearm, and stimulated surfaces in Part C of Experiment 3: Numbers for each orientation and position are the percentage of trials on which the handedness of subjects' responses matches the experimenter-defined handedness. (The percentages were tested against chance with a chi-square, $df = 1$, $N = 48$: Those greater than .85 or less than .15 are reliable at .001; those greater than .77 or less than .23 are reliable at .01; those greater than .708 or less than .291 are reliable at .05.)

The perceptual system has properties similar to both local surface-based and whole body-based systems. Stimuli on the front and back of the head are perceived within local frames of reference positioned behind those surfaces, with the top of those frames oriented like the top of the head, and the fronts of the frames oriented opposite to that of the front of the head. Thus, the front of the frame faces the assigned front of the stimulus even when physical mass intervenes between the skin surface receiving the stimulus and the frame.

Stimuli on other head and body surfaces are not perceived within a local frame of reference. Nor apparently are they described in a whole body-based system in which all stimuli are perceived with respect to a single frame assigned to the body (or trunk). (Even when the configuration of the body is held constant, stimuli on the different surfaces of the body are often perceived as if described in frames with differing orientation and position.) Nor are stimuli on surfaces other than the front and back of the head described in the frames used for the front and back of the head. If the head is at a nonstandard orientation and position with respect to the body, the interpretation of stim-

Table 3
Experiment 3, Part A: Orientation of Perceived Letter on the Hand in Various Orientations and Positions

Palm orientation & stimulated surface	% responses	Letter orient.[a]
Hand position: above the head		
Palm down		
Palm	64.5	Forward
Back	64.5	
Palm up		
Palm	74.9*	Forward
Back	83.2**	
Hand position: contralateral above		
Palm forward		
Palm	97.9***	Up
Back	100.0***	
Hand position: behind back		
Palm backward		
Palm	68.6*	Up
Back	74.9**	
Palm forward		
Palm	70.8*	Up
Back	85.3***	
Hand position: contralateral front		
Palm medial		
Palm	87.4***	Up
Back	91.5***	
Palm lateral		
Palm	97.9***	Up
Back	100.0***	
Hand position: down at side		
Palm down		
Palm	85.3***	Forward
Back	91.6***	
Palm up		
Palm	95.8***	Forward
Back	89.5***	
Hand position: forward		
Palm forward		
Palm	100.0***	Up
Back	91.6***	
Palm backward		
Palm	100.0***	Up
Back	93.4***	
Hand position: ipsilateral		
Palm lateral		
Palm	97.8***	Up
Back	97.8***	
Palm medial		
Palm	79.1***	Up
Back	58.2	

Note. Letter orient. = orientation of top of perceived letter. This orientation is described in terms of environmental or egocentric directions: up and toward the direction the head points; forward or toward the direction the front of the body faces (see Figure 8).
[a] The orientation designations (forward, up) "float" in the table because they are independent of hand position, palm orientation, and stimulus surface.
* Observed more reliably than expected by chance (as tested by chi-square, 1 *df*, $N = 48$, $p < .05$). ** Reliable to .01 (chi-square, 1 *df*, $N = 48$). *** Reliable to .001 (chi-square, 1 *df*, $N = 48$).

uli on other surfaces of the head does change from that when the head is in a standard position and orientation (Experiment 3), but the interpretation of patterns on other surfaces *does not* change (Corcoran, 1977).

The frames used to describe stimuli on surfaces other than the front and back of the head apparently depend on the body's intrinsic frame of reference (or a frame compromising among the orientations and positions of intrinsic frames of the head, upper, and lower body, and the environmental frame). These frames are chosen on the basis of the position and orientation of the stimulated surface.

Perceptual "Rules" Based on the Relative Orientation and Position of Surfaces

1. The most general perceptual rule is that a stimulus on a transverse or horizontal surface (Figure 6) below the upper chest of an upright body (and possibly even below the top of the head) is perceived in a frame positioned above and oriented toward the position of the surface with its top oriented forward. Thus stimuli on a downward-facing surface are perceived as mirror reversals—that is, facing upward.[6]

2. Another perceptual rule is that a stimulus on a frontoparallel surface in front of the body and above the level of the chest is perceived in a frame of reference behind the surface, its top oriented upward and its front oriented toward the position of the surface. Thus a stimulus on such a forward-facing surface is perceived as a mirror reversal—as if its front faced back toward the body; a stimulus on a backward-facing surface is perceived as having external handedness.

3. Stimuli on a surface other than the hand facing toward or away from the midsagittal plane are referred to a frame of reference oriented upward (in the direction where the top of the body is pointed) and positioned wherever necessary in the space around the body to directly face the stimulated surface. (Stimuli are not perceived as mirror reversals but as having external handedness.)

4. Stimuli on a surface in a frontoparallel plane and in a position other than in front of the head or neck are referred to a frame of reference oriented upward and positioned wherever necessary in the space around the body to directly face the stimulated surface. Again, stimuli are not mirror reversed.

5. The last (and most specific) rule refers to the hand in two orientations and positions. Rule 5a applies when the hand is in front of the head or chest. For example, when the right palm is in a sagittal plane and facing to the left, stimuli on the palm and back of the hand are described in a frame of reference positioned and oriented wherever necessary to directly face the surface. However, if the right palm is in a sagittal plane and facing to the right, stimuli on the palm and back of the hand are described in a frame positioned behind the hand, with its top upward (in the direction where the top of the body points) and its front facing toward the back of the hand. Rule 5b applies when the hand is above the head. When the palm faces downward

[6] The one exception to this rule may be for stimuli on the top of the head as it leans backward 180° relative to the lower body. However, results in this latter condition appear to be flawed by an ineffective manipulation of the head's position relative to the body.

Table 4
Experiment 3, Part B: Orientation of Perceived Letter on the Head in Various Orientations and Positions

Forehead orientation & stimulated surface	% responses	Letter orient.[a]
Head position: backward		
Up		
Forehead	18.7*	Forward
Back	2.0**	Up
Top	97.9**	
Head position: far backward		
Backward		
Forehead	8.2**	Up
Back	4.1**	Forward
Top	18.6*	
Head position: far forward		
Backward		
Forhead	0**	Up
Back	10.3**	Forward
Top	87.5**	
Head position: forward		
Down		
Forehead	100.0**	Forward
Back	100.0**	Up
Top	96.8**	
Head position: left		
Left		
Forehead	100.0**	
Back	100.0**	Up
Right	100.0**	
Left	100.0**	

Note. Letter orient. = orientation of top of perceived letter. This orientation is described in terms of environmental or egocentric directions: up or gravitational vertical; forward or toward the direction that the feet and front of lower body face (see Figure 9).
[a] The orientation designations (up, forward) "float" in the table because they are independent of head position, forehead orientation, and stimulus surface.
* Reliable to .01 (chi-square, 1 *df*, $N = 48$). ** Reliable to .001 (chi-square, 1 *df*, $N = 48$).

(in the direction where the bottom of the long axis of the body points), stimuli on the palm and back are described in a frame directly facing the external face of the surface. (Stimuli are not mirror reversed.) However, if the palm faces upward (in the direction where the top of the body points), stimuli on the palm and back of the hand are described in a frame beneath the hand, oriented toward the surface.

Unfortunately, no data yet specify more precisely than these rules the position and orientation of the frame used to describe a stimulus in this task. Corcoran (1977) concluded from his observers' introspections that, in effect, the frame was flexibly assigned wherever necessary to point toward a surface's position or its external face. This conclusion is not inconsistent with our results. It may be that the interpretative system allows some properties of the assignment of spatial organization to be imprecise. If so, these data may be well modeled by an approach used by McDermott and Davis (1984). These authors model the spatial relations between frames of reference by specifying coordinates that lie within ranges rather than have fixed values. Their model (for planning routes through uncertain territory) uses this sort of fuzzy set logic (Zadeh, 1975) to relate many frames of reference of different scales to topological and metric data bases.

Individual subject differences. The rules for perceptual interpretation formulated in the preceding section rely partly on

Table 5
Experiment 3, Part C: Orientation of Perceived Letter on Various Body Parts in Various Orientations and Positions

Part orientation & stimulated surface	% responses	Letter orient.[a]
Right foot above ground		
Sole down		
Top	100.0*	Forward
Sole	100.0*	
Right foot at midthigh		
Sole down		
Top	100.0*	Forward
Sole	97.8*	
Right forearm ipsilateral		
Palm forward		
Forward-facing	100.0*	Up
Backward-facing	100.0*	
Right forearm upward		
Palm forward		
Forward-facing	100.0*	Up
Backward-facing	97.9*	
Right hand at midthigh		
Palm down		
Palm	100.0*	Forward
Back	97.9*	
Right hand on chest		
Palm forward		
Palm	97.8*	Up
Right thigh horizontal		
Back down		
Front	97.9*	Forward
Back	97.9*	
Right upper arm forward		
Palm forward		
Forward-facing	100.0*	Up
Backward-facing	100.0*	

Note. Letter orient. = orientation of top of perceived letter. This orientation is described in terms of environmental or egocentric directions: up or toward the direction the head points; forward or the direction that the front of the body faces (see Figure 10).
[a] The orientation designations (forward, up) "float" in the table because they are independent of body position, part orientation, and stimulated surface.
* Reliable to .001 (chi-square, 1 *df*, $N = 48$).

between-subjects comparisons and thus may be less general or reliable than if they were based on within-subjects comparisons. This limitation is ameliorated somewhat by the fact that comparable trends were observed in conditions common to two or three of the experiments. Even in the few cases within an experiment in which stimuli on some surfaces at some positions and orientations were consistently perceived differently by various observers, usually less than about one third of the observers were inconsistent as individuals. Perhaps on the latter trials, stimuli were novel and lacked rules or were ambiguous in that two or more rules applies equally well. Some inconsistency may have arisen if rules evolved as the experimental session proceeded.

The robustness and generality of these results are indicated by their consistency within each experiment, by their similarity to previous findings, and by the fact that many of them have been replicated both with adult subjects who were blind either from birth or from an early age (Shimojo, Sasaki, Parsons, & Torii, 1986) and with children as young as 4 years old (Kamura & Shimojo, 1986).

General Discussion

Several factors seem to be reflected in the interpretative system implied by these results, though much remains to be discovered. There appear to be three privileged kinds of frames: local frames for the front and back of the head, the "central" frame(s) associated with the upper body, and special frames used for the hand in some orientations and positions. In addition, there seem to be important principal directions in which reference frames are often oriented. The head and hand surfaces may be given priority because they possess high concentrations of sensory receptors. We speculate that the upper chest area has special frames associated with it, because it is an effective central and general zone for referencing information about objects in front of the body and on horizontal surfaces of objects. We discuss these issues further in the following sections. (For a more theoretical discussion of these data and issues, see Parsons & Shimojo, 1987.)

The Head as a "Pilot" in Planning Action

The independence of the front and back surfaces of the head may be related to the fact that the anterior surface of the head possesses important sensory apparatus used to anticipate or plan action or locomotion. The initial planning of action may be processed in terms of the frame of reference used for the front and back of the head. The head can be moved out of line with the rest of the body, and, using the sensory apparatus, plans for sensorimotor activity can be made (with respect to the frame of reference of the front and back of the head). Then the rest of the body (and its accompanying reference frames) can be aligned with the frame of the front and back of the head, and action can be guided by the plans just formed. Thus, the independent status of these surfaces may be related to the head's role as a "pilot."

Perception With Respect to Principal Egocentric and Environmental Directions

There were no mirror reversals on two parallel and oppositely faced surfaces of a part in a particular orientation and position. In fact, the frames used to describe stimuli on parallel surfaces were nearly always aligned in a forward, downward, or outward (lateral) direction, depending on surface orientation. (An exception occurred when the surface was above the head, when the frames aligned in a forward, outward, upward, or downward direction, depending on surface orientation.) These principal directions may be relied on as a superstructure for the spatial information processing that underlies various perceptual, motor, and cognitive functions.

Perceptual "Rules" and the Frames of Reference Used in Coordinating Action

A stimulus on a body surface below the chest and behind the back is very likely to be perceived in a frame of reference positioned or oriented wherever necessary to directly face the stimulus. However, a stimulus on a surface in front of the body and above the chest is very likely not to be perceived in such frame. Nor are stimuli on a horizontal surface perceived in such a frame.

This property may relate to the existence of frames associated with the upper body (and near its center of mass) that may be habitually used for organizing the spatial properties of many stimuli other than cutaneous patterns. The space in front of the upper body, and the horizontal surfaces of objects in general, are important for action and locomotion. Processing of information from these regions is probably done by using frames of reference associated with the upper body. Ordinarily, when a body surface is used to build a representation of the orientation and shape of an object, it is aided by sensory apparatus on the head, and so information from cutaneous senses at that surface is likely coded with respect to these frames of reference. For sighted individuals, when a forward- or downward-facing skin surface (e.g., the palm) is interposed between the head/upper chest area and the object's surfaces, it occludes the contacted surface. The information gathered by that surface is most useful for action if it is in frames usually supporting visually coordinated action. It would be useful for cutaneous information received at different skin surfaces or at the same surface at different moments to be directly and initially represented with respect to one frame (see introductory remarks). Thus, perhaps for reasons of efficiency, people may use a frame of reference from this natural upper body set to perceive stimuli impinging on surfaces in the space in front of the upper body and stimuli on horizontal surfaces.

Special Frames of Reference for the Hand at Some Positions and Orientations

The unique pattern of results for the surfaces of the hand (Rule 5, described above) may also be a consequence of information processing that relates cutaneous or tactile information to more central frames. Possibly the palm's specialization for tactile, haptic, and prehensile purposes (Gibson, 1962; Revesz, 1950) dominates spatial information processing of the hand's surface. If so, it may be that only when the palm (and not the back) faces upward or outward (in these positions), is there an interposition of a tactile surface between likely locations for to-be-acted-on objects and the frames of reference useful for coordinating action.

Vertical Surfaces Below the Chest

There are no privileged frames of reference for, and no mirror reversals on, vertical surfaces below the chest (with the exception of the hand in some orientations; see Rules 3, 4, and 5). This rule has the advantage that a considerable number of possibilities (i.e., the number of possible surfaces, orientations, and positions multiplied by the number of possible frames) is covered by a single, simple, mapping rule (externalization). There may also be benefits in treating such vertical surfaces as (in a sense) to-be-acted-on objects.

"Active Touch"

Gibson (1962, 1966), following Katz (1925) and Revesz (1950), emphasized that in tactual exploration of an object ("active touch"), one perceives the form of the object, not the stimulation caused by the movement of one's body part. Thus, the same pattern of stimulation can produce different perceptual information because the perceptual system takes into account the spatial relations of the sensing surface of skin to the whole body and to the contacted object. Oldfield and Phillips (1983) asked subjects to interpret raised letter forms by active touch, and experimentally controlled the spatial relation among the sensing hand, the surface containing the letters, the subject's whole body, and the local environment. When stimuli were on a horizontal plane (in front of the upright body) facing in the same direction as the perceiver's head, they were perceived as having external handedness. If the stimuli were on the same horizontal surface but facing in the opposite direction, they were perceived as mirror reversals. Such results are consistent with ours and suggest that there may be common mechanisms underlying active touch and cutaneous perception.

Oldfield and Phillips's results also suggest that stimuli in a plane perpendicular to the gravitational vertical are perceived without respect to the position of the body in the environment.[7] However, they manipulated the orientation of the whole body with respect to the environment but did not manipulate the relative configuration of the body's parts. In Experiment 3, stimuli on the hand above the head are interpreted differently when the hand is above the head than when it is below the head. This shows that the perception of stimuli on a surface depends on its orientation with respect to the rest of the body, not with respect to gravity. Further research is required to understand how perception is influenced by spatial relations among the body, its parts, the cutaneous or tactile stimulus, and the environment.

Motor Production of Patterns

There are suggestive similarities in spatial information processing for cutaneous patterns and for the motor production of patterns. In recent studies, Shimojo, Parsons, and their coworkers observed similar patterns of mirror reversal for children and upright sighted and blind adults in cutaneous pattern perception and in the motor production of patterns on a writing surface (Kamura & Shimojo, 1986; Parsons & Shimojo, 1987; Shimojo, 1981; Shimojo et al., 1986). Thus, some of the spatial information processing we observed may underlie important and basic sensorimotor activity, possibly integrating cutaneous, haptic, and motor events with information about external objects.

[7] This tendency is also observed in the present paradigm (see Parsons & Shimojo, 1987.)

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