Mirror reversal by blind subjects in cutaneous perception and motor production of letters and numbers

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A letter drawn on the forehead is often perceived as its mirror reversal. Similarly, people produce mirror reversals when asked to write a letter on the underside of a table at which they are sitting. We varied the orientation and position of the stimulated or inscribed surface, and found several examples of these two mirror-reversal phenomena in blind subjects (who had no, or very little, visual experience), as well as in sighted subjects. Furthermore, the mirror-reversal rate of the two groups of subjects as a function of orientation and position of the surface was highly correlated. Thus, the mirror-reversal phenomena should be attributed to a nonvisual, spatial cognitive scheme that is perhaps shared by sighted and blind subjects.

When a letter is drawn on the forehead, it is cutaneously perceived as a mirror reversal of the experimenter-defined stimulus (Allen & Rudy, 1970; Corcoran, 1977; Duke, 1966; Krech & Crutchfield, 1958; Natsoulas, 1966; Natsoulas & Dubanoski, 1964). Such mirror reversals are also observed for stimuli on the forward-facing palm and back of the hand (Corcoran, 1977; Parsons & Shimojo, 1987), and on a forward-facing surface in front of the body that the fingers "actively" touch (Oldfield & Phillips, 1983). One account of these results is that people are able to imagine viewing their bodies from almost any position in order to "look at" or even "through" surfaces (e.g., the back of the neck and the forehead, respectively), and

that they prefer to do so in these cutaneous pattern perception tasks. This is consistent with the research showing that people can envision objects or scenes from arbitrary points of view in order to describe the spatial arrangement of their features (Attneave & Farrar, 1977; Huttenlocher & Presson, 1973; Pinker, 1980; Presson, 1982).¹ Another possible explanation is that subjects perceive a cutaneous pattern by reference to the movement they would make to reproduce it (Corcoran, 1977). This *analysis-by-synthesis* hypothesis assumes that subjects mentally simulate the actions that they would produce to trace the pattern at the stimulated surface. Recent work suggests that people can mentally simulate their actions accurately (e.g., Finke, 1979; Parsons, 1987b) and do so spontaneously in order to perceive stimuli in certain tasks (Parsons, 1987a, 1987b). This simulated movement may be described relative to one's mental representation of the body's intrinsic spatial organization. For instance, when the digit 7 is traced on the forehead (with "north" in the direction the top of the head points), the stimulus moves horizontally from east to west, and then downward to southeast, and we perceive it as a reverse 7 (Corcoran, 1977).

Parsons and Shimojo (1987) examined this phenomenon more systematically than had earlier researchers, analyzing the separate and interactive effects of factors

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such as body part, orientation and position of body part, and orientation of stimulus. Among other findings, they observed that when a stimulus was presented on surfaces of the hand and other body parts facing inward (i.e., toward the head or the trunk), it was very often perceived as matching the experimenter-defined pattern; however, when it was presented on outward-facing surfaces, it was usually mirror reversed. (This was true regardless of the position and orientation of the head with respect to the body; Corcoran, 1977; Parsons & Shimojo, 1987). Thus, in almost all cases, it is the orientation and position of the surface that determines its perception, rather than the body part or surface that is stimulated. Parsons and Shimojo (1987) also observed that the front and back of the head were exceptions to this rule, because regardless of the head's position and orientation relative to the rest of the body, stimuli on the forehead were perceived as mirror reversed, and stimuli on the back of the head were perceived as matching experimenter-defined stimuli. (However, perception of stimuli on the sides and top of the head were influenced by the head's position and orientation relative to the rest of the body or the environment.)

In these foregoing studies, particularly in that of Parsons and Shimojo (1987), the mapping from the earliest, and likely local surface-based, representation of a pattern to an object-based description was underdetermined because a pattern could be sensibly interpreted in more than one way, depending on the frame of reference imposed on it. Although one might have expected the perceptual system to employ a simple and egocentric system, these results have shown that this mapping is influenced in a complicated way by the spatial relations among the stimulus, surface, and whole body. For example, in the regular standing position, the mirror-reversal tendency was dominant for the forehead, but not for the back of the head, back, or thigh. Also, the mirror-reversal tendency was dominant on the palm when it was facing forward or downward when the arm stretched forward, but not when it was facing backward or upward (Corcoran, 1977; Heller, 1986; Parsons & Shimojo, 1987). Furthermore, results of Oldfield and Phillips (1983) and Parsons and Shimojo (1988) indicate that the spatial organization used to interpret cutaneous patterns is also influenced by the whole body's relation to the environment (gravitational forces). Examining the factors that determine the perceived spatial organization of stimuli may enhance our understanding of how the parts, surfaces, and surrounding space of the body are represented for purposes of perception, action, and cognition.

Interaction of Motor and Visual Information in Cutaneous Perception and Motor Production of Patterns

In performing these tasks, subjects sometimes report that they mentally "track" (or pursue) the tracing of the stimulus, or mentally simulate drawing it themselves. The analysis-by-synthesis hypothesis described earlier implies the existence of such motor components in the cognitive

processes associated with perceiving these cutaneous stimuli. In fact, mirror writing is very often observed when people are asked to draw a letter on the underside of a table at which they are seated (Trueman, 1965). The letter produced by the mirror reversal in this case matches the correct form of the letter inscribed on the upward-facing surface of the table: thus, the spatial organization of the motor patterns would look correct to the subject if the table were transparent. Shimojo (1981) found the same kind of spontaneous mirror writing on surfaces at other orientations and positions, such as an outward- or forward-facing surface in front of the subject, and the outward- or backward-facing surface of the back of a chair in which a subject is seated.² (In producing the latter motor pattern, the head and trunk of the subject were oriented forward, and the arm was twisted behind the back.)

The similar results observed in the cutaneous perception and motor production of patterns suggest that they may be supported by common processes. Several observations are consistent with this hypothesis: (1) Spontaneous mirror writing occurs on surfaces at many of the same positions and orientations at which mirror reversals of stimuli are perceived cutaneously. (2) The tendency toward mirror writing is affected little by peripheral factors such as which hand produced the movement, or the orientation of the grip on the pen. (3) Mirror reversals are also often observed in tracing patterns on one's own forehead and on one's forward-facing or downward-facing palm. These three observations have been made by Parsons and Shimojo (1988) and Shimojo (1981), and are also consistent with the results of Kamura and Shimojo (1988) and Parsons and Shimojo (1987).

Another similarity between performance in these cutaneous and motor production tasks is that subjects' introspections in each task very often include reference to visual experiences: "It's as if I saw the letter through my head from behind," "It's much easier imagining that the screen (the hand) is transparent," "I just mentally picture the pattern," and so forth. Judging from these protocols, "mental imagery" or "visual" schemas, which would seem to be based on subjects' past visual experience, are activated during performance. Furthermore, in the discussion of these findings, various researchers have employed visual terminology such as "mind's eye" or "viewpoint" either as an analogy or in a more literal sense (Allen & Rudy, 1970; Corcoran, 1977; Duke, 1966; Krech & Crutchfield, 1958; Pedrow & Busse, 1970; Podell, 1966). However, although it is apparently common for subjects to use mental imagery in performing these tasks, the observations of Corcoran (1977) and Shimojo (1981) contravene the idea that performance depends literally or *directly* on visual processes: (1) performances in both their tasks were not influenced by whether subjects' eyes were open or closed, and (2) in both tasks, the tendency to mirror reverse stimuli on a surface depended on the surface's position and orientation with respect to the body as a whole, and was independent of its spatial relation to the eyes.

Thus, if the tendency toward mirror reversal can be attributed to the visual nature of the imagery or strategy used in the task, and if the extent to which visual imagery or strategies are used depends on past visual experience, then the rate of mirror reversal in the cutaneous perception and motor tasks should be positively related to the amount of past visual experience. This prediction is consistent with the hypothesis described earlier that people mentally adopt particular viewpoints on the surfaces of their bodies. However, if the underlying cognitive processes are not directly related to visual processes, but rather to nonvisual (e.g., motor or spatial) components of a body schema, then past visual experience would not be a critical factor. We addressed this issue by examining cutaneous pattern perception by subjects blind from either birth or a very early age. It was also of interest to see how responses in the cutaneous perception task corresponded to those in the motor production task in blind as well as sighted subjects. If we observe a high correspondence in the two tasks, our results would suggest that common processes underlie cutaneous pattern perception and motor pattern production.

METHOD

Subjects

Eight blind males, whose native language and culture was Japanese, volunteered to participate in the experiment. They were students of the University of Tsukuba, School for the Blind. Table 1 summarizes each subject's age, current visual acuity in each eye, and age at and cause of loss of vision.³ In addition, 8 sighted subjects volunteered to participate in the experiment as a control group. The 4 sighted females and 4 sighted males, all Japanese students of Aoyama-Gakuin University and from 20 to 25 years of age, performed both tasks with their eyes closed.

None of the blind or sighted subjects were selected on the basis of their reading or writing skills, or any other such characteristic. The subjects were not given any information as to the purpose or expected outcome of the experiment until a postexperimental debriefing.

Design

Each subject performed a session of the cutaneous perception task and a session of the motor pattern production task. In both the blind and sighted groups, 5 subjects performed the perception task first and the motor task second; 3 subjects performed the tasks in the reverse order. In the cutaneous perception task, each of four letters was drawn once on each of 10 body surfaces (see Figure 1). The resulting 40 trials were performed in an order random and unique for each subject. In the motor production task, subjects drew letters or numbers on the six surfaces indicated in Figure 2. Trials were grouped by surface orientation and position, and were performed in the numerical order indicated in Figure 2. The subject drew four numbers or letters in random order on a specific surface, before drawing on the next surface. Each subject performed 24 motor production trials.

Procedure

Cutaneous pattern perception task. The subjects were first asked to draw four lowercase letters (*p*, *q*, *b*, *d*) on paper on a table before them. Four blind subjects were unable to do so, and were given training and practice until they were able to draw the letters without confusion.⁴ The four stimulus letters were drawn with a stylus on body surfaces and always in one continuous stroke starting with the bottom end of *p* and *q* and the top end of *b* and *d*. Thus, the stimulus patterns were spatiotemporally identical except for direction of stroke. (Because of the symmetrical relationships of these patterns, mirror reversal of a letter in this set yields the perception of a familiar letter, i.e., another member of the set; see Parsons & Shimojo, 1987.) The size of the stimulus pattern was 5–10 cm in maximum linear extent, depending on the body surface. The subject was standing during the session. On vertical surfaces, the letter was drawn with its top pointed upward; on horizontal surfaces, the letters were drawn pointed forward (i.e., in the direction that the front of the subject's body faces). The subjects were asked to report the identity of a letter spontaneously and immediately, without thought. Each response was categorized as either a match of the experimenter-defined (or external) stimulus (e.g., where the stimulus *p* is reported as *p* or *d*) or a mismatch (a mirror reversal) of that stimulus (e.g., where the stimulus *p* is reported as *q* or *b*).

Motor production task. The stimuli were the numbers 1 through 9 (except 8) and the lowercase letters *a* through *k* (except *i*). A subject was first asked to draw all the stimuli on paper on a table before him/her. If he/she could not draw some characters correctly, those characters were eliminated from the subject's stimulus set.

Table 1
Age and Vision Systems of Blind Subjects

Subject	Age (in years)	Estimated Age at Vision Loss	Cause of Blindness	Visual Acuity*
K.O.	24	0	Phthisis bulbi aphakia	OD: absolute blindness OS: light perception
H.S.	22	0	Phthisis bulbi (buphthalmos)	OD: absolute blindness OS: absolute blindness
A.H.	23	0	Congenital anophthalmos	OD: absolute blindness OS: absolute blindness
K.K.	29	0	Retinal detachment	OD: absolute blindness OS: absolute blindness
S.A.	20	0	Phthisis bulbi	OD: absolute blindness OS: absolute blindness
Y.T.	18	3	Congenital glaucoma	OD: absolute blindness OS: absolute blindness
H.T.	19	2	Retinoblastoma	OD: absolute blindness OS: absolute blindness
K.S.	24	Under 3	Congenital glaucoma	OD: absolute blindness OS: absolute blindness

*Acuity for the left eye (OS) and right eye (OD).

Figure 1. Cutaneous pattern perception task. Each of four lower-case letters (*p*, *q*, *b*, *d*) was drawn by the experimenter on each of the 10 body surfaces indicated, and subjects were asked to report the identity of the letter spontaneously and immediately.

(In some cases, an uppercase letter was substituted for a lowercase one.⁵) The experimenter chose one of the remaining numbers or letters and asked the subject to draw it.⁶ During each trial, an experimenter classified a response as either a match or a mismatch (i.e., mirror reversal) of the stimulus, using his observation of the subject's hand movement and the pattern drawn. When subjects produced an ambiguous or extremely distorted pattern, they were asked to repeat their response. These cases were rare, partly because the members of the set of stimuli assigned to each subject were designed to be readily differentiated from one another. If a subject questioned the experimenter about the ambiguity of the spatial organization of the motor pattern, he/she was told to rely on his/her immediate, spontaneous, and naive response in drawing the stimulus.

RESULTS

Most subjects showed mismatches in cutaneous pattern perception on several body surfaces, and mismatches in motor pattern production on at least one surface. Figure 3 shows the group data for mismatches and matches for each surface and task. The one subject blinded early in life (K.S.) produced data similar to the congenitally blind subjects, so the data were pooled for further analyses.

Figure 2. Motor production task. Subjects were asked to draw four numbers or letters on each of the six surfaces indicated. The numbers in the figure indicate the order of the surfaces with which trials were performed (see text).

The results with sighted and blind subjects were very similar for the cutaneous and motor tasks (Spearman's $r = .86$, $p < .005$, and $r = .99$, $p < .005$, for cutaneous and motor tasks, respectively). However, there were two significant differences between the two groups in the two tasks, and both were in conditions of the cutaneous perception task: the downward-facing palm with the arm stretched forward ($\chi^2 = 4.27$, $p < .05$) and the backward-facing or outward-facing palm with the arm stretched backward ($\chi^2 = 6.67$, $p < .01$). In both of these conditions, the blind subjects produced mirror reversals at a higher rate than the sighted subjects. The blind subjects' performance on the downward-facing palm in front of the body was very similar (88% and 91% mismatches) to that of sighted subjects in Parsons and Shimojo's (1987) study; however, the sighted subjects in the present experiment showed less of a tendency toward mirror reversal (only 66% mismatches).⁷

For the blind subjects, the rate of mirror reversal (mismatch) reliably deviated from chance (50%) on all but two surfaces (chi-square tests, $df = 1$, $p < .005$): the forward-facing palm with the arm stretched backward in the cutaneous pattern perception task and the backward-facing or outward-facing vertical surface behind the body in the motor production task. For sighted subjects, the mismatch rate was significantly different from chance in all conditions except the forehead, the downward-facing hand in front of the body, the vertical backward-facing palm behind the back in the cutaneous perception task, and the vertical backward surface in the motor production task (chi-square tests, $df = 1$, $p < .005$).

The extent of individual differences among blind subjects was comparable to that among sighted subjects. One exceptional blind subject (Y.T.) showed very few mismatches in either cutaneous perception or motor production tasks, and reported having adopted the experimenter's viewpoint because he found it easier. In the cutaneous perception task, few stimuli (8%) were perceived with a top-bottom inversion, as expected from previous data in sighted adults (Parsons & Shimojo, 1987).

The overall tendency to mirror reverse or externalize a pattern was quite similar in the cutaneous perception and motor production tasks for both sets of subjects for surfaces at the same orientation and position [$r = .72$, $F(1, 10) = 10.57$, $p < .01$].

DISCUSSION

Very similar tendencies for mirror reversal in cutaneous pattern perception and motor pattern production were observed in sighted subjects and in subjects who had no, or very little, visual experience. It is very unlikely, although possible, that the blind subjects simply guessed how people with normal visual acuity would perform in the task, and mimicked that performance, in conformity with what they thought were experimenter's expectations. In fact, the blind subjects did not know, and were surprised by, the typical results in sighted subjects. In addi-

Figure 3. Percentages of mirror-reversal or mismatch responses are shown for each surface in each task (textured bars). "Front" and "back" in the motor task indicate surfaces either in front of or in back of the body. The numbers in parentheses refer to conditions in the cutaneous and motor task; they correspond to the numbers in Figures 1 and 2. The absence of bars in Motor Conditions 2 and 3 indicate the 0% mismatch rate observed.

tion, the blind subjects were usually not sure what they were doing (i.e., whether they perceived matching or mismatching stimuli) during the performance, as is often the case with sighted subjects as well.

Overall, these results appear inconsistent with an explanation of the mirror reversals that is based on the use of visual information processing (e.g., as in the mind's eye notion suggested by Corcoran, 1977). Note that there is more than one kind of "visual" explanation conceivable. Visual information could be involved if the motor and cutaneous tasks invoked visual imagery or visual coding. Alternatively, visual information could be involved if the tasks involved use of a nonvisual spatial coordinate

system that has been developed specifically as a result of an individual's visual experience. Our findings are not consistent with either of these (see the following discussion). At present, the mirror-reversal phenomenon seems to be unrelated to eye position, visual perspective, visual imagery, or other visual factors.

It is possible that in many tasks congenitally blind subjects use cognitive strategies that are nonvisual and more egocentric than those used by sighted subjects (Millar, 1982). However, the mirror-reversal phenomenon studied here appears to be related to more fundamental processes shared by blind and sighted individuals. This is consistent with the notion that blind individuals' mental

representation of the world may not be as different as one might predict on the basis of a lack of visual imagery. Indeed, recent work has found that congenitally blind and sighted subjects show qualitatively similar performances in various imagery tasks such as mental rotation (Carpenter & Eisenberg, 1978; Marmor & Zabeck, 1976), mental scanning, property verification, paired-associate recall, and free recall (Jonides, Kahn, & Rozin, 1975; Kerr, 1983; Zimler & Keenan, 1983), spatial reasoning (Hollins & Kelley, 1988; Kennedy, 1980; Landau, Gleitman, & Spelke, 1981), and encoding of spatial information by active touch (Lederman, Latzky, & Barber, 1985).⁸ (Specifically, visual information such as the properties of perspective may be lacking in blind individuals' mental representations [Arditi, Holtzman, & Kosslyn, 1988; Hollins, 1985; Hollins & Kelley, 1988; Kennedy & Fox, 1977; Reiser, Guth, & Hill, 1982, 1986], although some related perceptual abilities improve with practice [Guarniero, 1974, 1977; Kennedy, 1982; White, Saunders, Scadden, Bach-Y-Rita, & Collins, 1970].)

The fact that sighted and blind subjects produce similar patterns of results in both the cutaneous perception and motor production tasks is consistent with the argument that sighted subjects' experience of visual imagery may be epiphenomenal (Pylyshyn, 1981) in the sense that it is not essential to perform the task. It is possible that a nonvisual body schema of some kind relates the motor and/or kinesthetic components of these perceptual and motor tasks to body surfaces or positions in near-body space (see, e.g., Jones, 1975), and that even the visual imagery in the sighted individuals is organized on this body schema (Parsons, 1987a, 1987b). An analysis-by-synthesis interpretation of mirror reversals is generally consistent with this conclusion. On the other hand, there was a significant difference between the blind and sighted subjects in two conditions of the cutaneous perception task (the downward-facing palm with the arm stretched forward, and the backward-facing palm with the arm stretched backward). In the former condition, the difference appears due to random variation; in the latter, it is unclear whether the difference is random variation, or reflects differences in strategy between the sighted and blind subjects (see Results).

Analysis-By-Synthesis Model of Performance of Cutaneous Pattern Perception

There are three independent assumptions in the analysis-by-synthesis interpretation. The first assumption is that cutaneous pattern perception depends on "mental simulation" of one's motor production of the stimulus at the stimulated surface. The only evidence for this is that derived from a few subjects' introspections. Furthermore, some evidence here is inconsistent with some extreme versions of an analysis-by-synthesis hypothesis. Our subjects did not have well-practiced motor habits for cutaneous stimuli, but produced results very similar to those of subjects who did have such well-practiced motor habits (i.e.,

the native English speakers of Parsons & Shimojo, 1987). Thus, familiarity with motor patterns in the literal sense is not an important factor. The second assumption of the analysis-by-synthesis hypothesis is that cutaneous stimuli are spatially organized with respect to the whole body (i.e., with respect to a "central" or intrinsic frame of reference). This assumption is consistent with results of this and many previous studies. The third (more implicit) assumption is that motor control is also organized with respect to the same central or intrinsic frame of reference of the body, as underlies cutaneous perception. The method of spatial organization implied in the second assumption is a sensible one for the perceptual-motor system to adopt, given the third assumption. It would be very useful if the perception of the shape and position/orientation of objects in the local environment could be represented with respect to a central frame of reference (or coordinate system), which could also be used for coordinating actions of the body (Hinton & Parsons, 1988). (However, at least in cutaneous perception, some surfaces, such as the forehead, appear to have a "privileged" status; see Parsons & Shimojo, 1987.) In accordance with this idea, mismatch rates were similar in both the sighted and the blind groups when the cutaneous and motor tasks were compared at the same position and orientation of surface. One exception to this rule was the vertical, forward-facing (and outward-facing) surface in front of the body where mirror-reversal rates were relatively low in the motor tasks in both the blind and sighted subjects. This discrepancy may be related in some way to the active nature of the motor task, in which the writing hand is a "center" of action. Further work is necessary for an explanation of these data.

Spatial Organization of Patterns

The sighted as well as the congenitally and early-blind subjects usually ask, before or during their performance in these tasks, which viewpoint they should adopt in organizing their perception or motor production of patterns.⁹ This suggests that, if so desired, they can interpret the stimulus as though perceiving it from the experimenter's position. However, mirror reversals are almost always the most spontaneous, immediate, and naive perceptions of stimuli on the forehead, and on the forward-facing and downward-facing palm. This suggests that the processes underlying mirror reversals on these surfaces are more fundamental than those underlying matched recognition. If so, the mirror reversals may appear earlier in development, and the flexible information processing observed in the adult may emerge later. Kamura and Shimojo (1988) found the same kind of mirror-reversal phenomena both in the cutaneous pattern perception and motor pattern production tasks in children as young as 4 years old. Unlike adult subjects, 4-year-olds did not show any hesitation or confusion about viewpoint when they perceived mirror reversals. Thus, analogous sets of results are obtained in cutaneous and motor tasks not only with normal subjects, but also with congenitally blind sub-

jects and young children. Overall, these findings make it more likely that the mirror-reversal phenomena reported here are not modality specific, but rather reflect more fundamental and general cognitive processes underlying both cutaneous pattern perception and motor pattern production. Such processes may reflect anatomical or functional constraints that are not specific to any particular modality or behavior.

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NOTES

1. The results of Corcoran (1977), for example, suggest that the point of view from which his subjects viewed their bodies was invariant among subjects for a particular condition, with a few exceptions, such as the outstretched arm.
2. This motor production task is more "active" in nature than the cutaneous perception described earlier.
3. Our blind subjects had only limited experience with Optacon, a device that optically reads configurations of letters and transforms them into cutaneously detectable stimulus patterns. Because this allows the blind to perceive the spatial configurations of letters as passively as can

sighted individuals, some complexity would be introduced into the interpretation of data from blind subjects who were heavy users of Optacon.

4. This test and training procedure was followed with all 4 of the subjects who were unable to draw the letters, regardless of the order in which they performed the cutaneous and motor tasks. The practice consisted of training of the subjects' motor production of the pattern. It is conceivable, as a result, that the training biased these 4 subjects to identify a stimulus on the basis of properties of its motor production rather than on the basis of properties of its "appearance" or mental spatial image. However, during this training the experimenter repeatedly grasped and guided the subject's hand until the subject could draw the letter without assistance. Thus, the training was primarily passive proprioceptive or kinesthetic perception, rather than active motor production. Furthermore, no systematic difference in the results was found between the groups with and without additional training. In addition, in the cutaneous perception task, the data of the blind (and sighted) subjects in this study are very similar to the data in comparable conditions of subjects who had never performed the motor production task (those in Parsons & Shimojo, 1987).

5. Rarely did a blind subject confuse two letters on the basis of orientation or mirror images (e.g., *b* and *d*). In most cases when a subject could not draw a letter, he simply could not remember its configura-

tion; and even when he drew the wrong letter, it was rarely a mirror reversal of the stimulus or of any other letter.

6. We could have used identical sets of stimuli for both the sighted and blind groups, by reducing the number of stimuli and giving a training session to the blind group. However, in light of the major differences between the two groups in motor habits and familiarity for letters and numbers, we judged the current procedure to be more appropriate because only those letters familiar to each subject were used.

7. There is no previously published study with a condition directly comparable to the condition here of backward-facing palm with arm outstretched behind the body.

8. However, some of these studies were not directly focused on comparing blind and sighted subjects' performance with respect to the issues discussed in this report.

9. However, there may be differences between blind and sighted individuals with respect to what they mean by such expressions. Landau and Gleitman (1985) have evidence suggesting that, in development, blind children endow visual expressions with meanings consistent with their nonvisual sensory experience.

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