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Early Development of the Ecological Self

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By the time they are 3 months old, infants commonly grab their feet and bring them into their field of view for long bouts of exploration. These long episodes of focused visual and haptic exploration of intertwined toes and fingers raise questions regarding the origins of knowledge about the self, a fundamental issue for developmental psychology. To what extent do infants understand that they are exploring their own bodies? When and how do they develop a sense of self as an entity, situated in the environment and differentiated from other objects (including people)? What is the nature of self-knowledge at the origins of development, and does it emerge prior to mirror self-recognition? These questions have been traditionally addressed within the context of emerging self-recognition (i.e., mirror self-recognition). In light of recent progress in infancy research, the self-recognition or mirror-based view on the origins of self-knowledge is inadequate. The ecological approach to perception and action, and in particular the principle of coperception and the theory of

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affordances formulated by J. J. Gibson (1979), provide a new, compelling way to look at the problem of the origins of self-knowledge.

In this chapter, I attempt to illustrate an ecological approach to the early development of perception and action in general and to the problem of the origins of self-knowledge in particular. First, I discuss the theoretical assumptions and principles of an ecological approach to early development and contrast them with traditional views. Then I review theoretical issues regarding the origins of self-knowledge in particular and compare the proposed ecological approach with the traditional view that postulates an original state of fusion and undifferentiation of the infant with the environment and that suggests that self-knowledge emerges with the expression of a conceptual self (i.e., self-recognition in front of a mirror). I review evidence demonstrating that infants from the onset of development are capable of directed action, expressing a sense of self as differentiated, organized, and situated agent in the environment. The growth of the ecological self is viewed as a main feature of early development.

OUTLINE OF AN ECOLOGICAL APPROACH TO BEHAVIOR AT BIRTH AND EARLY DEVELOPMENT

The proposed ecological approach to early behavior is grounded in the basic assumption that development originates from a mutual relationship between the neonate and the environment. Although no developmental theories deliberately overlook the organism–environment interaction as a source of behavioral changes and transformations, traditional views often account for this interaction in antagonistic terms, in particular in terms of a fundamental conflict between forces originating from the individual and pressures originating from the environment. Classic examples of such views are the tripartite model of psychosexual (personality) development proposed by Freud (1961) and the model of equilibration advanced by Piaget (1961) to account for cognitive development. Both models regard development as a vector resulting from the integration of conflictual forces from the organism and the environment.

In contrast to such theories, which emphasize conflict and contradiction as the source of developmental changes, another (ecological) way to look at development is to view it as the expansion of fundamental fits or functional links between organism and environment, expressed from birth. According to this view, children do not become sudden communicators as they start to use conventional language in their second year of life; rather, communication is a precocious behavioral propensity linking infants to their human environment (Stern, 1985; Trevarthen, 1974). Language simply adds new means for effecting the communicative function. The view of early development as the growth and expansion of basic behavioral propensities linking the young organism to its environment emphasizes functional continuity in development, rather than conflict and structural discontinuity.

Recent progress in infancy research prompts a radical revision of traditional conceptions of young infants' behavior as "random, unstructured, and . . . inconsistent" (Spitz, 1965, p. 54). It is now well established that the world of the newborn is not the buzzing confusion depicted by William James (1890). Much of the new findings provided by the recent surge of infant studies support the basic assumption of the ecological view, which assumes that organism–environment mutualities are expressed and expand from birth. Evidence demonstrates the existence of basic behavioral propensities, or functional fits, linking young infants to their environment. Instead of viewing infant behavior as random and disorganized, I propose that it is best described as a complex network of functional organizations that are operational from birth. The expression of these organizations correspond to behavioral propensities that guide the early transactions of the infant with the environment. Because of the existence of these propensities, early behavior can be viewed as functional "acts" rather than mechanistic "responses" or "reflexes," best described as a collection of action systems that are defined by the hypothetical function they serve (Reed, 1982). Sucking, for example, is a complex act expressed from birth and should be viewed as part of the nutritional or feeding system. This perspective, validated by recent research, is one that calls for a further understanding of the functional specificity of infant behavior (Rochat & Senders, 1991).

In his outline of a theory of action systems, Reed (1982) identified basic action systems expressed from birth that form the functional axes of early development. Aside from nutrition, these basic action systems include the orientation, communication, locomotion, and exploration systems. This categorization is based on what appear, to an observer, to be differential orientations and attunements of an active organism toward particular aspects of the environment. This functional taxonomy has great heuristic value, offering a molar view of infant behavior inclusive of its mutuality to the environment. It is an alternative to a mechanistic view that conceives of infant behavior as a collection of sensorimotor loops or reflexes, triggered by nonspecific stimulations. Rather than occurring in a vacuum, infant action is seen as inextricably tied to the environment and its resources or affordances for action (E. J. Gibson, 1982; J. J. Gibson, 1979; Rochat & Reed, 1987). Newborns are viewed as actively oriented toward the discovery of possibilities for action provided by the environment, including objects, people, goals, obstacles, and dangers. Again, in development, action systems define important axes or avenues of change. Considered as functional constraints, they scaffold early behavioral evolution.

As mentioned above, young infants appear remarkably selective and attuned to particular environmental features and resources. From the origins of development, infant behavior manifests a practical knowledge or "knowhow" regarding particular features and objects of the environment that have basic survival values. Newborns display a functional predisposition to engage in complex and optimal transactions with certain aspects of the environment. Systematic head orientation toward a sound source (Clifton, Morrongiello, Kulig, & Dowd, 1981), mouth orientation toward a familiar odor (Macfarlane, 1975), and rooting and mouth opening toward a perioral stimulation as an apparent preparation for sucking (Koupernik & Dailly, 1968; Rochat, 1993a) are examples of such functional predisposition expressed by neonates immediately after birth.

The expression from birth of a functional link between behavior and vital resources in the environment suggest the existence of a pure form of procedural knowledge: a sort of functional protocognition that is integral to the newborn's behavioral propensities. In relation to the rooting and

sucking of the neonate, the attainment of the functional goal of feeding that ultimately guides these behavioral patterns depends on the a priori existence of a specific object in the environment: the nipple. This dependence is functional and ecological in the sense that the optimum functioning of sucking behavior is linked to a particular object that pre-exists in the environment. The nipple is an object that can be viewed as a mediator between the infant and the nutritional resource of the environment. As an a priori object of the environment, the nipple must be defined from a functional point of view, in relation to specific characteristics framed by the codesign or mutual compatibility (Turvey & Shaw, 1987) between the infant's mouth and the maternal breast or any of its substitutes (e.g., rubber nipple, pacifier, thumb). From an ecological perspective, there is a functional reciprocity between the two, as they evolved to fit one another (codesign), existing for each other a priori. When the newborn is hungry and his or her behavior is guided by the functional goal of ingesting food through rooting, sucking, and swallowing, such behavior is oriented toward the oral capture of a particular physical entity, corresponding minimally to a "suckable" object and optimally to a nutritional nipple. The behavioral orientation expressed by the infant from birth is based on the functional mutuality existing between particular features of the organism (e.g., the mouth and its functioning) and particular objects furnishing the environment (e.g., suckable objects).

WHAT DEVELOPS IN THE COURSE OF THE FIRST WEEKS, AND HOW?

Behavioral propensities, action systems, and the functional goals attached to these systems define important axes or avenues of change, providing basic directions to early behavioral development. They form functional constraints, canalizing and supporting early ontogeny. New skills rapidly develop within each of the particular action systems, the functioning of these systems overlapping and becoming increasingly integrated. A good example is the early development of oral action in the course of the first 6 months. When presented with rubber nipples that are more or less ec-

centric in relation to the shape and material of the biological nipple, infants within weeks become increasingly sensitive to eccentric nipples, engaging in significantly less sucking activity and more oral exploration (Rochat, 1983). Such development points to the progressive differentiation and integration of a double functional orientation of infants' oral activity: feeding and exploration. At the onset of development, newborns' oral activity is essentially oriented toward feeding through the wellorganized and biologically determined sucking behavior (Crook, 1979). Within weeks, the mouth develops as the primary instrument of exploration, serving the double function of feeding and investigating objects in the environment (Rochat & Senders, 1991). By 6 months, the hands appear to take over the status of the mouth as a privileged instrument of haptic exploration. From 5 months on, infants tend to bring less novel objects to the mouth, developing new manipulatory skills such as fingering behavior, which allows fine haptic exploration of larger, graspable objects in coordination with vision (Rochat, 1989, 1993a).

Within the context of action systems and their complex interactions, there is an important process, viewed as an essential factor of early development, which might explain how early behavioral growth occurs. This process is the precocious ability as well as propensity to detect regularities in the environment, to pick up invariant information. It underlies rapid progress in detecting the affordances of the environment and in attaining the functional goals attached to the various action systems expressed at birth. Note that the propensity to detect invariant information is not exclusive to the infancy period, but represents an important factor underlying perception, action, and cognitive development at all stages (E. J. Gibson, 1969; J. J. Gibson, 1979; Piaget & Inhelder, 1974). However, infancy research demonstrates that this propensity is pervasive early in life, probably driving perceptual and action development from birth. For example, studies demonstrate that 1- to 2-month-olds have the ability to transfer information from one perceptual system (oral) to another (vision). After exploring various shaped and textured objects with their mouth, infants show signs of visual recognition of these objects, transferring amodal information from the oral to the visual system (Gibson & Walker, 1984; Melt-

zoff & Borton, 1979). These findings indicate that young infants detect invariant properties and regularities beyond the immediate diversity of perceptual experiences. Evidence of neonatal imitation also demonstrates the early ability of infants to pick up visual information specifying another person's behavior (e.g., tongue protrusion) and to match this information through another modality (i.e., proprioception) in order to reproduce this behavior motorically (Meltzoff, 1990). Note that this interpretation is valid to the extent that early imitation cannot be merely reduced to fixed action patterns or automatically triggered responses (e.g., see Anisfeld, 1991, and the empirical counterevidence advanced by Meltzoff, 1989). Again, the early propensity to detect invariant features of perceived objects, events, and people allows infants to gain increased control over the resources of their environment and to detect new affordances in the context of the various action systems and the functional goals they serve.

Among all objects explored by infants, the body is invariably present. From birth it is always felt, no matter what they are doing. The same mouth is involved in any feeding activity, the same legs are moving when kicking, the same face is expressing emotion when interacting with others. The repetition of the same actions allows the fine tuning of the body in relation to what the environment affords for action. In learning about affordances, infants learn equally about their own bodies and about their bodies' potential for action. Self-knowledge is indeed an important aspect of early development, often overlooked by developmentalists.

THE BODY AS A PRIMARY OBJECT OF KNOWLEDGE IN INFANCY

More than a century ago, William James (1890) distinguished two kinds of selves, the "I" and the "Me." The "I" corresponds to the self as agent and experimenter in the environment. It is the existential or situated self. The "Me," on the other hand, corresponds to the empirical or identified self: "what he [the individual] considers his, not only his body . . . but his clothes and his house" (James, 1890, p. 291). James's distinction is important because it accounts for two distinct levels associated with the prob-

lem of self-knowledge. It underscores the difference between the self that is identified, hence conceptualized, and the self as it is experienced at a phenomenal level in the transactions with the environment. The identified self ("me") entails recognition and recall, hence conceptual and declarative knowledge (an explicit sense of self according to Case, 1991). By contrast, the situated self ("I") does not entail recognition and recall; rather, it is based on the perception of the self as a differentiated and organized entity, situated as an agent in the environment. The recent discovery of remarkable abilities in young infants suggest that in development, expression of a situated self precedes and announces recognition and understanding of the self as an identified entity or explicit object of reflection.

The acquisition of novel knowledge about the world by young infants implies that they know basic things about themselves. If they search for a nipple, they possess the implicit knowledge that they own a mouth. When learning about the invariance of objects, they also learn about the permanence of their own bodies among other objects (Neisser, 1993). At a basic level, object knowledge and self-knowledge are inseparable. As J. J. Gibson (1979) proposed, perception implies coperception of the object and of the perceiver itself. This principle is true for young infants as well. For example, when perceiving an object as reachable, infants as well as adults perceive the relative distance of this object in reference to their own situation in the environment. By definition, the detection of any affordances for action implies some kind of self-knowledge: knowledge about the body, its effectivities, and its situation in the environment. By extension, knowing about objects is knowing about oneself. When infants start to plan manual action in order to retrieve an object hidden behind an occluder, this planning entails an understanding of some kind of object permanence (out of sight does not mean out of mind), as well as self permanence in terms of the enduring situation of the body in relation to the hidden object. Lewis and Brooks-Gunn (1979, p. 10) suggested that "The early differentiation of self and other should take place at the same time the child is differentiating its mother from others and is acquiring object permanence." At least at the origins of development and prior to the emer-

gence of more reflective, explicit knowledge by the second year, there is a basic reciprocity between object knowledge, the knowledge of what objects afford for action, and knowledge about the body, its effectivities, and situation in the environment. Note that this type of implicit or preconceptual knowledge about the self is not specifically human, probably an emergent property of any biological system that perceives and acts in relation to functional goals (see Rochat, 1995, for various comparative and noncomparative approaches to this basic question).

Theories of development, and in particular theories on the origins of self-knowledge, often overlook that the body is a primary object of discovery for the young infant, an object of knowledge prior to the emergence of the conceptual self typically measured by tests of self-recognition in front of a mirror or other medias (see below). The discovery of the body's effectivities in relation to the resources (affordances) of the environment is indeed a major achievement of early development. This discovery proceeds according to the same propensity or natural ability expressed from birth to detect invariant features of objects and events, except that it is oriented toward the body and the specification of what Neisser (1991) labeled the *ecological self.* The ecological self corresponds to a sense of self as a differentiated entity, a situated agent in the environment. It develops as part of the increased control of infants over the resources of their environment and the emergence of new skills to achieve functional goals. This sense of an ecological self, of the body as agent situated in the environment, is a major product of development from birth and in the course of the first few months. Before moving on to discuss research supporting this model, I describe traditional ways in which the early development of self-knowledge has been approached.

The vast majority of experimental studies dealing with the development of self-knowledge have reduced this problem to the emergence of the identified or conceptual self. In these studies, children of different ages are typically presented with their own image, whereas the experimenter records the behavioral expression of self-recognition. The most common experimental paradigm includes self-recognition in front of a mirror and sometimes self-recognition in photographs or audiovisual recordings. The

traditional mirror technique (Gallup, 1970; Guillaume, 1926; Preyer, 1887; Zazzo, 1981) continues to generate important studies, such as using mirrors to deform the image of the self (Mounoud & Vinter, 1981; Orbach, Traub, & Olson, 1980). Using the procedure elaborated by Gallup (1970) in his study of self-recognition in chimpanzees, Lewis and Brooks-Gunn (1979) reported that 15- to18-month-old toddlers looking at themselves in a mirror showed embarrassment on noticing that rouge has been applied to their nose by the experimenter (the "rouge" task). While staring at themselves in the mirror, they typically bring one of their hands to their nose. This behavior is interpreted as a sign of self-recognition. Zazzo (1981) showed that although 18-month-olds manifest self-recognition in the rouge task, it is only 3 to 6 months later that toddlers placed in front a mirror will turn around to look directly at a light they see blinking in the mirror. When presented with photographs or video recordings, children start spontaneously naming and pointing at themselves at about age 18 months (Lewis & Brooks-Gunn, 1979). Zazzo (1981) reported that by 3 years of age, children recognize themselves with no hesitation on a video recording and resist the experimenter's countersuggestion that images projected on the screen might not actually be of them.

Researchers have expressed reservations regarding the use of self-recognition in a mirror as an experimental paradigm to capture the developmental origin of self-knowledge. These reservations are based on considerations regarding the complexity of the mirror situation and the difficulty of determining the relevant information picked up by the infant when looking at the mirror. For instance, Loveland (1986) observed that self-recognition in a mirror requires the child to have mastered the perceptual and conceptual problem associated with the mirror as a reflecting object in the environment. Furthermore, she noted that self-recognition in a mirror is by definition indirect, because it is based on the perception of a bidimensional projection of the body that is inverted around its axis of symmetry. It affords visual perception pertaining to regions of the infant's own body that are not otherwise directly accessible to this modality (e.g., the face). For all these reasons, self-recognition in a mirror might imply a particular perceptual learning that adds up to the expression of

an implicit sense of self. Mirror self-recognition probably consists of more than what is required for a knowledge of an "implicit" sense of self (see Case, 1991).

Many studies confirm that at around 18 months of age children manifest unequivocal self-recognition and self-identification in front of a mirror. Nevertheless, this fact should not be understood as the developmental origin of the sense of self. Prior to self-recognition, or explicit self-identification of any kind, infants manifest an early (implicit) sense of self (Butterworth, 1990; Rochat, 1993c). The early capacity to detect amodal information and to extract perceptual information that corresponds to spatiotemporal invariants of the stimulation allows young infants not only to perceive objects and events, but also to situate themselves as perceivers and actors in the environment (the process of coperception emphasized by J. J. Gibson, 1979). This early capacity underlies the infant's ability to perceive a situated self.

EVIDENCE FOR AN EARLY SENSE OF SELF: THE ECOLOGICAL SELF

Evidence suggests that from the onset of development infants differentiate between themselves and the environment. This differentiation forms the basis for the development of self-knowledge in infancy (Butterworth, 1991; Donaldson, 1992; E. J. Gibson, 1993; Rochat, 1993c). In early theories of development, newborn infants were traditionally described as being in a state of fusion or undifferentiation with the environment (Piaget, 1952; Preyer, 1887; Wallon, 1942/1970). Contemporary research in infancy challenges the idea of an initial fusion, shedding a new light on the developmental origins of self-knowledge. In addition to neonatal imitation, evidence of an early sense of self as a differentiated entity in the environment is provided by the fact that infants within the first weeks of life adjust their posture differentially on the basis of vestibular–proprioceptive information or visual information specifying either ego motion or motion of the surroundings (Bertenthal & Bai, 1989; Butterworth & Hicks, 1977; Jouen, 1984). Facts demonstrating precocious sensitivity and at-

tunement to ongoing social interaction (Murray & Trevarthen, 1985; Tronick, 1980) and the ability displayed from birth to effect sensorimotor responses such as sucking to control auditory events (De Casper & Fifer, 1980; Eimas, 1982; Juscyk, 1985) or visual events (Kalnins & Bruner, 1973; Siqueland & DeLucia, 1969) further suggest that young infants express an early sense of self as agentive entities (Rochat, 1993c). The idea of an initial state of fusion with the environment is inconsistent with the empirical data assembled by recent research. From the onset of development self-knowledge is expressed in the form of a differentiation between interoceptive and exteroceptive stimulations and the ability to control features of the environment (Butterworth, 1990; Rochat, 1993c). However, questions remain regarding what kind of perceptual information determined the young infant's expression of a differentiated self.

From birth, infants experience contrasted perceptual and sensorimotor events that uniquely specify the self. When infants cry, the sound they hear is combined with kinesthetic and proprioceptive feedback. This intermodal combination is uniquely specifying the perceived self. Sounds originating from another person or any other objects in the environment will never share the same intermodal invariants. By the second month, when infants start to vocalize and to babble, they appear to explore systematically the specificities of their own voice and the potentials (or affordances) of their own vocal track.

Newborns show a robust propensity to bring their hands in contact with their face and mouth (Rochat, Blass, & Hoffmeyer, 1988). Some authors have observed that newborn infants spend up to 20% of their waking hours with hands contacting the facial region (Korner & Kraemer, 1972). This simple observation has implications for the perceptual basis of self-knowledge at the origins of development. As in the case of self-produced sound, when manually touching their own faces, newborns are experiencing a sensorimotor and perceptual event that uniquely specifies the self. This intermodal event is the *double touch* 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). Contacts of the baby with any other physical objects, surfaces, or

persons in the environment never correspond to a double touch intermodal event.

When do young infants start to show discrimination of unique perceptual events that specify themselves? In an ongoing experiment conducted at the Emory Infant Laboratory, my colleagues and I are assessing whether newborns discriminate between double touch stimulations and various external cutaneous (tactile) stimulations. Preliminary results indicate that such discrimination might occur very early in development. In this project, newborns' rooting responses are systematically analyzed (i.e., head turn and oral orienting toward a perioral tactile stimulation) in four different conditions. In one condition, the perioral stimulation originates from the index finger of the experimenter who is placed behind the infant and rubs intermittently the infant's left or right cheek for 20 seconds. At the beginning of stimulation, the infant's head is oriented at the center. In a second condition, the infant is stimulated by a pacifier held by the experimenter. In a third condition, infants are stimulated by their own hand, either left or right, gently held by the experimenter and rubbing their cheek. In contrast to the other conditions, this condition provides the infant with a double touch experience. Finally, in a fourth control condition, the hand of the infant is brought close to the cheek by the experimenter, without touching it. In this last condition, infants are stimulated only with the movement component of the arm passively 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 ($N = 12$ instances), suggest that the proportion of observed rooting in the direction of the stimulation depends on the condition. Infants tend to root more toward either the experimenter's finger and the pacifier, compared to their own hands. No rooting is observed in the fourth condition where the tactile component is absent. These preliminary observations indicate that early on, young infants might express differential responding to self versus external tactile stimulations (in other words, between "double" touch, specifying the self, and "single" touch, specifying external stimulations). Again, it is important to emphasize the importance of haptic stim-

ulations early in life, these stimulations being potentially a source for the perceptual specification of the self, hence part of the perceptual basis of an early sense of self.

EARLY PERCEPTION OF BODY EFFECTIVITIES

Considering the infant's predisposition to process amodal information and the active engagement of the neonate in interacting with the environment, Stern (1985) suggested that from birth through the first 2 months, infants start forming a sense of an emergent self. According to Stern, infants experience the organizing process of the self from the moment they are born. This organizing process starts with the first interaction of the infant with the environment, and in particular with the first social interaction. Sroufe (1990) proposed that during the first 6 months, regularities in the dyadic organization of the infant–mother interaction provide sufficient information for infants to form rudiments of an inner organization, or "preintentional" self (Sroufe, 1990). According to Sroufe, the preintentional self precedes the "intentional" self in development, emerging by 6 months when infants start to demonstrate purposeful acts to control their human environment (Sroufe, 1990). According to Case (1991, p. 218), 4-month-old infants manifest a clear sense of self stemming from the experience of personal agency in the environment. From this stage, infants begin to build a model of their own capabilities and a sense of self as an "object" in the environment. Our own research also demonstrates that progress in the control of posture during the first 6 months of life changes the way infants interact with the environment. In particular, the ability to sit independently by age 4–5 months is linked to the emergence of fine haptic exploration (fingering) and trunk involvement in reaching (Rochat, 1989, 1992; Rochat & Goubet, 1995). Progress in postural control is viewed as an important determinant of the emerging sense of self in early development (Rochat & Bullinger, 1994). It is now well established that 6- month-old infants discriminate with great accuracy whether an object is within reach or out of reach (Clifton, Perris, & Bullinger, 1991; Yonas & Hartman, 1993). As mentioned previously, this ability implies that infants have

a sense of their situation as agents in the environment and in particular a sense of their situation as reachers in relation to the object they plan to capture.

Infants are accurate in perceiving the effectivities of their own body for reaching (Rochat & Goubet, 1993). In two studies, we presented infants with an object for reaching, presented successively at four different distances. Infants were placed in an upright infant seat with the object centered at their shoulders' height. The nearest distance placed the object about 30 cm from the infant's torso, in alignment with the toes. The other three distances expanded from this referential distance by 5 inches. At Distances 1 and 2, the object was within reach of the infant. At Distance 3, it was at the limit of prehensile space; the infant could eventually touch it, but with intense stretching forward of the trunk and upper limbs. At Distance 4, the object was out of reach for the infant. During 30second presentations, we scored frequency and duration of gazing at the object, latency to reach, and reach attempts. In the first study, we compared three groups of 10 infants aged 5–6 months on the basis of their relative ability to control independent sitting (i.e., their ability to coordinate reaching of hands and leaning of the trunk).

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Results show that at Distances 3 and 4, gazing activities and the frequency of reach attempts increased depending on the infant's relative sitting ability. With increased control over self-sitting, infants demonstrated an expansion of the perceived limits of prehensile space. In the second study, 60 5- to 7-month-olds were analyzed with either light (2 g) or heavy (200 g) bracelets attached to their wrists. Reaching with heavy bracelets moved forward the infant's center of mass when reaching and reduced the limits of maximum reachability without losing balance. The rationale was that if infants were sensitive to this change, they should reach less with the heavy bracelets. Results indicate that at Distances 3 and 4 only, frequency of reach attempts decrease when infants are wearing the heavy bracelets compared to when they are wearing the light ones. These results suggest that infants as young as 5 months are sensitive to what their body affords for action, detecting and adjusting with remarkable accuracy the perception of their own body's effectivities. They adjust the planning of their ac-

tivity (reaching) by perceiving sudden experimental changes in their bodily characteristics (i.e., weighted limbs causing forward displacement of their body's center of mass). These results indicate that when starting to reach, infants appear to plan their reach on the basis of their perception of their situation in the environment and particular postural constraints. They detect visual and proprioceptive information specifying their relation as actors to the object and the points of maximum extension of the body without losing balance (i.e., points of postural reversibility). Note that the detection of points of postural reversibility determine the perceived limits of prehensile space by the infant and by adults (Rochat & Wraga, 1993). This detection is the direct expression of the ecological self, implying a sense of the body's effectivities in the planning of a reach act. However, what is the process underlying the early sense of self, and in particular the early development of the ecological self? I propose that self-exploration (i.e., the exploration of one's own body) is an important determinant of such development.

SELF-EXPLORATION BY YOUNG INFANTS

The few developmental studies describing infant behavior in front of a mirror in the course of the first year (i.e., prior to the first signs of self-recognition) suggest that before they are 6 months old, infants are actively involved in discovering their own reflection and show signs of perceptual discrimination between themselves and others. Although this discrimination does not imply self-recognition, it forms the basis of an early sense of self as a differentiated entity. Dixon (1957) described a first stage at around 4 months of age in which infants look briefly and soberly at themselves in the mirror but show immediate recognition and sustained attention to their mothers' reflection. Field (1979) demonstrated that 3-month-olds respond differentially to a mirror image of the self versus viewing an infant peer. In this study, the infant's facial expression, manual behavior, visual activity, and cardiac response were recorded systematically, and the results suggested a precocious discrimination between self-perception in the mirror and perception of others. Amsterdam (1972)

reported that between the ages of 3 and 5 months, infants show little social behavior in front of the mirror (i.e., they do not smile, laugh, and vocalize); such behavior becomes prominent by 6 months. In her study, Amsterdam showed that between the ages of 3 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. By age 14 months, infants become less interested in their own movement, and by 20 months they begin to withdraw and to show embarrassment 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 self-exploration of the hands has been recently documented in newborn infants (van der Meer, 1993).

Some studies have attempted to isolate the information (visual, proprioceptive, haptic) 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 either themselves or of others. This method allowed the assessment of the discriminant variables between the two video images on the basis of the preferential looking of the infant. Reporting only pilot observations with 11 infants, Papousek and Papousek found that infants prefer to look at images of the self or of others allowing for eye contact. Using a similar procedure but placing 1- to 24-month-old infants in front of two mirrors that were 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. Schulman and Karplowitz. noted that compared with 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, followed by an immediate inspection of its reflection in the mirror. Lewis and Brooks-Gunn

(1979), like most early infancy researchers (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 and proprioceptive feedback from body movements.

Using the principle of the choice method introduced by Papousek and Papousek (1974) but presenting infants with nonfacial images of the self, in particular their legs, Bahrick and Watson (1985) demonstrated the early detection of proprioceptive–visual contingency. On one of the TV monitors the infants had access to a contingent view of their legs and on another was simultaneously presented a noncontingent, prerecorded, view of the baby's own legs or the view of another baby's leg movements wearing identical booties (yoked-control design). The 5-month-olds look preferentially to the noncontingent view. Bahrick and Watson also observed this phenomenon in a situation where an occluder prevented the infants from seeing their legs directly. Three-month-olds show 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 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).

SELF-EXPLORATION AND THE DETECTION OF INTERMODAL INVARIANTS BY YOUNG INFANTS: NEW EVIDENCE

As mentioned at the beginning of this chapter, 3-month-old infants spend a great deal of time exploring their own bodies moving and acting in the environment. They appear to be attracted and actively involved in investigating the rich intermodal redundancies, temporal contingencies, and spatial congruence of self-perception. If they appear fascinated by the si-

multaneous experience of seeing and feeling the limbs of their own body moving in space at such a young age, the question is whether they are actually detecting the intermodal invariants specifically attached to self-produced movements.

Recently, we collected evidence of such detection in 3- to 5-month-olds (Rochat & Morgan, 1993, 1995). We demonstrated that by age 3 months, when infants start to show systematic visual and proprioceptive self-exploration, they become sensitive to spatial invariants specifying the self: that, for example, when feeling their own legs moving in a particular direction in space, they expect to see their legs moving in a similar direction. The demonstration of such calibrated intermodal space by young infants is based on five experiments recently conducted at the Emory Infant Laboratory. 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 was displayed a particular on-line view of the infant's legs, from different 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 and a small microphone was placed under the infant's feet that picked up a rustling–scratching sound each time the infant produced a leg movement. The sound of the leg movements was amplified and was heard by the infant from a speaker placed centrally on top of the TV. A camera placed under the TV provided a close-up of the infant's face for later preferential looking analysis, synchronized with the audio recording of the infant's leg activities. Blind coders entered in real time on two channels the infant's gazing at either the right or left side of the split screen, while the synchronized spectrogram of the audio recording of the infant's leg activity was entered in another channel and digitized into one second bouts of leg activity. In short, this technique allowed the co-analysis of preferential looking for either views of the legs and 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 prefer-

entially at one of the views and produce a differential amount of leg activity while looking at the preferred view. In all experiments, infants were presented with two different on-line view of their own legs on the split screen. In the first experiment, infants were presented with an ego and an observer's 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: orientation and relative movement directionality of the legs.

Regarding the experimental design, in all experiments infants were recorded 5 minutes in front of the display. The side of the view was counterbalanced among infants of each age group ($n = 10$). Overall, in the first experiment, infants at both ages and starting from 3 months of age expressed a differentiation between the two views of their legs: (a) They tended to look significantly longer at the observer's view (i.e., the noncongruent view), (b) after multiple comparisons between the two views, they tended to settle their gaze toward the preferred view as a function of the 5 min of testing time, and (c) 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.

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 where both views of the legs portrayed 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, infants were recorded 5 min in front of the display. The side of the view was counterbalanced among infants of each age group ($n = 10$). Overall, in the second experiment, infants continued to express a differentiation between the two views of their legs: (a) they tended to look significantly longer at the reversed view (i.e., the incongruent view); (b) following frequent comparisons between the views, they tended to settle their gaze toward the preferred view as a function of the 5 min of testing time; and (c) they generated significantly more leg activity while looking at the

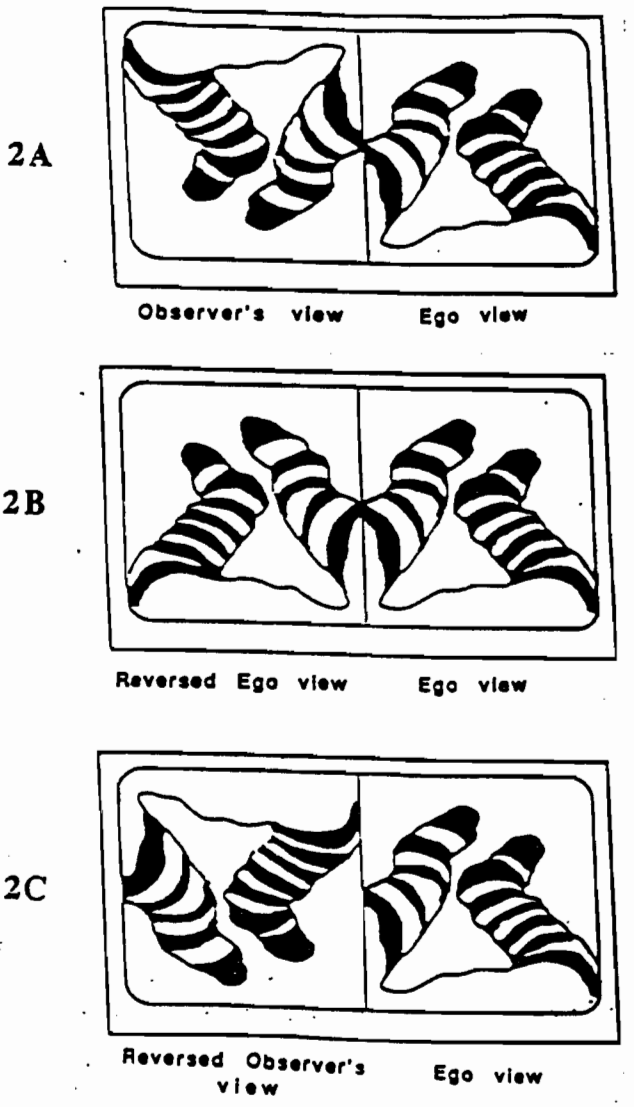

Figure 1

The two views of their own legs as seen by the infants on the TV display in the first experiment (2A), the second experiment (2B), and the third experiment (2C). From "Spatial Determinants in the Perception of Self-produced Leg Movements by 3- to 5-Month-Old Infants" by P. Rochat and R. Morgan, 1995, *Developmental Psychology, 31*, p. 629. Copyright 1995 by the American Psychological Association. Reprinted by permission.

reversed ego (incongruent) compared to the ego (congruent) view, expressing an increase of self-exploration in the context of the incongruent view that varied only in terms of movement's directionality.

In Experiment 1 orientation and movement directionality were confounded. To assess further movement directionality as a spatial determinant of the infants' apparent differentiation of the two views, we conducted a third experiment where the two views presented to the infant varied in orientation, as in Experiment 1, but with movement directionality congruent with the infant's own movements in both views (see Figure 1C). Again, infants were recorded 5 min in front of the display. The side of the view was counterbalanced among infants of each age groups ($n = 10$). In contrast to the first two experiments, infants did not show any preference for the view that was spatially incongruent with their own legs, any settling of their gazing as a function of testing time, or any significant increase in leg activity while looking at either view. Taken together, the results of these three experiments indicate that infants as young as 3 months show some discrimination between congruent and incongruent views of self-produced leg movements, the spatial determinant of this early discrimination being movement directionality rather than spatial orientation.

We (Morgan & Rochat, 1994) conducted two novel experiments to address the question of whether young infants are sensitive to changes in the relative position of their own legs they see moving on a screen. Again, 3- and 4–5-month-old infants were tested in a slightly modified procedure, presented with a composite, on-line (ego) view of their own legs, which kept constant both orientation and movement directionality of either legs, but altered their relative position on the screen. In the normal condition, 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. In the reversed condition, the legs positions were reversed: the left leg to the right and the right leg to the left side of the screen. 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 infants of each age group.

The rationale of this experiment was the following: it was predicted that if infants perceive the contrast between the normal and reversed conditions, they would 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 or the featural characteristics of the legs (i.e., the relative bending of the legs at the knees and ankles) across the two conditions.

To control for the potential determinant of the relative featural characteristics of the infant's legs (the legs' bending), which changed between normal and reversed conditions, we conducted another study where features of the legs were maintained constant while relative leg position was varied across conditions (normal and reversed). Again, we tested infants successively in the two conditions, wearing bulky socks to cover the bending of the legs. In contrast to the preceding experiments, the results indicated for both age groups ($n = 10$ infants in each), there was no significant difference in looking, gaze switching, and leg activity between the normal and the reversed conditions. These results and those of the preceding experiment 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. In our view, these results can be interpreted as the early expression of a calibrated intermodal space of the body or, in other words, the early expression of a perceptually based body schema.

Overall, the reported observations demonstrate that long before mirror self-recognition, and probably from birth, infants develop an early sense of self that is perceptual and action based. Self-exploration by young infants and the detection of intermodal invariants specifying the self as

agent are early facts of life. They are the source of a preconceptual self that develops rapidly in the course of the first months, announcing and preparing for later self-recognition.

CONCLUSIONS: REINTERPRETING THE ORIGINS OF SELF-KNOWLEDGE WITHIN AN ECOLOGICAL APPROACH

On the basis of the empirical evidence presented above, it is possible to renew the interpretation of the developmental origins of self-knowledge in the following way.

At the onset of development, infants have a sense of self based on intermodal perception and on the calibration of the different sensorimotor systems (e.g., visual, tactile, proprioceptive, auditory), which are typically co-engaged or working together within the repertoire of the newborn's action systems (e.g., sucking, rooting, grasping, orienting, imitating). Self-knowledge is primitively based on invariant information linked to the co-engagement of different modalities in self-produced movements. On the basis of their propensity to detect regularities, infants pick up intermodal invariants linked to self-produced movements. These invariants specify directly their own body as a differentiated and agentive entity in the environment.

In the course of the first weeks, as action systems expand and get further integrated, the perceived self is enriched by the infant's discovery of new intermodal invariants that accompany the development of new action patterns (e.g., reaching) and the detection of novel affordances (e.g., reachable objects). In general, from birth and long before the behavioral evidence of self-recognition in front of a mirror, infants manifest an early sense of self as a differentiated, coordinated, and agentive entity in the environment (Rochat, 1993c). This early sense of self corresponds to what authors have labeled the "I" (James, 1890); the "implicit self" (Case, 1991); the "existential self" (Lewis & Brooks-Gunn, 1979); or the "ecological self" (Neisser, 1991, 1993).

In an ecological perspective, the origins of self-knowledge are perception and action based. Active proprioception plays a central role in the

determination of an early sense of self. It provides infants from birth with information about the self as an invariant entity. Early behavior such as orienting, exploring, or imitating are by definition self-produced and directed, as opposed to triggered or passive as in the case of passive transports and postural adjustment caused by actions of caretakers or automatic responses such as the Moro response. Because from birth there are self-produced actions oriented toward functional goals, there may be rudiments of means–ends differentiation and coordination, a basic expression of the ecological self. Progress in infancy research suggests strongly the existence of an early dissociation and coordination between actions of the body and particular environmental resources, as in the case of oral–haptic exploration by neonates (Rochat, 1983) or neonatal imitation (Meltzoff & Moore, 1977). It is in this context that an implicit sense of self emerges, forming the origins of self-knowledge.

As proposed by Meltzoff (1990, p. 142), self-knowledge might be primarily mediated by pure spatiotemporal movement patterns: "there are good theoretical reasons for thinking that the first psychologically primary notion of self concerns not one's featural peculiarities but rather one's movements, body postures, and powers." Aside from the evidence of early imitation, recent research demonstrates that young infants are attuned to proprioceptive information in order to control complex actions such as reaching for a sound emitting or glowing object in the dark (Clifton, Rochat, Robin, & Berthier, 1994). Active proprioception combined with vestibular information is a self-referential system operating from birth, an integral part of any self-produced action and exploration that involve multiple modalities. This system provides basic information about the self as actor, whether it is in the context of an interaction with physical or biological resources (i.e., objects or people). This means that at least early on, the ecological self would develop equally within the social and physical realm. By the second month, when infants become markedly more people oriented and socially aware with the emergence of social expressions such as oriented smiling, the social context probably gains in importance over the world of physical objects in determining new forms of self-knowledge.

In conclusion, considering the inseparability of perception and action from birth, together with the basic principle of coperception emphasized by Gibson, it is reasonable to postulate that from the onset of development, information specifying the self as a differentiated, agentive, and situated entity in the environment does exist and is actively used by young infants. This information is at the origins of self-knowledge, announcing and preparing for the emergence of the conceptual self that has been extensively studied by developmental psychologists using mirror self-recognition tests. The enormous challenge for developmentalists is to understand and account for the functional link between the early sense of an ecological self, and the later sense of a conceptual–explicit self expressed by children capable of identifying themselves in specular as well as mental reflections. This question has not been addressed within the ecological approach presented in this chapter.

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