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# Perceived self in infancy

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**Abstract**

Research is presented suggesting that an implicit sense of self is developing from birth, long before children begin to manifest explicit (conceptual) self-knowledge by the second year. Implicit self-knowledge in infancy is rooted in intermodal perception and action. Studies are reported showing that at least from 2 months of age, infants become increasingly systematic and deliberate in the exploration of their own body and the perceptual consequences of self-produced action. From such exploration, infants develop a sense of their own body as a differentiated entity, situated and agent in the environment. Based on recent empirical findings, the perceptual determinants of such implicit sense of self are discussed. 

*Keywords:* Perception; Self; Infancy

## 1. Introduction

### *1.1. Perceived self in infancy*

By the middle of the second year, when facing their own specular image, young children begin to manifest clear signs of a conceptual sense of their own public appearance. They display unambiguous self-referencing behaviors when a spot of rouge has been surreptitiously placed on their face and they begin to show embarrassment while viewing their own mirror reflection (Bertenthal & Fisher, 1978; Lewis & Brooks-Gunn, 1979). These behaviors, among others, index self-recognition. They are inseparable from an awareness that what is reflected in the mirror refers to the bodily self, in the sense of embodied or physical appearance, and not to someone else (i.e., another child, Rochat, in press). Furthermore, the

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expression of secondary (self-conscious) emotions such as embarrassment demonstrates that children begin to conceive how they might be perceived by others. This is a remarkable and complex developmental shift marking the emergence of new levels of awareness regarding the bodily self, namely its place in the physical and social environment as a differentiated entity.

If behaviors expressing unambiguous explicit self-knowledge emerge by the second year, many questions remain regarding their developmental origins. What development precedes and eventually prepares infants to recognize and conceptualize how they might be perceived and understood by others? This is arguably among the most fundamental question of developmental psychology.

The aim of this paper is to consider the emerging sense of the bodily self in relation to the early development of perception and action. In general, we posit that the development of self-knowledge in infancy is rooted in multimodal perception and self-produced action. We propose that, aside from highly scaffolded and multimodal social exchanges with caretakers (Stern, 1985; Gergely & Watson, 1999; Rochat & Striano, 1999; Trevarthen, 1993), infants also learn who they are and what they are via the early development of actions oriented toward functional goals (e.g., touching an object for exploration, sucking to get nourishment) and the systematic exploration of the perceptual consequences of their own actions (e.g., whether the object is touched or not, whether nutrient is extracted from the object or not).

In the next section, we first briefly present the idea that self-knowledge is primarily implicit, pertaining to the sense of the own body in interaction with either objects or people. In following sections, we review observations suggesting that such implicit self-knowledge is manifest very early in development. In relation to perception and action, we present empirical evidence suggesting that infants, at least from 2 months of age, develop an implicit sense of self as agent of perceptual events in the environment. In a final section, we consider what might determine implicit self-knowledge in infancy. In particular, we review recent observations on the spatial and temporal determinants of early self-perception.

But first, what might infants know about themselves at an implicit level, long before they become explicit about their own identity, talking about themselves, or self-referencing in mirrors?

### *1.2. Implicit self-knowledge in infancy*

Some years ago, James J. Gibson (1979) eloquently articulated the idea that perception and action entails self-perception or an implicit sense of the own body situated and acting in the environment. Any organism exploring and gaining knowledge about objects in the environment, also explores and gains implicit knowledge about the self as perceiver and actor.

> Information about the self accompanies information about the environment, and the two are inseparable. Egoreception accompanies exteroception, like the other side of a coin. Perception has two poles, the subjective and the objective, and information is available to specify both. One perceives the environment and coperceives oneself. (Gibson, 1979, p.126).

If we accept Gibson's general statement, self-perception is inseparable from perception and action in the environment. From an evolutionary perspective, this proposal also implies that self-perception and a sense of self is not restricted to humans, since any organism that perceives and acts in the environment in a flexible, goal oriented way, coperceives itself.

In ontogeny, and to the extent that neonates' behavior is not considered as a mere collections of rigid reflexes, but rather as flexible action systems oriented toward functional goals (Reed, 1982; Rochat & Senders, 1991), Gibson's proposal also implies that from birth infants coperceive themselves in acting and perceiving in a resourceful environment. However, the question remains as to what is *coperceived* about the self? In particular, what do infants perceive of themselves in the course of the first months and long before the emergence of an explicit sense of self, when children can start to talk about how they feel and who they might be?

Neisser (1991) proposes that from the outset infants develop two kinds of implicit self-knowledge: knowledge about the self in relation to others (the *interpersonal self*) and knowledge about the self in relation to physical objects (the *ecological self*). Following Neisser, perceiving and acting in the social or physical realm correspond to two basic kinds of implicit self-knowledge developing from birth. The interpersonal self grows out of the infant's transactions with others, in particular the developing sense of shared experience and reciprocity. In the physical domain, infants develop a sense of their own body in relation to other objects (the ecological self). The ecological self is the sense infants develop of their own physical body as a differentiated and situated agent in the environment. The ecological self develops as infants interact with physical objects and also as they perceive their own body directly via self-exploration (Amsterdam, 1972; Rochat & Morgan, 1995; Rochat, 1998).

Neisser's conceptualization of the self in infancy is justified based on a growing body of observations provided by current infancy research. This research demonstrates that early on, infants develop a sense of themselves as situated, differentiated, and agent in the environment (see Butterworth, 1995; Neisser, 1995; Rochat, 1995), as well as a sense of themselves as communicative and reciprocating social agents (Fogel, 1993; Rochat & Striano, 1999a; Stern, 1985; Trevarthen, 1979). But this early manifestation of a sense of self in the physical and social domain is not a given but rather *develops via the active process of intermodal perception and exploration.* Implicit self-knowledge in infancy would be the product of such process which manifests itself from birth and possibly even prior to birth, in the confine of pregnancy.

### *1.3. Intermodal basis of self-perception in infancy*

From birth, when moving their limbs about, kicking, crying, sucking, or systematically bringing their hand to the mouth (Butterworth & Hopkins, 1988; Rochat et al., 1988), infants pick up perceptual information that specifies their own body as a unique entity in the environment. For example, when bringing their hands in contact with other body parts, in particular the highly sensitive facial and oral regions, young infants experience via combined double touch and perfectly contingent proprioception something that has the potential of uniquely specifying their own body or ecological self. If picked up, information associated

Fig. 1. Newborn rooting toward an external tactile stimulation.

with the experience of combined double touch and proprioception (i.e., the sense of own limb movements combined with, for example, the sensation of the hand touching the face *and* the face touching the hand), has indeed the potential of uniquely specifying the self.

Self-produced action and self-exploration come with the experience of uniquely contingent and analog perception across modalities. This is an important feature of what infants could gain from inspecting their own body in action, when for example inspecting their own hands moving in the field of view (Piaget, 1952). This experience specifies the body as differentiated from other objects in the environment. When my hand crosses my visual field, for example, I perceive that it is my hand and not someone else's, because I see it as well as I feel it proprioceptively moving at exactly the same time and by a commensurate amount. The experience of the body entails proprioception with contingent and analog inputs from other sense modalities.

There is now good evidence that early on infants discriminate between perceptual events that are either self- or not self-produced. For example, in a recent study we tested newborn infants within 24 hr of their birth to see whether they would manifest a discrimination between double touch stimulation specifying themselves, and external (one way) tactile stimulation specifying nonself objects (Rochat & Hespos, 1997). For testing, we use the robust rooting response all healthy infants manifest from birth and by which tactile stimulation at the corner of the mouth is followed by the infant's head turn with mouth opening toward the stimulation (see Fig. 1). Following a simple procedure, we recorded the frequency of rooting in response to either external tactile stimulation, the experimenter stroking the infant's cheek, or in response to tactile self-stimulation when infants spontaneously brought one of their hands in contact with their cheek. We found that newborns tended to manifest rooting responses almost three times more often in response to external compared to self-stimulation. These observations suggest that already at birth, infants pick up the intermodal invariants (single touch or double touch combined with proprioception) that specify self- versus external stimulation, showing evidence of an early sense of their own body, hence an early perceptually-based sense of themselves as differentiated entities. Note, that it can be argued that infants, particularly at such an early age, might be only discriminating between two nondescript perceptual events. We propose instead that such discrimination is fundamentally self-specifying as it involves proprioception, a perceptual system that conveys

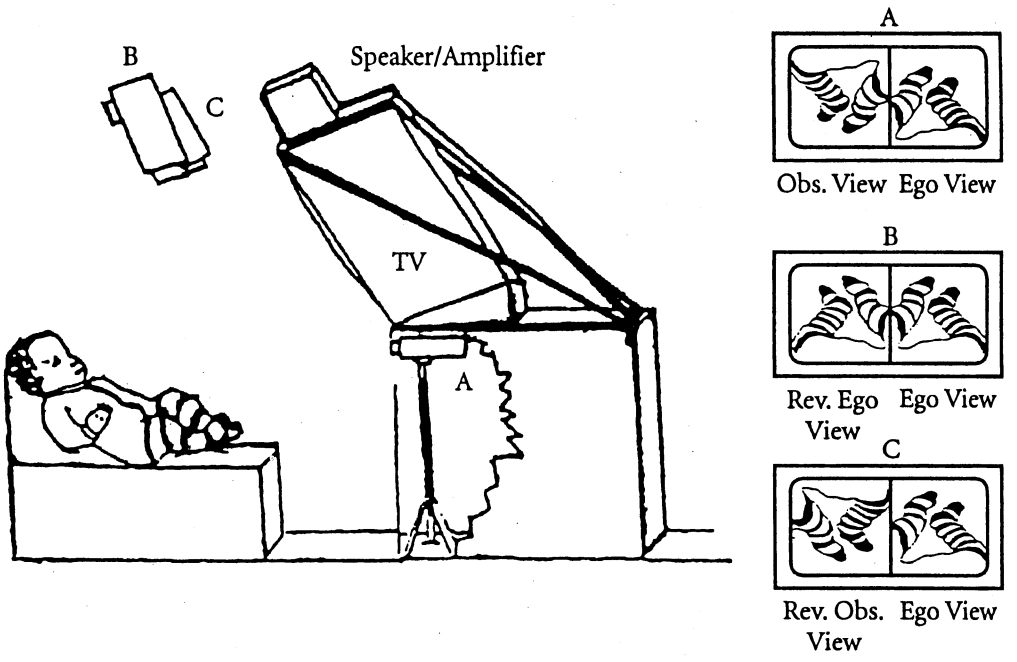


Fig. 2. Apparatus and the different views of the own legs presented to 3- and 5-month-old infants in the Rochat and Morgan, 1995 experiment on early self-exploration.

first and foremost information about the body and its situation in the environment. Proprioception, in conjunction with other perceptual systems, is indeed the modality of the self "par excellence."

If infants from birth appear capable of perceiving their own body as a differentiated entity, the question is what exactly do they perceive of their own bodies? In recent years we performed research suggesting that infants from at least 3 months of age, are aware of their own body as a dynamic and organized entity with particular featural characteristics (Morgan & Rochat, 1997; Rochat, 1998; Rochat & Morgan, 1995). In a series of studies, we measured 3- to 5-month-old infants' preferential looking to different views of their own body. For example, facing two on-line video images presented on a split screen, infants saw on each of them their own body videotaped from the waist down. Both views were on-line, thus perfectly contingent. When infants moved their legs, they saw them moving simultaneously on either sides of the screen (see Fig. 2).

Within this experimental set up, we measured infants' preferential looking for either view. One of the views presented their own legs as they would be specified via direct visual-proprioceptive feedback, for example by bringing them in the field of view while laying supine in their crib. The other view provided an experimentally modified on-line view of their own legs.

In general, what we found is that from 3 months of age, infants tend to look significantly longer at the unfamiliar view of the legs, namely the view violating visual-proprioceptive calibration of the body in terms of general movement directionality, relative movement of the limbs, as well as overall leg configuration in relation to the rest of the body (Rochat, 1998).

In particular, infants are shown to look significantly longer as well as to move their legs more, while looking at a view of their legs that changes the seen and felt directionality of movement, or that reverses the way legs move in relation to each other. In all, this research suggests that by moving and acting, infants by 3 months of age manifest an intermodal (i.e., visuo-proprioceptive) calibration of the body, developing an intermodal body schema. This body schema is an implicit, perceptually based "protorepresentation" of the body as specified by the intermodal redundancy accompanying perception and action. The intermodal redundancy specifying the body is experienced and appears to be explored by infants from birth and as they develop skills, expanding their repertoire of actions in the environment. It is even probable that self-specifying intermodal redundancy is a fact of life before birth, an intrinsic part of fetuses' experience as perceiver and actor in the womb (De Vries et al.; Prechtl, 1984). As they did during the last trimester of pregnancy, immediately after birth neonates continue to manifest haptic exploration via systematic hand-mouth coordination (Rochat et al., 1988). They also show remarkable visual-proprioceptive exploration. exploring the movement of their own hand(s) in their visual field (Van der Meer, Van der Weel, & Lee, 1995).

In summary, from the earliest age, perception of one's own movement specifies the body as a differentiated entity among other entities in the environment. Early on, infants appear to calibrate their own body based on intermodal invariants combining proprioception and other perceptual systems. We propose that this calibration forms the perceptual origins of the sense of infants' *own bodily self*, or sense of the body as differentiated, organized, and situated in the physical environment (i.e., the ecological self according to Neisser, 1991; see also Rochat, 1997).

Note that rather than the manifestation of an early sense of the bodily self, an alternative (leaner) interpretation of our observations would be that from the outset, infants appear merely to discriminate among various intermodal contingencies, whether self specifying or not. We argue that, in addition to intermodal contingencies detection, infants probably also detect invariant features of such contingencies. Among these invariant features, there is the basic fact that when perception and action are self-produced (as opposed to perceiving an external event), there is always a contingent proprioceptive feedback. The experience of proprioception with contingent feedback from other modalities (e.g., visual, auditory, tactual) is invariant features specifying self- versus nonself experience. Our own observations suggest that from birth infants appear sensitive to such self-specifying invariants (Rochat & Hespos, 1997). However, more research is needed to test and provide further support for this richer interpretation. Based on a habituation procedure, future research could test for an early categorical perception of self- vs. nonself specifying intermodal contingencies (i.e., discrimination of various intermodal experiences based on the presence or absence of contingent proprioceptive feedback).

### *1.4. Developing sense of self-agency*

Learning about the self is first and foremost becoming aware that "I" (i.e., a differentiated entity among other differentiated entities) can be the cause of changes in the environment. It is the awareness that from the own bodily actions can originate systematic perceptual

consequences that are controllable and explorable. The sense of self-agency is at the core of an implicit self-knowledge manifested in infancy. Many facts point to the early development of an implicit knowledge of the self as agent of changes in the environment, both physical and social.

Between 2 and 6 months infants develop social expectations as well as means to act as a function of these expectations to control their social environment (Rochat & Striano, 1999a). If caretakers engage in face-to-face interaction with them, infants expect a certain level of reciprocity in the exchange (Stern, 1985; Trevarthen, 1979). They manifest negative affects and marked disengagement following communicative disruption such as a sudden still-face from the partner (Tronick et al., 1978; Toda & Fogel, 1993) or sudden changes in the order of a familiar play routine such as a peek-a-boo game (Rochat et al., 1999). Within weeks, infants develop new repertoires of communicative actions controlling resources in their social environment. For example, by 3 months infants start crying in particular ways (i.e., whining and fussing) to gain attention from caretakers (Hopkins & Van Wulfften Palthe,1987). By 7 months, they begin to manifest deliberate strategies to re-engage a social partner who suddenly interrupts an on-going joyful face-to-face interaction by adopting a still-face (Striano & Rochat, 1999).

From at least 2 months of age, infants begin to show signs of becoming active social participants, starting to reciprocate with others and behave as communicative agents (i.e., socially elicited smiling, see Wolff, 1987). They develop a sense of their own efficacy and power in transforming their affective and social environment. This early developing sense of efficacy is not exclusive to the social domain. What happens in the social domain parallels development in the physical domain.

From birth, infants learn to be effective in relation to objects and events. For example, within hours after birth, neonates are capable of learning to suck in certain ways and apply specific pressures on a dummy pacifier to hear their mother's voice or see their mother's face (Decasper & Fifer, 1980; Walton et al., 1992). This remarkable instrumental learning capacity testifies to the fact that early on infants manifest a sense of themselves as an agent in the environment, an important aspect of the (implicit) ecological self (Neisser, 1995; Rochat, 1997). Lewis, Sullivan, and Brooks-Gunn (1985) show that already by 2 months of age, infants manifest pronounced positive affect (smiling and pleasure expression) when they succeed in causing an interesting auditory and visual event, capable of activating a music box by pulling a cord attached to one of their limbs. When the cord is surreptitiously disconnected from the box, suppressing infants' effectivity, they tend to switch expression from pleasure to anger. Early on, there is an hedonic dimension in learning to be effective in the world.

In interacting with objects in the environment, including their own body, infants also develop and manifest gauging and calibration of their own relative efficacy in the world, both social and physical. For example, when starting to reach systematically and successfully toward graspable objects (4–5 months), infants are shown to calibrate their action as a function of the distance that separate them from the target object (Field, 1976; Yonas & Granrud, 1985). They perceive the distance at which an object is reachable, factoring their own situation in the environment and their own degree of postural mobility (Rochat et al., 1999). Infants manifest reduced attempts to reach for an object that is slightly out of reach or far enough to jeopardize their balance. As a function of postural development and

developing degrees of behavioral freedom, infants show a remarkable ability to recalibrate their perception of what is reachable or not, for *themselves*, and in the particular situation they are in (Rochat et al., 1999).

If we do not consider the sense of self-agency as a biological given but rather determined (at least in part) by a growing experience with objects and people in the environment, what is the nature of this experience? We propose that this experience is active, goal oriented, and *intermodal* as it involves proprioception (sense of own bodily movements) in concert with the engagement of other perceptual systems (visual, auditory, olfactory etc.). Because it uniquely specifies the own bodily movements (no one but I can experience my own body moving from within), proprioception is indeed the modality of the self par excellence. The basis of perceived self-agency rests primarily on the coengagement of proprioception with other perceptual systems in the course of self-produced goal oriented actions (e.g., contacting, manipulating and transforming objects, causing interesting perceptual events, capturing others' attention). The coengagement of proprioception with other perceptual systems determines perceptual experiences that uniquely specify the bodily self as a differentiated (e.g., double touch, see above) and effective entity in the environment. Infants, from an early age, tap into this uniquely self-specifying perceptual experience. However, many questions remain as to what determines self-perception in infancy. Next, we present preliminary elements of response to these questions from recent research conducted in our Laboratory.

### *1.5. Determinants of self-perception in infancy*

If an implicit sense of self develops from birth on an intermodal basis (i.e., coengagement of proprioception with other perceptual systems), what is the underlying mechanism of self-discrimination? How can infants learn so quickly that certain perceptual experiences correspond to the self, are caused by the self, and other do not? We recently found that infants probably detect the proprioceptive coengagement specifying actions of their own body, as opposed to the actions or events caused by other entities, on different and sometime remarkably flexible perceptual bases. In the following sections, we discuss empirical observations on three of such perceptual bases: the intermodal perception of bodily space, the perception of intermodal timing, and finally the perception of intermodal form typically associated with self-produced actions.

### *1.6. Intermodal bodily space*

From an early age, the locus of self-specifying proprioceptive and visual perception does *not* need to be in the body per se. Infants from at least 3 months of age are capable of discriminating experimentally manipulated variations in visual-proprioceptive coengagement by looking at their own body *displaced* onto a distal TV screen (Bahrick & Watson, 1985; Rochat & Morgan, 1995; Schmuckler, 1996). In other words, early self-specifying proprioceptive and visual perception is not limited to the direct visual exploration of limb movements (e.g., hand waving in the field of view), but can be spatially "disembodied." There is an early capacity for an "ejection" outside the limits or physical envelop of the bodily self (Baldwin, 1925).

This does not mean that infants are not sensitive and somehow detached from any spatial factors in discriminating between self- and nonself experience. As early as 3 months, infants detect changes in general movement directionality (i.e., left-right reversal) between felt and seen leg movements projected on-line on a large TV screen in perfect temporal contingency (Rochat & Morgan, 1995). If infants are sensitive to spatial factors specifying their own body, these factors pertain to the general congruence in movement direction rather than in the precise spatial locus (within vs. outside the bodily envelop or skin).

The apparent ability of young infants to detect self-specifying intermodal information beyond the precise locus of their own body in space is certainly advantageous for later learning of tool use. In successful tool use, the tool (spoon, hammer, tennis racket or a driven vehicle) becomes an extension of the bodily self. Tool learners and users need to show great flexibility in extending the functional boundaries of their own body.

### *1.7. Intermodal timing*

If the spatial determinants of self-specifying perceptual experience appears to be limited to directionality congruence, what about timing? Does early self-perception depends on the perfect temporal coincidence between proprioception and vision, audition or other perceptions of the own body in action? In a recent study (see details below), as for the spatial determinants, we found that the temporal determinants of self-perception in infancy are remarkably broad and under specified. Rather than a lack, this can be interpreted as an early sign of opportunistic flexibility.

We tested groups of 1-, 2-, 3-, 4- and 5-month-old infants ($N = 10$ per group with gender equally represented in each group). Infants wore red and white striped socks and viewed their own legs moving on-line on two adjacent 19 inch TV monitors (see Fig. 3 and basic apparatus and procedure in Rochat & Morgan, 1995; Rochat, 1998). Each monitor was placed 1.5 meter away and slightly above the infants who sat on a 45° reclined infant seat. The reclined posture and upward presentation of the 2 images constrained the infant to get visual feedback of their own leg movements via the TV and not by looking at them directly.

Following a baseline period, infants were tested in 4 successive experimental testing conditions where one of the on-line image was delayed respectively by 0.5s, 1s, 2s, or 3s. The delay was obtained using a video broadcasting special effect device (Prime- Image Pipeline Video Delay Model 5066). Each trial condition lasted 1 min with 5 s intertrial intervals (total of 360 s of testing). The side of the delayed video feedback as well as the order of conditions were counterbalanced among infants of each age group.

Measuring preferential looking to either image in the various experimental testing conditions, we found that at all ages and for all conditions there was no systematic looking preference toward the delayed or not delayed video feedback.

The null results of this research indicate that what might be primarily detected by young infants is the *temporal regularity,* in the broad sense, of the visual feedback, whether it is delayed or not. This regularity probably overshadows the delay difference between the two video feedback of the legs presented simultaneously to the infant. It appears that infants pick up that both feedback conditions provide the same amount of visual-proprioceptive redun-

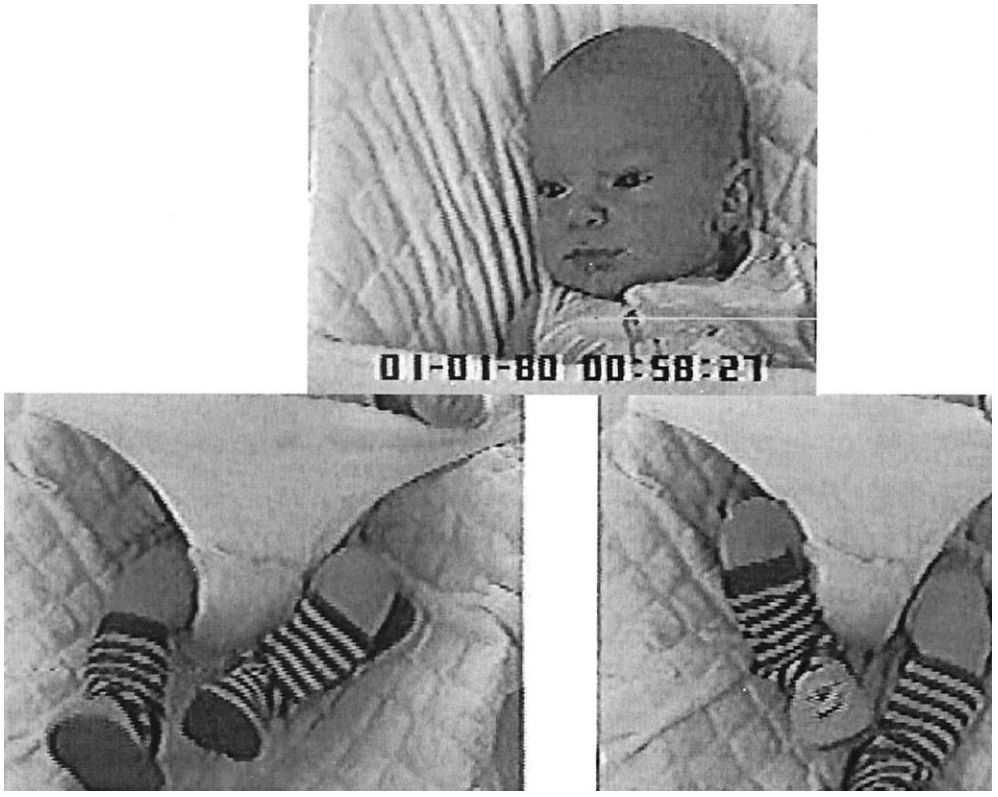


Fig. 3. Image of a 3-month-old infant facing two delayed or not delayed on-line projection of his own legs on two adjacent TV screens.

dancy and visual-proprioceptive congruence, despite the manipulated temporal delay differences (i.e., between 0 and 3 s).

This suggests that the early sensitivity to the timing of events might rest primarily on the detection of the relative amount of redundancy and congruence in the broad sense, *not* the precise temporal coincidence between visual-proprioceptive events per se. What infants are probably sensitive to is primarily how one event (proprioceptive) predicts another (visual), despite temporal delays between the two events. In our experiment, this predictability was maintained absolutely constant across conditions, hence undifferentiable. Infants had an equivalent proprioceptive and visual experience of the legs moving on the screens. Accordingly, infants showed no preference for any of the delayed or non delayed video feedback of their legs. Both being on-line and both provided 100% visual-proprioceptive predictability. As suggested by Watson (1984), up to a delay of 3 s, perfectly contingent proprioceptive and other modality feedback are self-specifying. However, with delays longer than 3 s, infants would eventually begin to discriminate the relative temporal discrepancy and perceive the other modality feedback as specifying a nonself event, possibly a social event (i.e., someone else, as suggested by Watson, 1984; Bahrick & Watson, 1985).

As adults, when viewing dubbed movie versions, we get used to and can tolerate a remarkable amount of discrepancy between visual and auditory feedback. In the case of

ventriloquism, visual information tends to be coordinated and aligned with a spatially dislocated sound source, giving the illusory perception of spatial coincidence. By analogy, our research shows that from a young age infants appear to tolerate and treat as equivalent proprioceptive and visual events that can occur with a temporal delay of up to 3 s. Note however that this delay, in the case of our experiment, was systematic. Proprioceptive and visual events were perfectly contingent, with more or less delay.

Beyond temporal contingency between proprioceptive and visual information, infants had the opportunity to detect matching vitality and spatial congruence between proprioceptive and visual feedback, despite more or less temporal coincidence between them. It is therefore feasible that a relevant aspect of multimodal information specifying self- and nonself events for the infant is the relative temporal contingency (i.e.,predictability which specifies perceptual coengagement) between proprioception and other modalities, whether delayed or not delayed, but also the *relative spatial congruence* or intermodal form between proprioceptive and other modality feedback (e.g. more or less matching amount and form of movement detected proprioceptively and visually). The term *intermodal form* stands for sensory pattern similarities that exist across coactivated perceptual systems (Watson, 1984). An example of intermodal form is the sensory pattern similarities that exist between fluctuating intensities of finger movements on the keys of a piano and the patterns of sound intensities associated with them.

Recently, we collected data suggesting that from 2 months of age, infants become attuned to the relative matching form of proprioceptive and other modality feedback, in particular proprioceptive and auditory feedback. Emerging sensitivity and attunement to intermodal form between proprioception and other modalities is an important, possibly the most important feature of learning about the self and self-agency in infancy.

### *1.8. Intermodal form*

If young infants appear flexible and to some extent remarkably permissive in their detection of equivalence between proprioceptive and other modality feedback specifying intermodal coengagement, that does not prevent them from rapidly developing an attention to the perceptual consequences of their own action. Ultimately, this developing attention, combined with a sensitivity to perfect temporal contingency (whether delayed or not delayed) is probably the basis of the learned discrimination between self- and nonself experience in infancy. But when do infants begin to pay attention and explore the perceptual consequences of their own action? When do they start to match actively the form of their own action perceived proprioceptively with the consequential events they perceive in another modality? If kicking a mobile, for example, when do they start to detect the relative spatial equivalence between their own limb movements perceived proprioceptively and the accompanying visible movements of the mobile in terms of amplitude, frequency, or overall animacy. Because temporal contingency detection appears to be remarkably flexible, intermodal form matching is likely to be the basis for learning about the self in infancy, and in particular learning about self-agency.

By analogy, it is also via a growing attention to intermodal form that infants develop sensorimotor skills requiring fine perception-action couplings (e.g., visually guided reaching

or visual-haptic coordination in object manipulation). For example, the well documented development of anticipatory reaching and grasping in infancy requires intermodal form matching of movement amplitude and velocity. The movement and opening of the hand(s) perceived and controlled proprioceptively are matched with the visible or auditory trajectory, size, and shape of the object target (Clifton et al., 1991; Clifton et al., 1994; Von Hofsten & Rönnqvist, 1988). Skill development and effective self-produced actions do rest on intermodal form matching between proprioception and other perceptual systems.

Although very early on and even immediately after birth infants demonstrate instrumental learning, sucking to hear their mother's voice or to see a bright image (DeCasper & Fifer, 1981; Siqueland & Delucia, 1969), we collected evidence suggesting that it is only by 2 months that infants begin to pay particular attention to the perceptual consequences of their own action (Rochat & Striano, 1999b). Our observations converge with other research pointing to an important transition at around this age, infants adopting what appears to be a new stance (contemplative and reciprocal stance) in their interaction with objects and people (Rochat, 2001). Major behavioral changes are reported by the second month, from the emergence of social smiling and change in face exploration (Wolff, 1987; Haith et al., 1977), to new levels of imitation and goal oriented actions (Meltzoff & Moore, 1994; Lewis et al., 1985). The following study suggests that infants by 2 months would also manifest a new attentional stance toward themselves, in particular toward the perceptual consequences of their own action.

We tested 2-month-old infants ($N = 18$) in a situation where they had the opportunity to experience different auditory consequences of their own oral activity on a dummy pacifier. The infants' modulation of oral activity was scored and analyzed relative to two types of contingent auditory feedback, either analog or nonanalog to the effort exerted by the infant on the pacifier. The dummy pacifier was connected to an air pressure transducer for recording of oral action. In six successive 90s trial blocks with counterbalanced order, every time infants applied pressure above a predetermined pressure threshold they heard either nothing (Baseline), a sound that was an analog to the pressure applied on the pacifier (Analog Condition), or a sound that was non analog to the pressure applied by the infant on the pacifier (Non-Analog condition). In the Analog Condition, there was a commensurate pitch variation of the sound with the oral pressure applied on the pacifier by the infant. In the Non-Analog Condition, each time infants applied pressure on the pacifier above threshold, they heard a two second sound with random pitch variation.

The rationale behind this study was that evidence of differential modulation in the Analog or Non-Analog conditions, whatever form such modulation might have, would index some voluntary control and the sense of a causal link between sucking and its auditory consequences, beyond mere temporal contingency detection and response-stimulus association. Results indicated that 2 month-olds showed clear signs of modulation of their oral activity on the pacifier as a function of the two experimental conditions. In the Analog Condition compared to the Non-Analog condition, they showed (1) significantly more frequent pressures on the pacifier just at threshold, (2) a significantly reduced average pressure amplitude, (3) a tendency toward less frequent high pressure amplitude on the pacifier, and (4) a tendency toward lesser variability of pressure amplitude. Note that the criterion for (1), just at threshold oral pressure responses was stringent (pressure precisely hitting threshold),

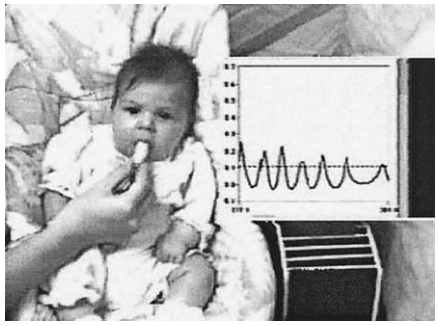

Fig. 4. Video image of an infant sucking on the dummy pacifier with superimposition of the on-line computer recording of positive pressure variation on it (From Rochat & Striano, 1999).

suggesting enhanced control of oral action on the pacifier in the Analog Condition providing commensurate auditory feedback.

In general, we found that 2 month-old-infants produced differential oral action when the auditory consequences matched both spatially and temporally their instrumental effort on the pacifier. Interestingly, such differential action was manifested from the beginning of testing, with no evidence of progressive learning. Following the rationale of the study, this modulation of oral activity demonstrates that by 2 months, infants are attentive to the spatio-temporal characteristics of the perceptual (auditory) consequences of their own actions. We interpreted these results as indexing systematic self-exploration and an emerging sense of self-agency (Rochat & Striano, 1999b). Note once again, that following the rationale of the experiment, because in either the analog and non analog condition infants were equally reinforced with temporally contingent auditory feedback, their oral response modulation is presumably indexing attention to the relative form of the proprioceptive (oro-haptic) and auditory feedback, beyond and above mere response-stimulus association. Infants, at least from 2 months of age, manifest active exploration and attunement to what Watson (1984) discusses in term of sensory pattern similarities across coactivated modalities, what we label here intermodal form.

But what about newborns? Does such self-exploratory behavior develop in the course of the first 2 months of life or is it a given propensity and capability at birth? To answer these questions, we tested healthy, full-term newborns ($N = 14$, with a mean age of 25 hr) in the exact same experimental conditions. An identical procedure and design was used, except that newborns were tested while laying supine in their bassinet, rather than sitting in a 60° reclined, well supported infant seat like the 2-month-old shown in Fig. 4. In sharp contrast to the older group of infants, we found no evidence of any differential sucking and oral activity by the newborns on the dummy pacifier as a function of Baseline, Analog, or Non-Analog Conditions. Despite this lack of oral response modulation, newborns did not merely act automatically on the pacifier. They showed some evidence of learning (familiarization) by generating less variable pressure amplitude on the pacifier during the second (final) baseline period, compared to the first. This result indicates that as a function of testing, they familiarized with the pacifier which was new to them and eccentric in form and substance compared to the biological nipple. However, they did not show any signs of

attention to the relative matching of self-produced action (proprioception+oral touch) and its auditory consequences.

In the context of this experiment and following our rationale, we concluded that newborn infants did not demonstrate any propensity to explore the auditory consequences of their oro-haptic activities on the pacifier. In contrast to the group of 2-month-olds, newborns did not provide any evidence of a sense of self-agency. However, this interpretation is inconsistent with other findings demonstrating instrumental sucking abilities in newborns, hence potentially some implicit sense of self-agency (Siqueland & DeLucia, 1969; Eimas et al., 1971; DeCasper & Fifer, 1980; Walton et al., 1992). Typically, in these other experiments, neonates were visually or auditorily reinforced based on specific intersuck or interburst intervals. In contrast, in our study, the auditory consequences depended upon patterns and amounts of positive pressure applied on the pacifier. This procedural difference might account for the lack of instrumental learning in our experiment, leaving open the possibility that the task might have been motorically too taxing for neonates.

To test this possibility, we tested recently a new group of newborns ($N = 41$) with a mean age of 36 hr in various conditions where once again they had the opportunity to experience contingent auditory consequences of their own oral activity on a dummy pacifier. In this study, however, we were specifically interested in testing newborns' ability to modulate and adapt their oral action in terms of amount of pressure (i.e., amplitude and duration) in order to hear a contingent sound, whether commensurate (analog) or not. In this research, the sound was always a 300 ms trill of discrete sounds of random frequency between 0 and 400 Hz (non analog).

Following a 5 min No Sound baseline, in one condition (Window condition) infants could hear a contingent sound as long as they maintain oral pressure on the pacifier within a certain window (between 0.1 and 0.4 psi). In another condition (No Window condition) they could hear a sound whenever they applied pressure above the minimum pressure threshold of 0.1 psi. In the latter condition, there was no upper limit. In short, each condition required different degrees of oro-haptic control in order to hear the sounds. We assessed newborns' relative ability to adjust and modulate oral activity as a function of condition by analyzing and comparing means and standard deviations of oro-haptic pressure amplitude, frequency, and pressure signals' width (see Rochat & Striano, 1999b for the details of similar analyses).

Results yielded no evidence of differential pressure applied on the pacifier in the Window or No Window conditions. Newborns did not display any hint of an ability to modulate their oral activity as a function of the two conditions in order to hear a sound. However, they did react to the sounds by generating markedly more oral pressure on the pacifier in the first 15 s of any of the experimental conditions following either the first No Sound baseline or the intertrial 5 s pause interval. However, this differential responding did not depend on condition, probably due to the global effect of sound causing behavioral state to change and making the newborn momentarily more active.

In relation to our first research, it is feasible that behavior indexing what we interpret as self-exploration by 2 month-olds (i.e., systematic modulation of action as a function of sensory pattern similarities across modalities) might still be motorically too taxing for newborns who do not show any evidence of flexibility in the application of oral pressure on the pacifier as a function of perceptual (auditory) consequences. Once again, this might be

linked to this particular dimension of their oral response (amplitude and amplitude width) as other parameters linked to the duration and frequency of sucking (intersuck and inter sucking bursts duration) lead researchers to discover remarkable instrumental learning in newborns (Siqueland & DeLucia, 1969; Eimas et al., 1971; DeCasper & Fifer, 1980; Walton et al., 1992). In the latter case, what was reinforced was sucking: a well organized and preadapted action system that appears to reveal some implicit sense of self-agency. It was not, as in our case, oral exploration in terms of generating and attaining a specific range of oral pressure amplitude.

It is important to note that in our research, self-exploration would entail some inhibition of a natural inclination toward high amplitude sucking. This inhibition, apparent by 2-month-olds as suggested by our first research (Rochat & Striano, 1999b), is probably still too demanding for newborns.

### *1.9. Intermodal and functional origins of self-knowledge*

There are at least two good and inseparable reasons to place the origins of self-knowledge at the outset of development, long before the emergence of language and explicit self-consciousness. The first reason is that infants from birth are not merely reactive to stimulation, but are actors in a meaningful environment (Rochat, 1997). The second is that, as proposed by Gibson (1979), perceiving and acting in the environment consist in *coperceiving* oneself as perceiver and actor.

Overall, implicit self-knowledge is evident prior to the emergence of language or any other symbolic abilities that are self-reflective and explicit. By the same token, from an evolutionary perspective implicit self-knowledge does not need to be viewed as limited to putatively self-conscious species (e.g., humans and some close primate relatives). In general, perceiving and acting adaptively in the environment, taping into its resources and constantly adjusting to its rich features, does specify knowledge about what furnishes this environment (objects or conspecifics), as well as about the animal itself in terms of its fitness and effectiveness.

In this paper, we have tried to show that preverbal infants develop an implicit sense of themselves, long before they utter their first conventionalized word and begin to function symbolically by, for example, identifying themselves in a mirror and maybe manifesting embarrassment and expressing self-conscious emotions in relation to a fictive audience. This implicit sense of self accompanies and develops in parallel to functional actions some manifested immediately after birth (e.g., sucking, visual tracking, or imitating, see Meltzoff & Moore, 1995). These flexible, hence adaptive actions imply to some degree a sense of the bodily self as differentiated, situated, and agent in the environment: what Neisser (1991) describes as the “ecological self” (see also Rochat, 1998).

We reviewed some facts from recent infancy research suggesting that the nature of an implicit sense of self in infancy is perceptual, intermodal in particular, relative to the coengagement of proprioception and other perceptual systems. Infants from birth can experience the presence or absence of this coengagement which is uniquely self-specifying. They are born with the experiential ability to differentiate between perceptual events that are or are not self-generated and appear to use such ability in acting in their environment. We

have seen, for example, that infants immediately after birth do seem to root differentially toward self and externally triggered (non self) tactile stimulation (Rochat & Hespos, 1997).

Research shows that the intermodal specification of the self in infancy is complex, not reducible to simple temporal and spatial determinants. If infants from 3 months of age appear to discriminate between more or less temporally contingent visual and proprioceptive feedback (Bahrick & Watson, 1985; Schmuckler, 1996), as well as more or less spatially congruent visual and proprioceptive feedback (Rochat & Morgan, 1995), the basis for such discrimination remains elusive. It appears that infants are remarkably flexible and permissive in the detection of proprioceptive plus other modalities coengagement. Proprioceptive and other modality feedback do not need to be located in the body, nor do they need to coincide precisely over time. It appears that early on, infants develop a global, remarkably encompassing sense of their own body involvement. This probably helps them in developing control over their own action in relation to multiple and changing consequences that are explored via modalities other than proprioception (e.g., visually or auditorily). In addition, it helps them detecting causal links between their own actions and events that can be remotely contingent and congruent (e.g., causing by the gentle touch of a button a very noisy, greatly animated, and possibly delayed behavior in a mechanical toy).

To conclude, early self-knowledge development is inseparable from the early development of controlled, goal oriented actions. Implicit self-knowledge by young infants grows in parallel to developing action systems that entail the intermodal coengagement of proprioception plus other modalities. As manual reaching, object manipulation and exploration, locomotion, or communication with others develop, so is the implicit sense of themselves as differentiated, situated, and agent entities in the environment. Aside from developing a sense of themselves by interacting with others in highly scaffolded social exchanges (Stern, 1985; Trevarthen, 1993), infants also learn about themselves and develop implicit knowledge about their place and effectivity in the world by learning to act and perceive adaptively in the physical environment.

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