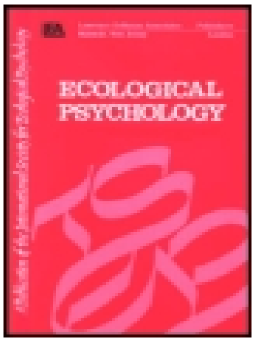

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Intermodal Calibration of the Body in Early Infancy

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Three experiments are reported addressing the issue of what kind of visual–proprioceptive information is picked up by young infants when engaging in the visual exploration of self-produced movements of their legs projected onto a video display. Results of the first experiment indicate that 3- to 5-month old infants show discrimination between a normal view of their own legs and a view that reverses the left–right location of both legs on the screen. Results of the second experiment show that there is no such discrimination when the overall featural configuration of the legs is occluded. In relation to Experiment 1, these results suggest that infants are sensitive to the invariant featural characteristics of the legs, in particular, how they relate to the rest of the body. Finally, results of the third experiment replicate infants' pattern of visual preference toward a view that reverses the seen and felt overall movement directionality, using a successive instead of a simultaneous visual presentation paradigm. These results provide further evidence of the early development of an intermodal calibration of the body. This calibration is interpreted as the perceptual foundation of the body schema and the early expression of an ecological self.

Prior to self-recognition in front of a mirror or explicit self-identification of any kind, infants express a sense of their own body as a differentiated agent situated in the environment (E. Gibson, 1993; Neisser, 1991, Neisser, 1993; Rochat, 1993; 1995). This bodily sense of self corresponds to an "ecological" as opposed to a more conceptual sense of self. The *ecological self*, according to Neisser (1988), is primarily defined by two distinguishable kinds of information: optical and kinesthetic. The first kind is specified by an optical flow field locating the self at the point of observation. The second kind specifies "the existence of a bounded, articulated and controllable body." This perceptual information includes "not only what we see,

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but what we feel we can do" (p. 6). Self-perception primarily occurs as a result of the infant's intermodal experience with visual–proprioceptive, proprioceptive–auditory, and tactile (double touch; see Rochat & Morgan, 1995a) information picked up when acting within the environment. Very few studies have attempted to specify the particular intermodal information underlying self-perception by young infants.

It has been demonstrated in converging lines of research that, from birth, infants exhibit intermodal coordination. The sensory modalities do not function independently, but are coordinated to control action from birth. Wertheimer (1961) demonstrated that newborns will turn their eyes toward a sound source. In addition, Trevarthen (1974) and von Hofsten (1982) demonstrated that newborns coordinate their arm movements into a pattern of prereaching that appears to be controlled by vision. Further evidence of the integration of visual–proprioceptive information with the control of motor movements exists in studies of newborn eye–head coordination (Bullinger, 1977; Krementizer, Vaughan, Kurtzberg, & Dowling, 1979). Evidence of facial imitation in newborns demonstrates the coordination of vision and proprioception from the outset of development (Field, Woodson, Greenberg, & Cohen, 1982; Maratos, 1973; Meltzoff & Moore, 1977, 1983). Meltzoff and Moore (1983) proposed that early facial imitation is based on an active process of intermodal matching. In their view, neonatal imitation is mediated by an amodal matching process between proprioceptive and visual information. Using this process, from birth, infants are capable of mapping the visually perceived model to their unseen facial gestures. Such intermodal capacity suggests that infants from an early age might be sensitive to and pick up intermodal information specifying their own body as a differentiated entity situated in the environment (the ecological self).

Self-produced movement is a particularly important source of the intermodal information specifying the ecological self. In a study by Harris, Cassel, and Bamborough (1974), 8- to 28-week-old infants tracked a moving target only when the object moved alone against a background, but not when the background moved in conjunction with the object. These observations suggest that infants differentiate their own movement from the movement of objects in the environment. Kellman, Gleitman, and Spelke (1987) have shown that 4-month-old infants perceived a rod occluded in its center as being an incomplete object when it was held stationary in front of them. In contrast, infants perceived it as complete or unbroken when the same rod was moved back and forth behind its occluder. However, when the infant was moved horizontally relative to the display (display = background and object), creating the same translated projection on the infant's retina as in the moving rod condition, the rod was once again perceived as being incomplete or broken as in the stationary condition. The differentially perceived object in the self-motion versus the object-motion condition is evidence that infants use visual–proprioceptive information to discriminate between self-movement and the independent movement of objects in the environment. In these examples, self-movement and its consequences (objects moving in conjunction with the self) specify a differentiated and situated bodily self.

Few studies have attempted to specify the perceptual information young infants pick up when exploring self-produced movements, an activity infants systematically engage in by 3 months (Rochat & Morgan, 1995a). The optical flow world for a human infant is different from that of adults. Because infants are unable to locomote on their own, they rely on the assistance of caregivers to move them through the environment. One implication of this perspective on the world and themselves is that infants spend much of their time watching (vision) and feeling (proprioception) their own movements in a nonlocomoting, exploratory mode. For example, observations of young infants (3–4 months old) have revealed that infants spend a great deal of time waving their own hands in front of their field of view. The movements of their fingers during such bouts of self-exploration involve surprisingly complex sequences of movements well before infants begin to grasp objects systematically (White, Castle, & Held, 1964). During such bouts of exploration, infants may be noticing the invariant positions of their various body parts (e.g., of the fingers and the arms and legs) as well as the feelings that correspond to different visuo–spatial transformations of these body parts. Some of the possible sources of cross-modal invariants infants may be detecting in perceiving their own movements include the rhythmic synchrony between optically specified and proprioceptively specified movement, spatial transformations in the three-dimensional geometry of their limb movements, the symmetry between the two sides of the body as their limbs move relative to their body midline (e.g., abduction and adduction of leg and arm movements), and the featural or configurational aspects of the way their body is shaped (e.g., the general manner or invariant form of the arm resulting from its characteristic bending at the wrist and elbow). In an attempt to investigate the possible sources of invariant information young infants are sensitive to when viewing their own movements, Bahrick and Watson (1985), using a preferential looking paradigm, showed that young infants discriminate the absence of temporal contingency (i.e., the rhythmic synchrony or simultaneity) between visual and proprioceptive feedback in the perception of self-generated movements. Five-month-old infants are shown to discriminate between a prerecorded image of another infant's legs moving and an on-line image of their own legs. Bahrick and Watson concluded from these results that by 5 months of age, infants are able to discriminate visual–proprioceptive contingency accompanying self-produced movements and that this discrimination may form the basis of self-perception in infancy. Rochat and Morgan (1995b) conducted three follow-up experiments to the one by Bahrick and Watson using a similar but modified version of a preferential looking paradigm. In the Rochat and Morgan (1995b) studies, temporal contingency (synchrony or simultaneity of vision and proprioception) was held constant in both of the views presented to the infant participants (i.e., both images were in real time), while the spatial arrangement of the legs was systematically varied. In one condition, infants simultaneously viewed two on-line views of their own legs on a TV screen, one in which movement directionality on the TV screen was congruent with their own movements and one in which movement was opposite in direction to their own movements (incongruent movement directionality). Rochat and Morgan (1995b) observed that from three months of age, infants looked significantly longer and showed significantly more leg activity while looking at the view that was incongruent with their own movements. The leg activity observed was in the form of the spontaneous, stereotypical leg movements described in 1981 by Thelen (i.e., bouts of single-leg kicks, both-legs-together kicks, alternating leg kicks, and foot rubbing). The results suggest that early on, infants manifest an intermodal calibration of their own body in motion as demonstrated by their differential looking and leg activity behavior while experiencing the presented displays.

In discriminating conflicts between the way infants' legs appear to them as compared to the way their legs feel, infants demonstrated that they are attuned to intermodal invariants that underlie the calibration of proprioceptive and visual space during rhythmic, synchronous movement. In particular, in Rochat and Morgan's (1995b) study, infants were shown to use this visual–proprioceptive information to determine general changes in movement directionality (i.e., visual congruence or incongruence in the movement of the legs in the right to left direction relative to the environmental frame of reference). The objective of the present experiments was to further address the question of infants' sensitivity to the movement directionality of their legs, but within the frame of reference of the body rather than of the general surrounding environment. In addition, the question of whether the legs' configurational or featural characteristics toward the body midline affect infants' perception of their legs' relative, invariant position was addressed.

On a descriptive level, the legs move relative to each other in constrained spatial configurations. For example, each leg has a muscle–joint configuration that individually determines the degrees of their behavioral freedom. In addition, the behavioral degrees of freedom of each leg are constrained by the invariant point of their attachment to the rest of the body. Intermodally speaking, each individual leg is invariably felt to be moving on the ipsilateral side to which it is seen. We hypothesized that such visual–proprioceptive information is available to the infant during the exploration of self-produced movement and may also specify the location of the legs on the body relative to each other.

From a dynamic point of view, given the fact that the relative movement of each leg is invariantly associated with a particular side of the body, the question addressed in the current research is whether infants will discriminate a change in this invariant information when the integrity of their legs' configuration relative to their body's midline is altered. The type of movements investigated in the current research are qualitatively different from the environment-relative movements varied in Rochat and Morgan (1995b). In particular, the general right–left direction of the legs with respect to the environment was maintained congruent to the visual and proprioceptive feedback of each individual leg's motion. Consequently, the question of whether infants would be able to discriminate the particular movement information altered while viewing images of their own legs when the relative position (relative point of attachment to the rest of the body) of the legs is switched from left to right on a video display.

Concretely, in two different experimental conditions, proprioceptive information (feedback from the muscles and joints) of the relative movements of the legs (abduction and adduction of the legs to the body midline) was made either to conflict with or match the self-produced movement normally seen and felt by infants. In the conflicting condition, the relative position of the legs on the body was switched from left to right. Thus, when infants moved their legs toward each other (adduction of one or both legs to the body midline), they were actually seen as moving away from each other on the display in front of them. Similarly, when infants' leg movements were felt as moving away from each other (abduction of one or both legs away from the body midline), they were seen as moving toward each other on the display. In a nonconflicting condition, the legs were displayed in their normal position relative to the body's midline. The present research was designed to investigate whether infants discriminate such changes.

EXPERIMENT 1

In the first experiment, infants were seated in front of a display similar to the display in the Rochat and Morgan (1995b) study. However, instead of a preferential looking paradigm (i.e., two views of the legs side by side), infants were presented successively and in two different conditions with one on-line video image of their legs from the waist down (one pair of legs in each condition). In one condition, infants saw their legs in their *normal* relative position; and in another condition, the legs' relative position was *reversed* from left to right (see Figure 1A & 1B). Temporal contingency between seen and felt movement as well as the spatial congruence of the general right–left movement directionality of the legs with respect to external space was maintained constant. What changed between the two conditions was the relative position and therefore the relative movements of one leg in relation to the body midline (right leg to the left of the screen and left leg to the right). In the condition in which the location was changed (see below for details), when the infant moved one leg toward the other (an adductive movement), she saw on the screen the leg corresponding to the appropriate (ipsilateral) side moving away from the other (an abductive movement).

On a developmental level, and based on the findings of Rochat and Morgan (1995b), 3- and 4–5-month-old infants were tested. The perception of body-midline-relative movement directionality was thought developmentally to follow the perception of general right–left environmental movement directionality that 3-month-olds appear to discriminate (Rochat & Morgan, 1995b). The rationale for such an hypothesis was that perceiving the relative movements of the legs probably requires increased differentiation of individual body parts than the perception of

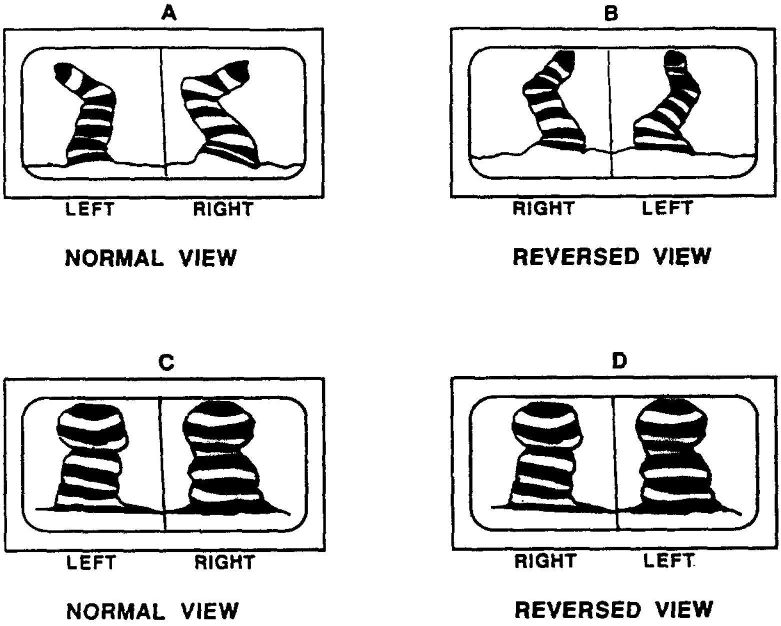

FIGURE 1 The video display as it appeared to the infants in Experiments 1 and 2 for (a) the Normal condition of Experiment 1, (b) the Reversed condition of Experiment 1, (c) the Normal Condition of Experiment 2, and (d) the Reversed condition of Experiment 2.

more general, environment-relative forms of movement. Because 4–5-month-old infants tend to have more coordinated patterns of movement than 3-month-olds and have had more opportunity to look down directly at their legs moving, it was expected that the older infants would be more attuned to the invariant relative position of their legs than 3-month-olds. Therefore, we predicted that the older group of infants would show different exploratory behavior across the two conditions.

Method

Participants. Twenty-two healthy, full-term infants were tested. Ten were three-month-olds (M = 3 months, 12 days) ranging from 3 months, 0 days to 3 months, 28 days. Twelve were 4- to 5-month-olds (M = 4 months, 27 days) ranging from 4 months and 1 day to 5 months and 27 days. Infants were recruited from a participant pool consisting of over 500 infants born in the Atlanta area. Parents were contacted by phone and invited to participate with their infant. Overall, 26 infants were tested. Of the 4 that were not included in the final sample, three cried or looked less than 15% of each 2 min trial at the TV, and one crossed his legs over the foam divider (as described in the Apparatus and Procedure section), interfering with the experimental manipulation. Fifteen percent, a minimum of 18 sec of looking per trial, was chosen as a minimum criterion for inclusion in the final sample. This criterion was chosen based on pilot observations revealing that infants did not seem to be fully engaged in the display if they did not have ample opportunity to move and consequently view their own movements on the TV screen.

Apparatus and procedure. Both groups of infants were successively presented with two on-line video images of their own legs from the waist down on a 25-in. video monitor (Panasonic CT5824). The general procedure was similar to the one described in the studies by Rochat and Morgan (1995b), except that the two different views of the legs were presented sequentially rather than simultaneously as in the preferential looking paradigm used in the original experiments. The infants were seated in an infant seat, reclined 60°, looking up toward the TV that was inclined 30° above their head at a distance of 1 m. The reclined posture prevented the infants from seeing their own legs directly. In this paradigm, two cameras (Panasonic black-and-white CCTV HWV–BL294) were placed 2 in. apart and clamped onto a bar installed into the walls of the experimental room, 1 m above the midpoint of the infant's body.

In the normal condition, the camera on the left side of the infant filmed the infant's left leg, and the camera on the right filmed the right leg. Both images (one leg in each) were projected onto corresponding sides of the vertically split screen TV, using a Pelco video splitter (Pelco US100DT). In the reversed condition, the cameras were adjusted manually so that the image of the left leg was projected to the right side of the TV screen and the image of the right leg was projected to the left side of the screen.

A foam block 4 in. wide, 4 in. high, and 7 in. long, that blended in with the color of the white seat on which the infant was seated, was sewn to the cloth of the infant seat and placed between the infant's legs, so that the infant's legs remained a minimum of 4 in. apart and did not cross each other, disrupting the composite image of the infant's body on the split video screen. On the video screen, both the normal and the reversed conditions formed a composite of the infant's legs from the waist down, so that the visual image formed the completed lower half of the infant (see Figure 1, A & B). The infant seat itself was covered with a white quilted material, so that changes in the texture gradient (shadows) were minimized in the image. Both conditions (normal and reversed) had the same spatial orientation relative to the infant (legs coming up from the bottom of the screen); and the movement of each individual leg on the screen was identical in direction and temporal synchrony to the infant's own movements.

In the normal condition, visual feedback of the on-line leg movements occurred on the side relative to the body in which they occur normally. As a result, in this condition, each leg was seen and felt on the ipsilateral region of visual–proprioceptive space, corresponding to the normal intermodal calibration of the legs. In particular, the right leg was felt as moving on the right side of the body, although the visual feedback of its movements was perceived in the right visual hemifield. In contrast, in the reversed condition, each leg was seen in the contralateral visual hemifield. Thus, visual feedback of leg movements was perceived in the contralateral visual hemifield.

The order of presentation of the normal and reversed conditions was counterbalanced across participants of each age group. Hence, five infants in each group viewed the normal condition first and five viewed the reversed condition first. To entice the infant to look at the TV and to visually equate the image of each leg, long socks with black and white stripes were put on the baby's feet and legs. Furthermore, as in Rochat and Morgan (1995b), to entice them to move their legs and ensure that the action produced could be better viewed on the screen, a small tie pin microphone (Realistic 33–1063) was placed under the foam block between the infants' feet, on the lower part of the seat, taped to the underside of a sheet of white paper. The sheet of paper acted to spread out the sounds that the infants made while kicking their feet near the area over the microphone. The microphone, invisible to the infant, was connected to a mini-amplified speaker system (Realistic 32–2040, 16.5 cm × 12.5 cm) affixed on top of the TV. Contingent to any leg movement, this setup produced a commensurate rustling–scratching sound originating from the speaker on top of the TV monitor. This auditory feedback provided the infant with contingent sound accompanying the legs' movements and a quantitative measure of leg activity for later analysis. The contingent sounds enticed the infant to generate more movement and to orient toward the location of the sound produced (the video monitor).

A third camera (Panasonic S–VHS movie camera, AG–450) was placed 1.5 m away in front of the infant providing a close-up video recording of the infant's eyes and an audio recording of the amplified leg activity sounds. This third camera was placed under the table supporting the TV monitor. The video recording was used to code infants' looking behavior and amount of leg activity while they gazed at the either side of the video screen. The infant's view of the split screen as it appeared to the infant over the 4-min testing session for both conditions was also recorded by a video cassette recorder (Panasonic AG–1270).

After the infant was sitting comfortably in the seat in front of the TV monitor, a preliminary calibration of the infant's relative gaze to each side of the video screen was performed and videotaped by the third camera. In this calibration phase, a rattle was shaken in front of the monitor. The calibration phase lasted approximately 15 sec, during which a colorful Mickey Mouse print curtain covered the TV screen and the microphone–speaker system had not yet been turned on.

Immediately after the calibration phase, the test phase began. Infants were shown the normal and reversed conditions in alternating sequence (2 min each trial) for a total of 4 min. The test phase started when the curtain was lifted from the screen and the microphone–speaker was turned on. During the entire testing session, one experimenter stood directly behind the infant, invisible to the infant facing the TV. This experimenter changed the views during the test and checked for any changes in quality of the two views during the session. This was accomplished by an experimenter angling the cameras in between trials such that each camera filmed the leg it had not yet filmed. When changing to the reversed condition, the experimenter angled both cameras slighty toward each other until the two images on the vertically split screen swapped locations from right to left, switching the legs' position on the display. When changing the views to the normal condition from the reversed condition, the experimenter angled the cameras so that they were parallel to each other, each camera pointing down toward the leg directly below it. This experimenter put a panel up in front of the third camera while changing the angle of the cameras to mark the beginning of condition changes for later coding of the videotapes and to hide the condition change from the infant's view. At the end of the entire 4-min test, the curtain was put back over the TV monitor. The intercondition interval was approximately 4 sec.

Scoring and Dependent Measures

Following the paradigm and scoring procedures used by Rochat and Morgan (1995b), the audio and video recording of the camera providing a close-up of the infant's face was scored for (a) absolute duration (in seconds) looking and percent of overall looking at the display, and (b) the percent co-occurrence of looking at the display and leg activity.

Looking measures. Two independent coders coded the videotape (from camera 3) of infant looking behavior at the TV monitor display using a computerized event recorder with multiple input channels running on the computer's clock. A channel for looking behavior was controlled by a predetermined key on the computer's keyboard. Whenever the infant stopped looking at the TV, the coder removed her finger from the key, and resumed pressing it when the infant looked in the direction of the screen again. Coders were blind as to which condition the infant was viewing while coding the infant's gazing behavior.

After coding a condition, a program calculated the total number of seconds that the infant looked at the display. To examine looking duration as a proportion of the total trial time, the percentage of time looking at either condition over each 2-min trial was calculated.

Leg activity while looking. In both conditions, infants viewed their own leg movements on-line. As a result, a contingency loop was generated in which leg movements are seen and felt as they are produced, giving the infant immediate visual–proprioceptive feedback during testing. Therefore, the extent to which infants perceived the visual–proprioceptive correspondence between their own movements and the movements on the display was measured by the amount of leg activity produced while looking at the display in both conditions. In general, previous research comparing leg activity while looking at the display versus looking away from the display has shown significantly more leg activity while looking at the display (Rochat & Morgan, 1995b) indicating that infants experience the apparatus instrumentally.

Although a coder made a pass through the video recording coding the infants' looking, the audio recording of the sound generated by the infants' leg movements via the microphone placed under a sheet of paper on which their feet rested was digitized by a Ceder Sound Digitizer (CSD from Ceder Technology) and imported into the computer on another channel of the event recorder. The digitized sound, corresponding to the leg movements of the infant, was initially recorded as a partial sound spectrogram (volume over time). At the end of the coding, the program performed a post hoc transformation of the imported sound spectrogram into successive periods of activity or no activity of the legs. This transformation used a different channel of the event recorder from the one on which looking activity was simultaneously coded. The leg activity transformation was based on a set threshold corresponding to one-third of the maximum input recorded on the sound spectrogram. In general, when the sound picked up exceeded the one third threshold, the program transformed a threshold crossing as an episode of leg activity of 2 sec in duration and recorded this on a channel of the event recorder. Based on pilot observations with this paradigm, the unit of 2 sec was chosen to approximate the characteristics of a typical bout of an infant's leg movements.

Based on the simultaneous records entered on the channels of the event recorder (looking and thresholded leg activity), a program calculated the relative duration in seconds of (a) looking at the TV monitor, (b) leg activity, and (c) the co-occurrence of leg activity and looking at the TV monitor. The co-occurrence of looking at the display and leg activity was calculated in terms of duration of leg activity as a percentage of the total time spent looking at the monitor during a particular condition: [(leg activity while looking at a particular condition) / (looking at this particular condition) × 100].

For the measures of looking at the display and leg activity while looking at the display, within and between coders reliability tests performed on approximately one third of the participants (7 out of the 20 infants) yielded Pearson–r's greater than .90.

RESULTS

Looking measures. Analysis of the time the infants spent looking at the TV was first performed. A 2 (age) × 2 (condition) mixed-design analysis of variance (ANOVA) revealed a significant main effect of condition, $F(1, 20) = 12.59$, $p < .002$, and no Age × Condition interaction. A similar analysis of the percentage (see Table 1) of time looking at the TV for each condition yielded a significant main effect of condition only, $F(1, 20) = 12.56$, $p < .002$. In general, Table 1 shows both groups of infants looked at the display significantly more during the normal condition.

Leg activity while looking. For both groups of infants, the amount of leg activity while looking at the TV in the normal condition was compared to the amount of leg activity while looking at the TV in the reversed condition. A 2 (age) × 2 (condition) mixed-design ANOVA revealed a main effect of condition, $F(1, 18) = 5.442$, $p < .04$, and a significant Age × Condition interaction, $F(1, 20) = 6.019$, $p < .03$. Overall, the older group of infants showed significantly more leg activity while looking at the normal compared to the reversed condition (See Table 1). This preferential pattern was further supported by the fact that 17 out of the 22 infants showed more leg activity while looking at the normal view of their legs compared to the reversed view ($p < .05$, binomial test).

TABLE 1
Results of Experiment 1: Means and Standard Deviations of Task Measures in the Normal and Reversed Conditions, for Each Age Group

	Looking Duration[a]		*Looking Percentage*[b]		*Leg Activity*[c]	
Age (Months)	*Normal*	*Reversed*	*Normal*	*Reversed*	*Normal*	*Reversed*
3						
M	76	68	64	57	30	31
SD	25	30	21	25	18	18
4–5						
M	62	41	51	34	31	19
SD	29	25	25	19	15	11

[a] In seconds. [b] Percentage duration of looking at the TV. [c] Percentage duration of leg activity while looking at the TV.

DISCUSSION

The results showed that both groups of infants manifested differential looking behavior across the two conditions. In particular, both groups of infants demonstrated increased looking at the normal compared to the reversed condition. With respect to age, only the older group of infants showed more leg activity while looking at the display in the normal compared to the reversed condition. Although the results were opposite in direction to what was originally expected based on the findings of Rochat and Morgan (1995b), infants did show discrimination between the two views of their legs. This apparent inconsistency compared with previous research in which infants have typically shown more interest in the incongruent view of their legs raises issues of the possible reasons for infants' opposite preference in the present research. One of these issues may be due to an artifact of the testing situation (successive vs. simultaneous presentation of the two views of the legs) and is directly addressed in the third experiment.

Our results, however, suggest that from as early as 3 months of age, infants are sensitive to differences in the relative movements of their legs toward or away from their body's midline and/or some other form of information that was incidentally varied between the two displays. Although relative leg position was altered in the first experiment, more than one kind of perceptual information was available to infants in perceiving their own legs on the display. It was initially intended that the relative position of the legs, and therefore only the legs' relative movement to each other, was what was different across the two conditions. However, movement information was confounded with featural, configurational information in both displays. Perhaps changes in the featural characteristics of the legs across the two conditions were responsible for the infants' pattern of looking and kicking, not just the dynamics of the leg movements on the display. The featural characteristics corresponded to differential bending of the ankles and knees across conditions on the screen (See Figure 1, A & B). To control for these differences, a second experiment was conducted.

EXPERIMENT 2

In Experiment 2, the featural characteristics of the legs were partially occluded. Specifically, the same procedure as in Experiment 1 was repeated but with the infants wearing bulky striped socks that obscured the bending of their legs (see Figure 1, C & D). The dynamic information specifying the legs' relative position, as well as a more general outline of the legs, was still available on both displays (enough information to specify two "squirming protuberances" Gibson (1979/1986, p. 234). The question addressed by Experiment 2 was whether infants would still be able to discriminate the change in leg position (as would be revealed by their continued discrimination between the two displays), when the featural characteristics of the two legs remain constant.

Method

Participants. Twenty healthy, full-term infants were tested. Ten were 3-month-olds (M = 3 months, 20 days) ranging from 3 months and 13 days to 3 months and 29 days. Ten were 4- to 5-month-olds (M = 4 months, 28 days), ranging from 4 months and 1 day to 5 months and 27 days. Infants were recruited from a participant pool consisting of over 500 infants born in the Atlanta area. Parents were contacted by phone and invited to participate with their infant. Overall, 25 infants were tested. Of the five that were not included in the final sample, three cried and two looked less than 15% of the test period at the TV.

Apparatus and procedure. The procedure and apparatus was the same as in Experiment 1 with one exception: Instead of black and white striped socks covering the legs, bulky, black and white striped socks were worn by the infant (see Figure 1, C & D).

Scoring and dependent measures. The scoring and dependent measures for Experiment 2 were the same as in Experiment 1. For both the looking and leg activity while looking measures, within and between coders reliability tests performed on approximately one third of the participants (7 out of the 20 infants) yielded Pearson *r*s greater than .90.

RESULTS

Looking measures. Analysis of the absolute time (in seconds) infants spent looking at the TV during the normal versus reversed conditions was first performed. A 2 (age) × 2 (condition) mixed-design ANOVA revealed no main effect of condition, $F(1, 18) = .979, p < .4$, and no Age × Condition interaction. A similar analysis of the percentage (see Table 2) of time looking at the TV for each condition yielded no significant effect of condition, $F(1, 18) = .893, p < .4$. In general, both groups of infants looked at the display equally in both the normal and the reversed condition.

Leg activity while looking. For both groups of infants, the amount of leg activity while looking at the TV in the normal condition was compared to the amount of leg activity while looking at the TV in the reversed condition. A 2 (age) × 2 (condition) mixed-design ANOVA revealed no main effect of condition, $F(1, 18) = .017, p < .9$, and no Age × Condition interaction, $F(1, 18) = .96, p < .35$.

TABLE 2
Results of Experiment 2: Means and Standard Deviations of Task Measures in the Normal and Reversed Conditions for Each Age Group

	Looking Duration[a]		*Looking Percentage*[b]		*Leg Activity*[c]	
Age (Months)	*Normal*	*Reversed*	*Normal*	*Reversed*	*Normal*	*Reversed*
3						
M	83	72	69	61	28	25
SD	24	17	20	14	15	17
4–5						
M	66	68	55	57	21	25
SD	25	33	21	27	10	17

[a] In seconds. [b] Percentage duration of looking at the TV. [c] Percentage duration of leg activity while looking at the TV.

Overall, both groups of infants showed the same amount of leg activity while looking at the normal and reversed views of their legs (see Table 2).

DISCUSSION

In this second experiment, the relative amount of looking and leg activity was not significantly different for the normal versus the reversed condition. The fact that infants did not show different patterns of looking or kicking while looking across the two conditions may be due to either an insensitivity to the independent variable or an unintended artifact of the testing situation. In the first case, infants may not have been sensitive to the conflict created on the display between proprioception and vision when the relative movements of the legs were altered and the featural characteristics of the legs were occluded. Such an insensitivity would suggest the importance of featural or specific configurational information in the perception of relative leg position. In the second case, one possible artifact may have been that the bulky socks, in addition to obscuring the featural characteristics of the legs, may have dampened some of the dynamics of the displays, obscuring some of the movement information specifying a change in relative leg position across the two conditions.

Regarding both of these accounts, the first is considered to be more plausible. Although the bulky socks were not form-fitting, they did not appear to obscure movement; rather, they merely occluded the usual shape of the legs across the two conditions. To confirm that the same amount of leg activity was produced in this experiment compared with the first experiment, a *t* test was conducted comparing the amount of leg activity while looking at the display in the normal condition of the first experiment (see scoring and dependent measures section for the calculation of this value) to the leg activity produced while viewing the normal condition of the present experiment. The results of the *t* test show that there was no significant difference in the amount of leg activity produced across these two similar conditions, $t(19) = 2.196, p < .15$. Thus, the actual amount of self-generated leg movement was comparable across experiments; suggesting that the featural characteristics of the legs and not the dynamic nature of the display was altered by the bulky socks.

The combined results of Experiments 1 and 2 are interpreted as initial evidence of the importance of featural characteristics in the perception by 3- to 5-month-old infants of self-produced movement, and in particular in the perception of the relative position of the legs moving in visual–proprioceptive space.

EXPERIMENT 3

Questions remain as to why infants in the present research showed a reversed pattern of preferential looking (preference for the normal view) compared to previous studies (Bahrick & Watson, 1985; Rochat & Morgan, 1995b). One hypothesized reason might be due to an artifact of the testing situation. In the original Bahrick and Watson and Rochat and Morgan studies, as well as in recent studies by Schmuckler (1996), data were collected using a preferential looking paradigm in which the infants simultaneously viewed an incongruent and congruent view of their legs, not in succession as in the present research. The question examined in the next experiment was whether infants would show an analagous pattern of preference in the sequential looking paradigm used in the present research. To examine this possibility, the third experiment was designed to attempt a replication of Rochat and Morgan's results. Such a replication would indicate that the novel, sequential procedure used in this research is directly comparable to the simultaneous preferential looking situation used in previous studies. Therefore, a differential pattern of preferential looking obtained using the sequential method, as in the first two experiments, would suggest that the phenomenon observed does not depend on the method used. Specifically, a replication of previous findings (Experiment 2 of Rochat & Morgan, 1995b) was performed, using the sequential paradigm of the current research. In particular, the question was whether the same looking and leg activity pattern would be demonstrated using a sequential presentation procedure.

METHOD

Participants. Ten healthy, full-term infants were tested. Five were 3-month-olds and 5 were 4–5-month-olds (M of the full sample = 4 months and 2 days, ranging from 3 months and 8 days to 6 months and 8 days). Infants were recruited from a participant pool consisting of over 500 infants born in the Atlanta area. Parents were contacted by phone and invited to participate with their infants. Overall, 18 infants were tested. Of the eight that were not included in the final sample, four cried and four looked less than 15% of the test period at the TV.

Apparatus and procedure. As in Experiment 2 of Rochat and Morgan (1995b), infants were presented with a reversed ego view and an ego view of their own legs in real time (see Figure 2). In the ego view, the directionality of movement was congruent with the infants' own movements to either the right or the left. In particular, when the infants moved their legs to either the right or to the left, the legs on the TV monitor moved in the corresponding direction. In contrast, the reversed ego view presented to the infant was identical but reversed with respect to the direction of the infant's leg movements. Using the modified camera from the first two experiments, when the infant moved to the right in the reversed ego view, the movement on the screen was to the left. Similarly, when the infant moved to the left, the leg movement on the screen was to the right. This modification was the only difference between the two views.

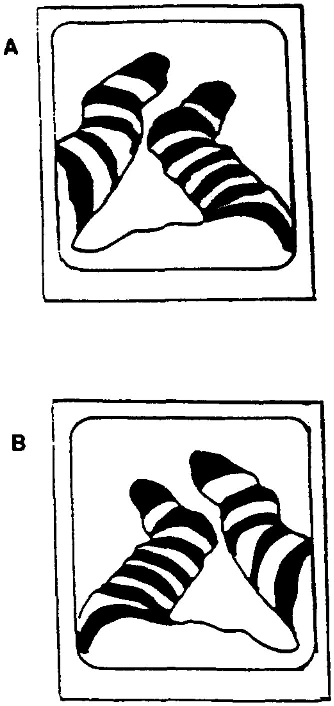

FIGURE 2 The video display as it appeared to the infancts in Experiment 3 for (a) the Ego condition, and (b) the Reversed Ego condition.

The design was the same as it was for the first two experiments. In particular, infants viewed each condition (ego vs. reversed ego view of their own legs) for 2 min. The order of presentation of the two views was approximately counterbalanced between subjects of each age group.

Scoring and dependent measures. The scoring and dependent measures for Experiment 3 were the same as in Experiments 1 and 2. For both the looking and leg activity measures, within and between coders reliability tests performed on approximately one third of the participants (4 out of 10 participants) yielded Pearson rs greater than .90.

RESULTS

Looking measures. Analysis of the time the infants spent looking at the TV during the ego versus the reversed ego conditions was first conducted. A 2 (age) × 2 (condition) mixed-design ANOVA revealed a significant main effect of condition, $F(1, 8) = 7.79, p < .02$, and no Age × Condition interaction. A similar analysis of the percentage (see Table 3) of time looking at the TV for each condition yielded a significant effect of condition, $F(1, 8) = 7.77, p < .02$. In general, both groups of infants looked at the display significantly more during the reversed ego condition (See Table 3). This pattern was further supported by the fact that 9 out of 10 infants spent more time looking at the reversed ego view of their legs compared to the ego view ($p < .02$, binomial test).

TABLE 3
Results of Experiment 3: Means and Standard Deviations of Task Measures in the Normal and Reversed Conditions for Each Age Group

	Looking Duration[a]		*Looking Percentage*[b]		*Leg Activity*[c]	
Age (Months)	*Normal*	*Reversed*	*Normal*	*Reversed*	*Normal*	*Reversed*
3						
M	64	71	53	59	19	26
SD	30	25	25	21	20	18
4–5						
M	56	75	46	63	19	28
SD	20	19	17	16	12	15

[a] In seconds. [b] Percentage duration of looking at the TV. [c] Percentage duration of leg activity while looking at the TV.

Leg activity while looking. For both age groups of infants (5 younger, 5 older), the amount of leg activity while looking at the TV in the ego condition was compared to the amount of activity while looking at the TV in the reversed ego condition. A 2 (age) × 2 (condition) mixed-design ANOVA revealed a marginally significant main effect of condition, $F(1, 8) = 4.184$, $p < .07$, and no Age × Condition interaction, $F(1, 8) = .062$, $p < .81$. Overall, although marginally significant, both groups of infants tended to show more leg activity while looking at the reversed ego view of their legs (See Table 3). This trend was further supported by the fact that 9 out of 10 infants showed more leg activity while looking at the reversed ego view of their legs compared with the ego view ($p < .02$, binomial test).

Discussion

These results replicate the pattern found in the original Rochat and Morgan (1995b) experiments: infants looking longer at the incongruent and less familiar view of their own legs. The replication of the infants' preference for the reversed ego view of their legs in this experiment further demonstrates that the left–right directionality of movement relative to the environment is a crucial variable determining infants' increased engagement in the incongruent display regardless of whether a sequential looking method (this study) or a simultaneous preferential looking method was used. Furthermore, the results of this third experiment indicate that the opposite pattern of discrimination by infants observed in Experiment 1 compared with previous research (Rochat & Morgan, 1995b) is probably not due to the method used (sequential procedure), but to the phenomenon observed.

GENERAL DISCUSSION

Three experiments were conducted to determine whether young infants are able to discriminate between different spatial arrangements of their own legs moving on a screen. In the first experiment, we asked whether infants are able to discriminate a change in the relative position of their legs as specified by their legs' abduction and adduction movements toward or away from the body midline. Infants were found to discriminate between the normal and reversed conditions, showing more looking and leg activity while looking at the view that depicted their legs in their normal relative position (i.e., the normal view) compared to the condition in which the legs were reversed in position from left to right. Such discrimination is indicative of the infants' attunement to the visual–proprioceptive calibration of their bodies as an organized and coherent moving entity. A second control experiment was conducted to more specifically investigate the type of perceptual information infants use to discriminate between the normal and reversed views of their legs. This second experiment revealed that when featural information about the legs' configuration or outline is systematically occluded from the display (by placing bulky socks on the infant's legs), infants no longer show a systematic pattern of discrimination between the two views. The combined results of Experiments 1 and 2 suggest that direction of motion relative to the body midline may be an important spatial determinant in the perception of self-produced movement by infants as young as three months of age. Interestingly, this perceptual ability was manifested only when changes in the featural characteristics of the legs were clearly available on the display (as in Experiment 1). Note that any adult observer could readily discriminate the difference in featural information across conditions in Experiment 1, based on a static image of the legs as shown in Figure 1, A and B. However, in Experiment 2, a static image of the legs from either condition wuld not be enough to reveal the main difference between the two experimental conditions (e.g., see static images in Figure 1, C & D).

Finally, to validate the use of the different testing situation (sequential looking as compared with simultaneous looking) in Experiments 1 and 2 as compared with previous research and to further explore whether an artifact of this situation could have accounted for the reversed pattern of preference found compared to the original findings of Rochat and Morgan (1995b), so a third control experiment was conducted. In this experiment, the sequential procedure was tested by attempting to replicate the results of Rochat and Morgan (Experiment 2). The results replicated the original findings, with infants preferring to look at the spatially incongruent view of their legs (the reversed ego view), in which the left–right movement directionality of the legs in relation to the environmental frame of reference was changed. This replication suggests that the opposite preference in looking behavior found in Experiment 1 of the present research reflects the nature of infants' reaction to the independent variable and cannot merely be accounted for by an artifact of the sequential testing procedure.

Overall, the findings of the present research may be interpreted as additional evidence for the early expression of a calibrated intermodal space in the perception of self-produced leg movement, in which the invariant information from the motion and featural configuration of one body part is specified in relation to another body part within the bodily frame of reference. The development of such intermodal calibration is probably the byproduct of the process of early self-exploration, a means by which infants learn about the effectivities of their own body and perceive the invariant relations of its parts. Early in development and at least by 3 months, infants can be observed actively attending to their own movements, systematically experiencing the coactivation of several sensory modalities at once (e.g., vision, proprioception, touch, audition; Rochat, 1995; Rochat & Morgan, 1995b). During these early bouts of self-exploration, infants might detect regularities in the intermodal experience of self-produced movement. During such coordinated activity, which happens quite typically and often in 3- to 5-month-olds (e.g., infants waving their hands in the field of view and gazing at their legs), the infant may pick up the invariant position of the hands and arms, and perhaps the fingers, by repeatedly exploring the inherent constraints in the movements of these body parts. Such exploration is probably at the origins of an early perceptual body schema pertaining to the invariant structure of the body.

The question remains as to why infants showed the opposite pattern of preference in Experiment 1 of the present research compared with previous related findings in which infants have been shown to look longer at the more incongruent view of their legs (Bahrick & Watson, 1985; Rochat & Morgan, 1995b; Schmuckler, 1996; Schmuckler & Fairhall, 1996). A discussion of these contrasting results requires a better description of the experience of the infant when viewing these displays. On a phenomenological level, the perception of general movement directionality (Rochat & Morgan, 1995b; and this article's Experiment 3) involves proprioception and vision of congruent or incongruent left–right movements of the legs with respect to the environment. In the experience of body reference frame movements, however (Experiments 1 and 2), the general left–right movements of each of the two legs with respect to the environment is unchanged. In other words, each individual leg is seen moving in the direction in which it is felt to be moving. However, in the reversed condition of Experiment 1, the oddity of the condition was based on the fact that the proprioception of the legs' movements toward or away from the body's midline (abduction–adduction) were visually experienced as reversed in direction on the video screen. This description of the experience of the infant and the fact that the differences in the movement of the legs were not discriminated by the infants when featural configuration or outline of the legs were occluded (Experiment 2) suggests that featural characteristics of the legs play a role in specifying the internal organization of the body to infants when perceiving their own limbs moving.

The fact that infants were more engaged in and preferred to look at the normal view compared to the reversed view may have been due to an overall avoidance of activity while viewing the reversed view. There are at least two possible reasons why infants may have been more avoidant of the reversed view of their legs. First, the reversed view of the legs might have been less reinforcing to the infants than the normal view. In particular, by switching the side of the video screen on which each individual leg was seen, the visual feedback of a single leg's movement on the ipsilateral side of the screen was removed. Although the image of the legs was intended to be a composite image with a line down the middle (produced by the screen splitter) the infants may have tended to focus on one side of the screen at a time. Assuming that infants tended to look at the ipsilateral side of the display when moving a particular leg, constant visual feedback of that leg might be necessary for the infant to maintain interest in the display. If infants had this one-sided focus, it may have had the effect of momentarily removing visual contingency rather than altering it, as was intended by the experimenters. A separate analysis of the side of the screen infants were gazing at was conducted; however, suitable reliability between coders was not obtained. Future research is planned that addresses the question of whether the amount of visual contingency provided by only one side of the display is what determined infants' relative interest in a particular view. For example, in ongoing research (Morgan, 1997, dissertation in progress), we are experimentally manipulating the side of the display in which movement toward the body midline is reversed. By changing the body-relative movements on one side of the body, the question of whether infants perceive the invariant symmetry of their own body will be addressed.

A second reason why infants might have been inhibited while looking at the reversed view of their legs would be that this view was very odd, causing them to avoid it. Accordingly, altering the relative position of the legs in the visual field was too disruptive to the infants' finely calibrated intermodal space. This disruption may have prevented infants from exploring and matching the correspondence between their own felt movement and the seen movement on the display. Further research is needed to compare the relative disruption caused by altering infants' visual feedback of their own body's spatial organization.

Finally, other evidence on the perception of self-produced movement in infancy demonstrates that alternate patterns of infant engagement depend on the display presented to young infants. In a recent study (Rochat & Morgan, in press) the pattern of preferential looking and leg activity was reversed, depending on whether self-produced movement occurred in a self-oriented versus an object-oriented situation. In this research, infants were presented with either a congruent or inconcruent on-line view of their own legs on a video screen (ego and reversed ego views). In one condition, infants viewed their own legs without a target to kick at. In another condition, they viewed their legs plus an object–target that produced a sound each time it was kicked. The results indicated that from 3 months of age, infants tended to reverse their pattern of visual attention depending on the condition. Specifically, infants tended to look longer at the congruent view of their legs in the condition where an object target was presented, and showed the reverse behavior in the no–object condition. The results revealed that depending on the nature of the task, different patterns of visual attention are expressed. These results provide additional evidence that the incongruent view of their own legs may not always be the most interesting to infants.

The present research demonstrates that in addition to being attuned to the correspondence between the the way the legs feel and look as they are moving, infants are also attuned to the inherent organization or location of their legs relative to each other. The information picked up by infants specifying this organization includes the relative dynamics of the limbs when the featural characteristics of the legs are clearly visible. Further research is needed to determine what information precisely specifies the inherent organization of the body and whether a complete disruption of this organization may be disturbing to young infants. In particular, what role do the featural characteristics of the legs play in specifying the relative position of the limbs on the body, and how do infants use this information to coordinate and plan action? Further research is planned that will attempt to delineate the role of the features of the body in specifying the body's organization to young infants. This will be achieved by varying the relative clarity of these features using a video editing technique.

Young infants' precocious intermodal attunement to the correspondence between vision and proprioception while moving their limbs as well as their observed attunement to the relative position of their legs provides new evidence that there is an early understanding of the body's inherent organization (body schema) from as early as three months of age. This early understanding may be present from birth or acquired as a result of redundant multimodal experience gained through early self-exploration.

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REFERENCES

Bahrick, L. E., & Watson, J. S. (1985). Detection of intermodal proprioceptive–visual contingency as a potential basis of self-perception in infancy. *Developmental Psychology, 21*, 963–973.

Bullinger, A. (1977). Orientation du la tête nouveau-né en presence d'un stimulus visuel [Newborn head orientation in the presence of a visual stimulus]. *L'Année Psychologique, 2*, 357–364.

Field, T., Woodson, R., Greenberg, R. G., & Cohen, D. (1982). Discrimination and imitation of facial expressions by neonates. *Science, 218*, 179–181.

Gibson, E. J. (1993). Ontogenesis of the perceived self. In U. Neisser (Ed.), *The perceived self: Ecological and interpersonal sources of self-knowledge.* Cambridge University Press.

Gibson, J. J. (1986). *The ecological approach to visual perception.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc. (Original work published 1979)

Harris, P. L., Cassel, T. Z., & Bamborough, P. (1974). Tracking by young infants. *British Journal of Psychology, 65*, 345–349.

Hofsten, C. von (1982). Eye–hand coordination in the newborn. *Developmental Psychology, 18*, 450–461.

Kellman, P. J., Gleitman, H., & Spelke, E. S. (1987). Object and observer motion in the perception of objects by infants. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 586–593.

Kremenitzer, J. P., Vaughan, H. G., Kurtzberg, D., & Dowling, K. (1979). Smooth pursuit eye-movements in the newborn infant. *Child Development, 50*, 442–448.

Maratos, O. (1973). *The origin and development of imitation in the first six months of life.* Unpublished doctoral dissertation, University of Geneva.

Meltzoff, A. N., & Moore, M. K. (1977). Imitation of facial and manual gestures by human neonates. *Science, 198,* 75–78.

Meltzoff, A. N., & Moore, M. K. (1983). Newborn infants imitate adult facial gestures. *Child Development, 54,* 702–709.

Morgan, R. (1997). Intermodal perception of body symmetry and structure by 3- to 5-month-old infants. Unpublished manuscript, Emory University, Atlanta, GA.

Neisser, U. (1988). Five kinds of self-knowledge. *Philosophical Psychology, 1,* 35–59.

Neisser, U. (1991). Two perceptually given aspects of the self and their development. *Developmental Review, 11,* 197–209.

Neisser, U. (1993). The self perceived. In U. Neisser (Ed.), *The perceived self: Ecological and interpersonal sources of self-knowledge* (pp. 3–21). New York: Cambridge University Press.

Rochat, P. (1993). Connaissance de soi chez le bébé [Self-knowledge in infancy]. *Psychologie Francaise, 38,* 41–51.

Rochat, P. (1995). Early objectification of the self. In P. Rochat, (Ed.), *The self in infancy: Theory and research* (pp. 53–72). Amsterdam: North–Holland.

Rochat, P., & Morgan, R. (1995a). The function and determinants of early self-exploration. In P. Rochat (Ed.), *The self in infancy: Theory and research* (pp.395–418). Amsterdam: North–Holland, Elsevier.

Rochat, P., & Morgan, R. (1995b). Spatial determinants in the perception of self-produced leg movements by 3- to 5-month-old infants. *Developmental Psychology, 31,* 626–636.

Rochat, P., & Morgan, R. (in press). Two functional orientations of self-exploration in infancy. *British Journal of Developmental* Psychology.

Schmuckler, M. A. (1996). Visual–proprioceptive intermodal perception in infancy. *Infant Behavior and Development,* 19, 221–232.

Schmuckler, M. A., & Fairhall, J. L. (1996, April). *Visual–proprioceptive intermodal perception using point light displays.* Poster presented at the 10th Biennial International Conference on Infancy Studies, Providence, RI.

Thelen, E. (1981). Kicking, rocking, and waving: Contextual analysis of rhythmical stereotypies in normal human infants. *Animal Behavior, 29,* 3–11.

Trevarthen, C. (1974). The psychobiology of speech development. In E. H. Lenneberg (Ed.), Language and brain: Developmental aspects. *Neurosciences Research Program Bulletin, 12,* 570–585.

Wertheimer, H. (1961). Psychomotor coordination of auditory and visual space at birth. *Science, 134,* 1692.

White, B., Castle, P., & Held, R. (1964). Observations on the development of visually guided reaching. *Child Development, 35,* 349–364.