The Self in Infancy: Theory and Research
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CHAPTER 19

The Function and Determinants of Early Self-exploration

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From birth, the body is a primary object of knowledge and exploration. This fact has been rather overlooked by students of infancy, who have focused their research efforts on the origins of perception and the development of early cognition in relation to external (nonself) objects and events. If infants are actively involved in exploring and learning about their environment from birth, they are equally involved in exploring themselves. Not only do they coperceive themselves in the act of perceiving objects, as suggested by Gibson (1979), but they also spend much of their awake time systematically investigating their own body and directly experiencing the consequences of their own actions.

Considering that from an early age infants display exploratory activities that appear to be specifically oriented toward the discovery of their own body's features and characteristics, questions remain as to what young infants know about their own body and how they learn about it. This chapter is an attempt to address these questions by reviewing recent research that has begun to investigate the issue of the function and determinants of early self-exploration. It is proposed that a basic function of self-exploration is to specify the fundamental difference between perceptual self- and nonself-events: events that pertain to the self, and those that do not. We discuss the fact that infants from birth perceive events that uniquely specify either the self or other objects in the environment. We propose that at the origins of a discrimination between self- and nonself-stimulation, there are specific intermodal experiences that emerge via early self-exploration. In support of this proposal, recent empirical findings on the temporal and spatial determinants of self-exploration in infancy are presented.

Early Discrimination Between Self- and Nonself-experiences

If there is a perceptual function associated with self-exploration, it is to specify what pertains to the self, in particular to foster the development of a discrimination between sensory experiences originating either from the self or from objects that are external to the self. Considering that this discrimination is very basic, forming the cornerstone of any conceptualization of the self in the context of comparative psychology, developmental psychology, cognitive psychology, and even robotics, self-exploration construed as a process underlying such discrimination is of great theoretical importance. For example, the assumption of a lack of such discrimination by young infants led William James (1890) to initially depict the blooming, buzzing confusion as characteristic of infants' early sensory experience. Aside from the famous quote, James's theoretical assumption also constrained his views on what needs to develop early in life. If infants do not initially discriminate between self- and nonself-stimulation, how do they come to do so, and on what basis? Inversely, if infants are born with a basic capacity to discriminate between self- and nonself-experiences, what is the nature of this capacity, and how does it develop?

We propose that infants, from birth, and possibly from the confines of pregnancy, learn to discriminate between self- and nonself-stimulation. This learning is based on self-exploration, which is expressed from birth and from which infants actively experience fundamental perceptual contrasts between stimulation originating from the self, and stimulation originating from external objects and events. Before discussing the nature of the perceptual experiences specifying the self at the origins of development, and because we assume that these experiences are mediated by self-exploration, let us first define what we understand by the term *self-exploration.*

Self-exploration is a class of behavior through which infants are perceptually oriented toward their own body. They touch themselves, listen to self-produced sounds by vocalizing, or bring their hands and other limbs into the field of view for visual inspection. They also get tense and agitated for the apparent sake of getting tense and agitated, engage in circular reactions, and attend visually or auditorily to the traces of their own actions on objects (see Rochat, this volume). Although self-exploration can be identified as a class of early behavior, it is more than a behavioral inventory: *It is a specific process through which infants become perceptually attentive to their own body and engage in a perceptual dialogue with themselves*. Again, we propose that this process enables infants to specify themselves as entities that are perceptually differentiated from other objects, people, and any external events occurring in the environment. To a certain extent, self-exploration needs to be distinguished from object exploration, as the emphases of each are by definition opposite, one specifically oriented toward things that are external to the body, and the other toward the own body. However, both self- and object exploration inform infants about themselves and in particular how they are situated, differentiated, and are agents in the environment. Both processes specify the infant's ecological self (Neisser, 1991; Rochat, in press). Although the focus here is on self-exploration, self-exploration and object exploration are complementary processes at the origins of the perceptual specification, and eventual conceptualization of the self. But what do infants specifically gain from self-exploration? We propose that, primarily, they gain specific intermodal experiences that form the foundations of the perceptual discrimination between self- and nonself-stimulation.

From birth, infants experience contrasting perceptual and sensorimotor events that potentially inform them about their own body as an object differentiated from others in the environment. When infants cry, the sound they hear is combined with kinesthetic and proprioceptive feedback. This intermodal combination uniquely specifies their own body. Sounds originating from another person or any other objects in the environment tend not to share the same intermodal invariants. Aside from vegetative sounds such as crying, coughing, or sneezing, infants from birth produce sounds (i.e., comfort sounds that rapidly become more articulated: precursors of speechlike production) and explore the specificity of their own voice and the potentials (or affordances) of their own vocal track (Oller, 1980; Stark, 1980).

In addition, newborns show a robust propensity to bring their hands in contact with their face and mouth (Rochat, Blass, & Hoffmeyer, 1988). Some researchers have observed that newborn infants spend up to 20% of their waking hours contacting the facial region with their hands (Korner & Kraemer, 1972). This simple observation might have implications for the perceptual basis of an early experience of the body as a differentiated object. As in the case of self-produced sound, when newborns manually touch their own face, they potentially experience a sensorimotor and perceptual event that uniquely specifies their own body as a differentiated object. This intermodal event is the "double-touch": the experience of the cutaneous surface of the hand contacting the cutaneous surface of the facial region, which could be any other region of the body surface (von Glasersfeld, 1988; see Figure 4). The baby's contact with any other physical object, surface, or person in the environment will never correspond to a double-touch intermodal event.

But when do young infants start to show discrimination of unique perceptual events, which underlies the ability to perceive their own body as an object different from other objects in the environment?

Based on a microanalysis of hand-mouth coordination in newborn infants, Butterworth and Hopkins (1988) report that when infants bring their own hand(s) in contact with the face, this cutaneous self-stimulation is not accompanied by any of the rooting responses normally observed when an external object contacts the same facial location. These observations suggest an early ability to discriminate between environmental (single-touch) stimulation, and self-stimulation (double-touch + proprioceptive stimulation).

In an ongoing experiment conducted at the Emory Infant Laboratory, we are assessing whether newborns discriminate between double-touch stimulation and various external cutaneous (tactile) stimulation. Preliminary results indicate that such discrimination might occur very early in development. In this project, newborns' rooting responses were systematically analyzed (i.e., head turn and oral orienting toward a perioral tactile stimulation) in four different conditions. In one condition, the perioral stimulation originated from the index finger of the experimenter, who was positioned behind the infant and intermittently rubbed the infants' left or right cheek for 20 seconds. At the beginning of stimulation, the infant's head was oriented at the center. In a second condition, the infant was stimulated by a pacifier held by the experimenter. In a third condition, infants were stimulated by their own hand, either left or right, which was gently held by the experimenter and rubbed against the infant's cheek. In contrast to the other conditions, this condition provided the infant with a double-touch experience. Finally, in a fourth (control) condition, the hand of the infant was brought close to the cheek by the experimenter, without touching it. In this last condition, infants were stimulated only by passive movement of their own arm as it was moved toward the cheek by the experimenter.

Preliminary results obtained with six 3 to 4-week-old infants, each stimulated in each condition once to the right and once to the left side (for a total of 12 instances), revealed that the proportion of observed rooting in the direction of the stimulation appears to depend on the condition. Infants tended to root more toward either the experimenter's finger or the pacifier, compared with their own hand. No rooting was observed in the fourth condition, where the tactile component was absent. These preliminary observations indicate that early on, young infants might potentially express differential responding to self- versus external tactile stimulation: in other words, between double touch, specifying the self, and single touch, specifying external stimulation. Again, it is important to emphasize the importance of haptic stimulation early in life: This stimulation is a potential source of the perceptual specification of the self, and hence becomes a part of the perceptual basis of an early sense of self.

Aside from vocalizing and touching themselves, infants from birth experience the contrast between movements that include their own body, and those that do not. This contrast is based on different intermodal information specifying either egomotion or motion of objects moving in the environment independently of the self. Egomotion is uniquely specified by combined information from the proprioceptive, visual, and vestibular systems, whereas environmental motion is specified by information from the visual system only. It appears that from an early age, however, infants have a propensity to adjust their posture based on visual information specifying egomotion, with no contingent vestibular stimulation (see chapters by Jouen & Gapenne; Bertenthal & Rose, this volume). They manifest postural adjustments that counteract the information from optic flow specifying egomotion. The fact that infants do not appear to discriminate between self and the environment in this particular situation suggests that there may be two separate classes of environmental information that infants use to specify the self: object movement versus movement of the whole surround. However, evidence exists that young infants use self-produced movement as a source of information for differentiating their own bodies from the surrounding environment. In an experiment 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. Infants typically experience themselves as moving if the background does not remain fixed relative to their own position. In addition, a clever study by Kellman, Gleitman, and Spelke (1987) demonstrated that 4-month-old infants do have the capacity to discriminate between egomotion and the independent movements of an object and are sensitive to the presence or absence of contingent visual-vestibular information. Infants perceived a rod occluded at its center as being an incomplete or broken object when it was stationary. When the same rod was moved back and forth behind the occluder, it was perceived as complete or unbroken. In contrast, when the infant was moved horizontally relative to the stationary object, creating the same translated projection on the infant's retina as in the former case where only the object moved, the object once again was perceived by the infant as being incomplete or broken. The differentially perceived object in the self-motion versus the object motion condition — despite exactly the same visual information — is evidence that proprioceptive/kinesthetic information is used by young infants to discriminate self-movement from independent movement of objects in the environment.

Temporal Determinants of Early Self-exploration in the Mirror

It is now well established that young infants manifest temporal contingency perception between their own actions and the transformations they cause in the environment (Watson, 1979, 1985, 1994). Lewis, Sullivan, and Brooks-Gunn (1985) report that 2-month-olds whose wrists are connected to a mobile hanging above their crib rapidly learn the contingency between their own arm movements and the movements of the mobile. They display an expression of joy in the process of discovering instrumental arm pulls, and an expression of anger during a period of extinction when arm and mobile are disconnected. It appears that very early on, and probably from birth, infants have the propensity to detect information specifying the contingency between their own actions and their visual consequences (Kalnins & Bruner, 1973; Watson, 1979, 1985; Rovee-Collier, 1987; Siqueland & DeLucia, 1969), as well as information specifying the spatio-temporal congruence of events perceived bimodally (i.e., via vision and audition: see Spelke, 1976; Kuhl & Meltzoff, 1982). The perception of temporal contingency is central to early development. It is a source of information that specifies objects and events, as well as the body as an agent in the environment. Lewis and Brooks-Gunn (1979) and other students of early infancy (Guillaume, 1926; Wallon, 1942/1970) have suggested that the origins of self-perception correspond to the discovery by the young infant of the contingency between visual stimuli and proprioceptive feedback from body movements. Self-exploration in a mirror affords the detection of the perfect visual-proprioceptive contingency. Early on, infants appear to attend to it.

Few developmental studies have described infant behavior in front of a mirror in the course of the first year (i.e., *prior* to the first signs of mirror self-recognition using the mark task). Before 6 months, infants are shown to be actively involved in discovering their specular image, manifesting signs of perceptual discrimination between themselves and others in a mirror. Again, note that this discrimination does not yet imply any self-recognition, but is an expression of self-exploration. Dixon (1957) described a first stage at around 4 months of age in which the infant looks briefly and soberly at herself in the mirror but shows immediate recognition and sustained attention to the mother's specular reflection. Field (1979) demonstrated that 3-month-olds respond differentially to a mirror image of the self versus an infant peer. In this study, the infant's facial expression, manual behavior, visual activity, and cardiac response were recorded systematically. Field's research suggests the existence of a precocious discrimination between the specular image of the self, and of another person. Amsterdam (1972) reported that between 3 and 5 months, infants show little social behavior in front of the mirror (i.e., smiles, laughs, and vocalization), which only becomes prominent by 6 months. In her study, Amsterdam showed that between 3 months and 12 months, the majority of infants spend time observing their own movement in the mirror, exploring the particular visual-proprioceptive correspondence offered by the mirror's reflection. Interestingly, by 14 months, infants become less interested in their own movement, and by 20 months begin to show embarrassment and withdrawal in front of the mirror (Amsterdam, 1972; Lewis & Brooks-Gunn, 1979). It thus appears that in the context of the mirror situation, self-exploration is particularly prominent during the first year.

Aside from the mirror situation, self-exploration is evident starting at 3 months of age, when infants display long episodes of self-examination; in particular, exploration of their hands in motion (Piaget, 1952). Such exploration and visual control of manual activities have been recently documented in newborn infants (Van der Meer, Van der Weel, & Lee, 1995; Van der Meer & Van der Weel. this volume). However, very few researchers have attempted to isolate the information (visual, proprioceptive, haptic, etc.) that young infants might be sensitive to when engaged in self-exploration. Papousek and Papousek (1974) placed 5-month-olds in front of two different video images of themselves. Based on the preferential looking of the infant, this method allowed the assessment of the discriminating variables between the two video images. Reporting only pilot observations with 11 infants, Papousek and Papousek found that infants preferred to look at the image of themselves in which eye contact was possible. Using a similar procedure but placing 1- to 24-month-old infants in front of two mirrors that are either flat, blurred, or distorted, Schulman and Kaplowitz (1976) showed that prior to 6 months, infants tend to look more often at the clear rather than the blurred image of themselves, and showed less interest in the distorted image compared to the flat, nondistorted mirror image. Interestingly, Schulman and Kaplowitz note that compared to older infants, 1- to 6-month-olds spend more time looking at a particular mirror, although they do not yet show complex behavior such as looking at a particular body part and then immediately inspecting its reflection in the mirror.

Using the principle of the choice method introduced by Papousek and Papousek (1974) but presenting the infant with nonfacial images of the self, in particular their legs, Bahrick and Watson (1985) demonstrated the early detection of visual-proprioceptive contingency. On one of the TV monitors, the infant had access to a contingent view of his/her legs, and on another was simultaneously presented a noncontingent, prerecorded view of the baby's own legs or of another baby's leg movements wearing identical booties. Bahrick and Watson showed that 5-month-olds preferentially looked to the noncontingent view. They also observed this phenomenon in a situation where an occluder prevented the infant from seeing his/her legs directly. Three-month-olds showed split preferences, looking either much longer at the contingent, or much longer at the noncontingent, view. Overall, Bahrick and Watson demonstrated that early perceptual discrimination of the self does not correspond only to facial images of the self, but includes other parts of the body. This is important because it shows that young infants are sensitive to visual and proprioceptive contingency in general, and not only to the contingency of eye contact as suggested by previous researchers, who emphasized the social rather than perceptual context in which first discrimination between self and others takes place (Dixon, 1957; Papousek & Papousek, 1974). Nevertheless, questions remain as to what information is relevant to the young infant in his/her discrimination of intermodal proprioceptive-visual contingency. What is actually detected by the young infant? Is it a temporal contingency, a spatial congruence, or a combination of both, i.e., a spatio-temporal contingency? Recently, we conducted a series of experiments demonstrating that self-produced movements by young infants entail not only the detection of temporal contingency, but the perception of *spatial congruence* . Thus, these two factors may be viewed as main determinants of self-exploration in early infancy.

Spatial Determinants of Early Self-exploration

In exploring their own body, infants develop expectations about the intermodal correspondence between the proprioception of their body moving in space and its visual consequences. Observations of young infants reveal that by 3 months, infants look systematically at their hands and move them in the field of view for long, careful inspections. From an early age (approximately 3–4 months), infants also commonly grab their feet and bring them in front of their eyes for long bouts of visual-proprioceptive exploration. These bouts of self-exploration provide infants with the opportunity to detect the intermodal invariants that uniquely specify their own body.

To further understand what determines early self-exploration, we investigated the extent to which young infants are sensitive to the relative spatial congruence of visual-proprioceptive information. Using a video technique analogous to the one used by Papousek and Papousek (1974) and Bahrick and Watson (1985), we systematically manipulated the spatial configuration of visual feedback pertaining to self-produced movements. In contrast to former studies, we maintained the temporal contingency between visual and proprioceptive information perfectly constant, varying only their relative spatial congruence. We review our experiments and their results below, in relation to each spatial aspect manipulated.

As a general paradigm, we used infants' preferential looking to different on-line views of their legs from the waist down. This paradigm is a modified version of the one used by Bahrick and Watson (1985). Infants were placed in front of a large television monitor with a split screen. On either side of the split screen a particular *on-line* view of the infant's legs was displayed, from separate cameras placed at different angles or with optical characteristics such as a left/right reversal.

To entice the infant to visually attend to the TV display, attractive striped socks were put on the infant. A small microphone was placed under the infant's feet that picked up rustling/scratching sounds each time the infant produced a leg movement. The leg movements' sounds were amplified and were heard by the infant from a speaker placed centrally on top of the TV. A camera was placed under the TV that provided a close-up of the infant's face for later preferential-looking analysis. This image was synchronized with the audio recording of the infant's leg activity. Blind coders entered in real time the infant's gazing on two channels of a computerized event recorder corresponding to either the right or left side of the split screen. Meanwhile, the synchronized spectrogram of the audio recording of the infant's leg activity was entered in another channel and digitized into 2-second bouts of leg activity (see Rochat & Morgan, 1995, for details). In short, this technique allowed the coanalysis of preferential looking of either view of the legs and for the amount of self-produced leg activity.

The rationale for these experiments was that if infants showed discrimination between the two views of their legs, they should look preferentially at one of the views and should produce a differential amount of leg activity while looking at the preferred view.

Overall Directionality Congruence

In the first experiment (Rochat & Morgan, 1995), infants were presented with an *Observer's view* and an *Ego view* of their own legs (see Figure 1A). Each view was provided by a camera placed either above and behind the infant, or above and in front of the infant. There were two basic spatial differences between the two views: 1) orientation; and 2) overall movement directionality of the legs. Regarding the experimental design, in all experiments infants were recorded for 5 minutes in front of the display. The side of the view was counterbalanced among subjects of each age group ($N = 10$). Overall, in the first experiment, infants at both ages and from 3 months of age, expressed a differentiation between the two views of their legs: 1) they tended to look significantly longer at the observer's view (i.e., the noncongruent view); 2) after multiple comparisons between the two views, they tended to settle their gaze toward the preferred view as a function of the 5 minutes of testing time; and 3) they generated significantly more leg activity while looking at the observer's view (noncongruent) compared to the ego (congruent) view, expressing an increase in self-exploration in the context of the nonfamiliar view.

In order to untangle the confound between differences in spatial orientation and spatial directionality of the two on-line views presented in the first experiment, we conducted a second experiment in which both views of the legs depicted a similar orientation (two ego views), the two views being only different in relation to leg movements' directionality (see Figure 1B). Inversion of movement directionality was obtained by using a camera with a left/right inverted tube. Again, 3- and 5-month-old infants were recorded for 5 minutes in front of the display. The side of the view was counterbalanced among subjects of each age group ($N = 10$). Overall, in the second experiment, infants of both ages continued to express a differentiation between the two views of their legs: 1) they tended to look significantly longer at the reversed ego view (i.e., the incongruent view); 2) following frequent comparisons between the views, they tended to settle their gaze toward this preferred view as a function of the 5 minutes of testing time; and 3) they generated significantly more leg activity while looking at the reversed ego (incongruent) compared to the ego (congruent) view, expressing an increase in self-exploration in the context of the incongruent view that varied only in terms of the overall directionality of movement.

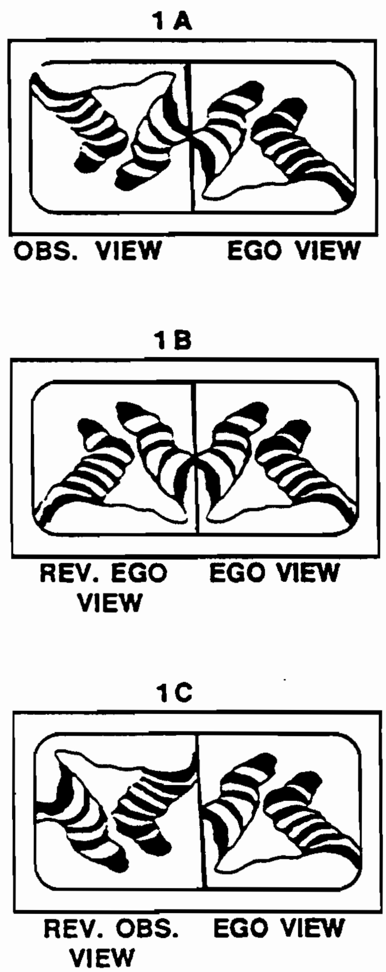

FIGURE 1. The two views of their own legs as seen by the infant on the TV in the first 3 experiments (Rochat & Morgan, 1995). (A) Observer view vs. Ego view (Experiment 1); (B) Reversed Ego view vs. Ego view (Experiment 2); (C) Reversed Observer view vs. Ego view (Experiment 3).

Relative Orientation of the Body

To assess the extent to which the relative spatial orientation of the body is a determinant of early self-exploration, we conducted a third experiment in which the two views presented to the infant varied in orientation only (Rochat & Morgan, 1995). Using the same experimental paradigm and procedure, movement directionality was kept congruent with the infant's own movements in both views, but the legs' orientation corresponded either to an Observer's view or an Ego view (See Figure 1C). The view in which movement directionality was congruent, yet inverted in orientation (reversed Observer's view) was obtained by using the camera with the inverted tube. It changed the orientation of the legs but not the overall directionality of their movements. Again, 3- and 5-month-old infants were recorded for 5 minutes in front of the display. The side of the view was counterbalanced among subjects of each age group ($N = 10$). In contrast to the other experiments, infants at both ages did not show any preference for either of the two overall orientations, nor any settling of their gaze as a function of testing time, nor any significant increase in leg activity while looking at either view. The results of this experiment indicated that infants do not appear to be sensitive to orientation changes of their own legs when overall movement directionality is maintained constant. In relation to the other experiments, the findings suggest that infants as young as 3 months discriminate between congruent and incongruent views of self-produced leg movements, the spatial determinant of this early discrimination being movement directionality rather than the global spatial orientation of body parts.

Relative Directionality Congruence

Recently, we conducted two new experiments to address the question of whether young infants are sensitive to changes in the *relative* position of their own legs that they see moving on a screen (Morgan & Rochat, 1994). Again, 3- and 4- to 5-month-old infants were tested in a slightly modified procedure: They were presented with a composite, on-line (ego) view of their own legs, in which both the orientation and movement directionality of either leg were kept constant, but their relative position on the screen was altered. In the Normal view, infants saw their legs in their normal relative positions: the right leg to the right of the screen and the left leg to the left (see Figure 2A). In the Reversed view, the legs' positions were reversed: the left leg to the right and the right leg to the left side of the screen (see Figure 2B). Both left and right images of one leg originated from two separate cameras placed behind and above the infant. Infants were shown the normal and reversed conditions in four alternating sequences of 2 minutes. Order of presentation was counterbalanced among subjects of each age group.

The rationale of this experiment was the following: If infants perceive the contrast between the normal and reversed conditions, they should tend to look and kick differentially across these two conditions. Results of this experiment showed that infants from 3 months of age manifest differential looking and kicking behavior across the two conditions. For both groups, infants tended to reduce their looking and leg activity when presented with a reversed relative location of their legs on the screen. These results suggest that young infants are sensitive to differences in the relative movements and/or the featural characteristics of the legs (i.e., the relative bending of the legs at the knees and ankles) across the two conditions.

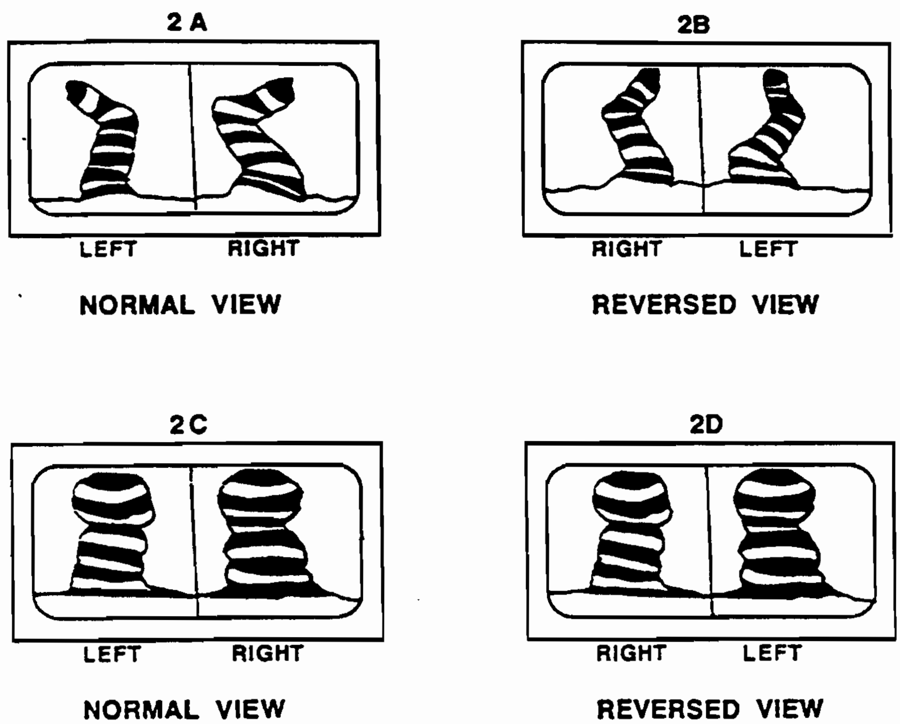

FIGURE 2. The legs as they appeared to the infant on the TV in both conditions of Experiments 4 and 5 (Morgan & Rochat, 1994). (A) Normal view (Experiment 4); (B) Reversed view (Experiment 4); (C) Normal view with bulky socks (Experiment 5); (D) Reversed view with bulky socks (Experiment 5).

Featural Characteristics of the Body

In order to control for the potential determinant of the relative featural characteristics of the infant's legs (the legs' bending) that changed between the normal and reversed conditions of the latter experiment, we conducted another study where features of the legs were maintained constant while relative leg *position* was varied across conditions (Normal and Reversed). Again, infants were tested successively in the two conditions, and wore bulky socks to cover the bending of the legs (see Figures 2C and 2D). In contrast to the preceding experiment, the results indicated for both age groups (N = 10 infants in each) no significant difference in looking, gaze switching, and leg activity between the normal and reversed conditions. These negative results, in conjunction with the positive ones obtained in the preceding experiment in which infants did not wear any bulky socks, indicate that featural characteristics of the legs, combined with relative movement directionality, form important spatial determinants in the perception of self-produced leg movements by infants as young as 3 months of age. Results of the second experiment suggest that relative movement directionality *alone* is not a significant spatial determinant in the perception of self-produced movements. However, the fact that the relative position of the legs in space appears to be discriminated reveals that infants express a calibrated intermodal space of the body as early as 3 months.

Overall, the change in the legs' position created a pattern of movement that was very unlike the pattern of movement infants see when looking down at their own legs. However, the preference for the less novel view is difficult to interpret, given the tendency in our other experiments for infants to look and kick more actively at the more novel view. In general, the results of these experiments demonstrate that the visual-proprioceptive experience of the legs moving while in their proper relative positions combined with their usual featural outline in space seem to be important determinants of early self-exploration. In addition, the invariant information of the relative position of body parts detected by infants may be considered to be one of the earliest expression of a body schema.

Goal-orientation and Self-exploration

In the final set of studies conducted so far, the question of whether self-exploration serves a unique function relative to other forms of exploration, such as the exploration of sounding objects, was asked. Using the sequential looking paradigm similar to the one described in the previous experiments, we further examined infants' sensitivity to changes in the spatial arrangement of their legs while moving. Specifically, when the seen movements of the legs (based on feedback from a video image) are opposite in direction to how the legs are felt to be moving, will infants show different patterns of looking and leg activity depending on the nature of the task? A new experimental condition was added, in which infants were oriented toward the goal of contacting an object with their foot, which sounded when touched (Morgan & Rochat, in press). This new condition was compared to the behavior infants express when the task is purely self-oriented in nature, i.e., when no object is present (see Figure 3). Again, two groups of infants were tested (at 3 and 4–5 months). Infants were presented successively with an on-line image of their own legs. As in the previous experiments, because they were reclined and the monitor was at an angle, infants were unable to see their own legs directly.

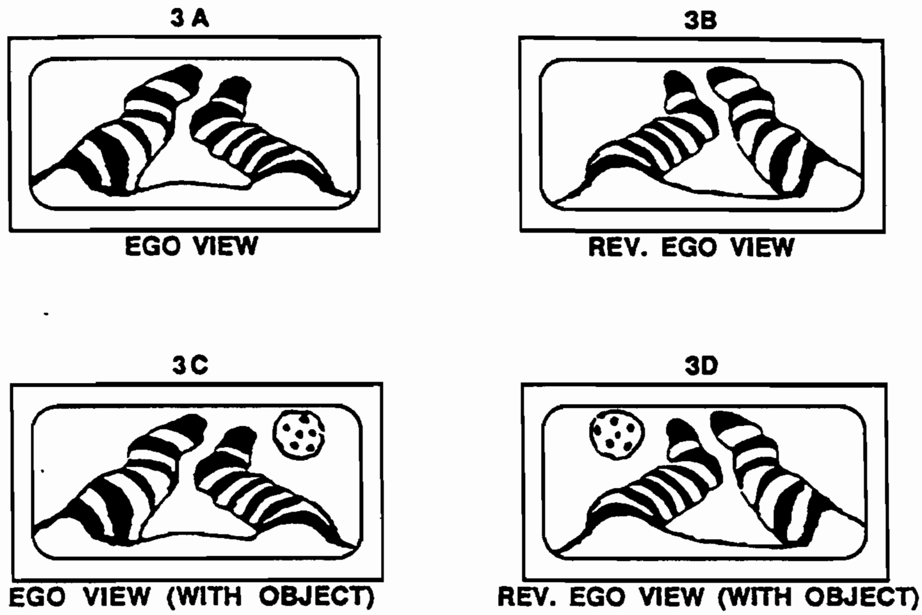

FIGURE 3. The legs as they appeared to the infant on the TV in all 4 conditions of Experiment 6 (Morgan & Rochat, in press). (A) Ego view. (B) Reversed Ego view. (C) Ego view with object. (D) Reversed Ego view with object.

Infants viewed their legs in two different conditions. In the first condition, they were presented with their own legs moving on the TV with no object to kick at (see Figures 3A and 3B). In the second condition, they viewed their legs and an object that sounded when contacted by their foot (see Figures 3C and 3D). Within each condition, infants experienced two different situations for 2 minutes each. In one situation, they viewed a spatially congruent on-line image of their legs from the waist down (Ego view, Figures 3A & 3C). In another situation, a modified camera, placed in the same position, provided the infant with a similar ego view, except that a left/right reversal of the image on the TV screen provided a spatially noncongruent view of the legs (Reversed Ego view, Figures 3B & 3D). The situations within each condition and the side of the object were counterbalanced across trials.

The rationale of the study was that, if infants were able to discriminate between the different conditions, they would show differential looking and leg activity across the object versus the no-object conditions. In particular, in the condition in which the task was self-oriented in nature, infants would look longer and show more leg activity for the Reversed Ego view, as in Rochat and Morgan (1995). In contrast, because of the goal-oriented nature of the task in the condition where the object was present, the opposite pattern of behavior was predicted. The rationale for this prediction was that congruent visual-proprioceptive feedback would facilitate contact with the object, the functional goal of the task.

The results revealed that depending upon the condition (object vs. no-object), infants showed significantly different patterns of looking and leg activity for the Ego versus the Reversed Ego views of their legs. Specifically, they looked longer and showed more leg activity when looking at the Reversed Ego view when there was no object present and looked longer at the Ego view when an object was present. At both ages, results confirmed the predicted patterns of looking and leg activity. These results extend the findings of Rochat and Morgan (1995), which showed that infants prefer looking at displays modifying the directionality of their own leg movements. The present results suggest that infants are able to modulate their activity depending on the context and function of the task. Infants preferentially use the congruent view of their legs in the object condition in order to control their attempts to contact the object, a spatially oriented motor task. In contrast, when infants are engaged in the exploration of their own body (no-object condition), the activity pattern is reversed, as there is no specific spatial goal to direct their movements.

The results of this last research suggest that young infants can be differentially oriented while self-exploring. They look preferentially at either the image corresponding to the familiar or unfamiliar visual-proprioceptive correspondence of their own legs, depending on whether or not there is a spatial orientation attached to the task (i.e., whether or not self-produced leg movements have a "spatial address"). Early on, the pattern of infants' visual attention to self-produced leg movements is determined by the nature of the task. Overall, these latter results indicate that young infants express flexibility in the functional orientation of self-exploration.

Conclusion: Self-exploration and Intermodal Body Schema in Early Infancy

The research reviewed above suggests that early on, infants pick up invariant information specifying their own body as a differentiated entity in the environment. This information is intermodal and pertains to the coengagement of proprioceptive and other perceptual systems (e.g., vision, in the research reviewed above).

From at least 3 months of age, infants discriminate visual-proprioceptive information that is either consistent or inconsistent with regular perceptual feedback they experience when, for example, feeling, hearing, or seeing moving parts of their own body. Both temporal contingency (Bahrick & Watson, 1985) and spatial congruence (Rochat & Morgan, 1995) of visual, auditory, and proprioceptive feedback determine young infants' exploration of self-produced movements.

The reviewed observations suggest that young infants are sensitive to the dynamic features of their own body, in the same way that they are precociously sensitive to the dynamic features of physical objects in their environment (Gibson & Spelke, 1983; Kellman, 1993). However, there is a fundamental difference between self-perception (own body perception) and object perception. Objects come and go; the perceptual array is constantly refurbished with novel objects, events of appearance, reappearance, and disappearance. In contrast, there is a permanence attached to the perception of the own body that is based on the coactivation of proprioceptive and other perceptual modalities. This permanence supports the early and rapid construction of the body as a privileged object of knowledge. From birth, whenever movement is generated, and whether this movement has an external or internal cause, it always carries information about the body as a whole, its present postural configuration, and the relative position of its parts.

Young infants and neonates are actively engaged in picking up this information, which they use to calibrate the features and effectivities of their own body. Self-exploration is an important process underlying such calibration. This process, in which infants are perceptually attentive to their own body, entails the coactivation of multiple modalities (visual, tactile, proprioceptive, auditory, etc.) that specify its spatial and temporal organization.

To the extent that young infants manifest an intermodal calibration of the body (i.e., detection of temporal contingency and spatial congruence of intermodal feedback accompanying self-produced movements), they possess an implicit, intermodal *body schema*. This precocious body schema is fundamentally active (dynamic) and perceptually based. It does not imply any explicit representation of the features and organization of the body as in the concept of *body image* introduced by Schilder (1935). The term *body schema* is used here in the sense proposed by Gallagher and Meltzoff (in press), and is based on the contrast between body image and body schema discussed by Gallagher (1986): "The body schema, as distinct from body image, is a nonconscious performance of the body ... an active, operative performance of the body, rather than a copy, image, global model, or conception of the existing parts of the body. The schema is the body as it actively integrates its positions and responses in the environment" (Gallagher, 1986, p. 548). In other words, the body schema corresponds to the perception and calibration of the body and its effectivities (Rochat, this volume). It can be construed as an implicit process accompanying any goal-oriented actions and the perception of self-produced movements. It is the process of a *dynamic mapping of the body, the differentiation of its parts, and how these parts relate to one another in space and time.* When, for example, an infant brings one hand in the visual field, he does not gain only visual-proprioceptive information about the hand, but also information about the relative situation of this part of the body in relation to all the other parts that are simultaneously perceived via tactile, vestibular, or proprioceptive feedback. In other words, there is no such thing as the discrete perception of a particular body part because they are all linked in the posture and position of the body as a whole. For example, when an infant reaches for an object, this action implies more than the perception of the hand and of the object target. It entails the perception of the body as a whole, with posture scaffolding any particular action (Rochat & Senders, 1991; Rochat & Bullinger, 1994). In goal-oriented action, the body is mapped into an *intermodal body schema.*

The mapping and calibration of the body by young infants implies movement and action, whether this action is oriented toward the body, as in the case of newborns' hand-mouth coordination (Rochat, Blass, & Hoffmeyer, 1988), toward external objects, as in the case of early reaching (Hofsten, 1982), or toward people, as in the case of neonatal imitation (Meltzoff & Moore, 1977). In other words, the body schema corresponds to the active calibration of the body and its effectivities in relation to functional goals (e.g., bringing hand to mouth, contacting an object, or imitating others). Considering that it is inseparable from oriented action, and to the extent that newborn behavior is not merely reflexive but corresponds to goal-oriented actions (see Rochat; Gibson; this volume), an implicit body schema is expressed from birth. When bringing their hand to the mouth, and because this action is not random or reflexive (Butterworth & Hopkins, 1988; Rochat, 1993), neonates express the implicit knowledge of their mouth and hand as situated subsystems of their own body. As illustrated in the example of Figure 4, the hand moves toward the mouth, and the mouth opens in anticipation of a manual contact. This coordinated action implies some rudiments of a mapping of bodily space; in particular, some implicit knowledge about the relative situation of hand and mouth as they move toward one another.

The existence of an innate body schema is suggested by the report of phantom limbs in some cases of congenital aplasia (Weinstein & Sersen, 1961). Further support for an innate body schema is provided by the demonstration of neonatal imitation (Meltzoff & Moore, 1977), which implies that newborns possess some tactile-kinesthetic mapping of their own body that they are capable of matching to the movement they see in another person (see Gallagher and Meltzoff, in press, for a detailed discussion). In the case of imitation, the implicit body schema pertains to both the mapping of the own body in relation to the body of another person (the model), and the intermodal matching of visual and tactile-kinesthetic information. In particular, imitation of facial expression entails the translation of visual information pertaining to the model into the actual tactile-kinesthetic control of the imitative act.

A B C

FIGURE 4. Hand-to-mouth coordination by a 10-minute old newborn infant. (A) Beginning of the sequence: The neonate displays anticipatory mouth opening prior to hand-mouth contact; (B) The hand approaches the mouth; (C) The hand touches the mouth, and the infant experiences a "double touch." Photographs by Philippe Rochat of his daughter Cléo.

To the extent that a body schema is expressed from birth, what is the value of self-exploration as a potential opportunity to calibrate the spatial and temporal configurations of the body? If early on, infants manifest that they possess an implicit knowledge about their own body, this early expression of a body schema is linked to limited and rapidly developing goal-oriented action systems (orienting, imitating, feeding, etc.). Rapid changes in the infant's behavioral repertoire, physical growth, and the emergence of new implementations of body parts within novel coordinative structures and action systems require a constant recalibration of the body and of how subsystems of the body relate spatially and temporally to one another. There is indeed a constant and necessary recalibration of the body schema. For example, the emergence of reaching redefines the mapping of the hands and how they relate spatially and temporally to the rest of the body. In order to reach successfully toward an object, the infant is required first to maintain the overall posture and balance of the body (Rochat, 1992). In learning to reach successfully and efficiently, babies learn about new bodily constraints that call for a redefinition of the body schema. Likewise, when infants start to sit on their own, this progress opens up new possibilities of manual action. As self-sitting frees the upper limbs from the encumbrance of maintaining balance, reaching by self-sitting infants entails a larger prehensile space (Rochat & Bullinger, 1994; Rochat & Goubet, 1995). This development is accompanied by the ability to reach with either one or two hands, at greater distances, and with a broader span, redefining the effectivities of the hands in relation to objects in the environment, but also in relation to the rest of the body. Although the relative location of the hands on the body remains invariant, the emergence of new body effectivities in reaching changes the dynamics of the hands in relation to the rest of the body. In other words, the development of new degrees of behavioral freedom and the emergence of new coordinative structures imply a recalibration of the body schema.

In addition to serving the essential function of providing young infants with the opportunity to discriminate between self- and nonself-stimulation, it is in the context of such recalibration that self-exploration continues to serve the function of specifying the body and its effectivities, beyond the first months of life.

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