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Self-perception and action in infancy

Abstract By 2–3 months, infants engage in exploration of their own body as it moves and acts in the environment. They babble and touch their own body, attracted and actively involved in investigating the rich intermodal redundancies, temporal contingencies, and spatial congruence of self-perception. Recent research is presented, which investigats the spatial and temporal determinants of self-perception and action infancy. This research shows that, in the course of the first weeks of life, infants develop an ability to detect intermodal invariants and regularities in their sensorimotor experience, which specify themselves as separate entities agent in the environment. Recent observations on the detection of intermodal invariants regarding self-produced leg movements and auditory feedback of sucking by young infants are reported. These observations demonstrate that, early in development and long before mirror self-recognition, infants develop a perceptual ability to specify themselves. It is tentatively proposed that young infants' propensity to engage in self-perception and systematic exploration of the perceptual consequences of their own action plays an important role in the intermodal calibration of the body and is probably at the origin of an early sense of self: the *ecological self*.

Key words Self-perception · Action · Infancy · Body schema

Self-exploration in infancy

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

Newborns show a robust propensity for bringing their hands into contact with their face and mouth (Rochat et al. 1988). Some authors have observed that newborn infants spend up to 20% of their waking hours contacting the facial region with their hands (Korner and Kraemer 1972). This simple observation might have implications regarding the perceptual basis of early experiences of the body as a differentiated object. As in the case of self-produced sound, when manually touching their own face, newborns are potentially experiencing a sensorimotor and perceptual event that uniquely specifies their own body as a differentiated object. 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). Contact by the baby with any other physical object, surface, or person in the environment will never correspond to a double-touch intermodal event.

But when do young infants start to show discrimination of unique perceptual events that could *potentially* be a perceptual basis for the specification of their own body as a differentiated object among other objects in the environment?

Based on a microanalysis of hand-mouth coordination by newborn infants, Butterworth and Hopkins (1988) reported that, when infants bring their own hand(s) into contact with their face, this cutaneous self-stimulation is not accompanied by any of the rooting responses normally observed when an external object contacts the same facial location. These observations recently confirmed experimentally by Rochat and Hespos (1997) suggest an early ability to discriminate between environmental (sin-

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gle-touch) stimulation and self-stimulation (double-touch + proprioceptive stimulation).

A few developmental studies describing exploration of self-produced movements in front of a mirror in the course of the first year (i.e., prior to the first signs of self-recognition) indicate that, before six months, infants are actively involved in discovering the contingency of mirror reflection. Amsterdam (1972) reported that, between 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. Interestingly, by 14 months, infants become less interested in their own movement and, by 20 months, begin to show embarrassment and withdrawal in front of the mirror (Amsterdam 1972; Lewis and Brooks-Gunn 1979). It thus appears that, in the context of the mirror situation, self-exploration is particularly prominent during the first year. Apart from the mirror situation, self-exploration evidently starts at 3 months of age when infants display long episodes of self-examination, in particular exploration of their hands in motion (Piaget 1952). Such exploration of the hands has been documented in newborn infants (Van der Meer 1993).

Very few studies have attempted to isolate the information (visual, proprioceptive, haptic, auditory, etc.) young infants might be sensitive to when engaged in self-exploration. A major aim of the present proposal is to capture some of the intermodal information potentially determining self-exploration in early infancy. Existing studies relevant to this aim are scarce. Papousek and Papousek (1974) placed 5 month olds in front of two different video images, either of themselves or of others. Based on the preferential gazing of the infant, this method allowed the assessment of the discriminant variables between the two video images. Reporting only pilot observations with 11 infants, Papousek and Papousek (1974) found that infants prefer to look at images of the self or of others allowing 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 show less interest in the distorted image than the flat non-distorted mirror image. Interestingly, Schulman and Kaplowitz (1976) noted that, compared to older infants, 1- to 6-month olds spend more time looking at a particular mirror, although they do not yet show complex behavior, such as looking at a particular body part, followed by an immediate inspection of its reflection in the mirror. Lewis and Brooks-Gunn (1979), like most early infancy students (Guillaume 1926; Wallon 1970) have suggested that what determines early self-exploration is 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 the infant with non-facial 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 infant had access to a contingent view of his/her legs and, on another, was simultaneously presented a non-contingent, pre-recorded, view of the baby's own legs or the view of another baby's leg movements wearing identical booties (yoked-control design). These authors showed that 5 month olds preferentially look to the non-contingent view. They also observed this phenomenon in a situation where an occluder prevented the infant from seeing his/her legs directly. Three month olds show split preferences, looking either much longer at the contingent, or much longer at the non-contingent view. Overall, Bahrick and Watson (1975) demonstrated that early perceptual discrimination of the self does not correspond only to facial images of the self, but includes other parts of the body. This is important because it shows that young infants are sensitive to visual and proprioceptive contingency in general and not only to the contingency of eye contact, as suggested by previous researchers, who emphasized the social rather than perceptual context in which first discrimination between self and others takes place (Dixon 1957; Papousek et al. 1974). Nevertheless, this research left questions open as to what information is relevant to the young infant in his/her discrimination of intermodal proprioceptive-visual contingency.

Visual-proprioceptive calibration of the body

By three months, infants spend a great deal of time exploring their own body as it moves and acts in the environment. Early on, infants appear to be attracted to and actively involved in investigating the rich intermodal redundancies, temporal contingencies, and spatial congruence of self-perception. If, early on, infants appear fascinated by the simultaneous experience of seeing and feeling the limbs of their own body moving in space, the question is whether infants, beyond a mere fascination, 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 and Morgan 1995). In particular, we have been able to demonstrate that by 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 the infant's preferential looking towards different on-line views of their legs from the waist down. As illustrated in Fig. 1, infants were placed in front of a large television monitor with a split screen. On either side of the split screen, a particular *on-line* view of the infant's legs was displayed, from different cameras placed at different angles or with optical characteristics such as a left/

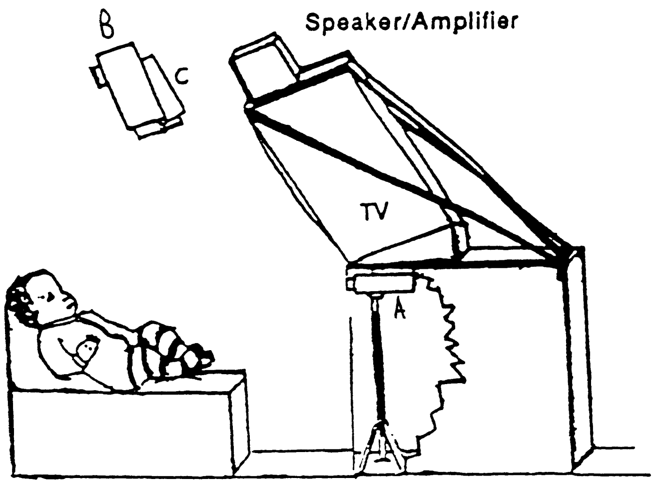

Fig. 1 Apparatus and experimental set up of an infant wearing black and white socks while reclined in front of a large TV monitor projecting an on-line view of the legs from the waist down. Camera *A* provided a close-up of the infant's face for the analysis of gazing at the display, Camera *B* and *C* each provided a particular view of the legs (i.e., ego vs. reversed-ego view)

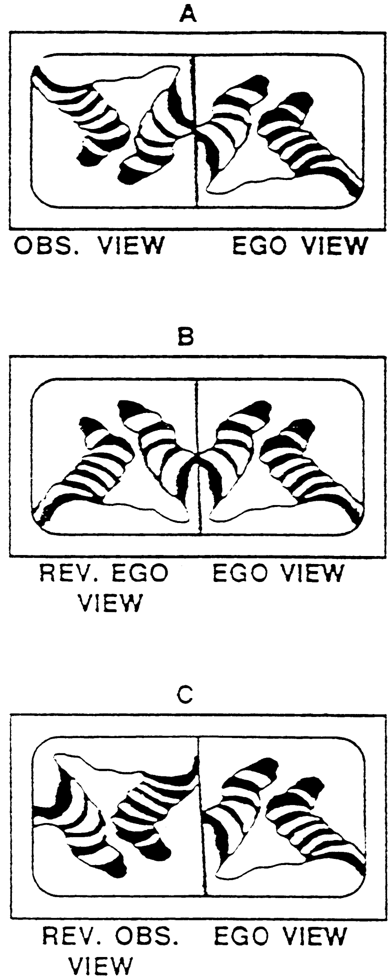

Fig. 2 The two views of their own legs as seen by the infant on the TV in the three experimental conditions studied in Rochat and Morgan (1995): **A** observer (*obs.*) view vs. ego view (experiment 1), **B** reversed- (*Rev.*) ego view vs. ego view (experiment 2), **C** reversed-observer (*Rev. obs.*) view vs. ego view (experiment 3)

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, which picked up a rustling/scratching sound each time the infant produced a leg movement. The leg movements' sound 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 1-s bouts of leg activity. In short, this technique allowed the co-analysis of preferential looking at either view 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 preferentially look 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 Fig. 2A). Each view was provided by a camera placed either above and behind the infant, or above and in front of the infant. There were two basic spatial differences between the two views: (1) orientation, and (2) relative movement directionality of the legs.

Regarding the experimental design, in all experiments, infants were recorded for 5 min in front of the display. The side of the view was counterbalanced among subjects of each age group (3 and 5 months old, n=10). Overall, in the first experiment, infants at both ages and from 3 months of age onwards express a differentiation between the two views of their legs: (1) they tended to look significantly longer at the observer's view (i.e., the non-congruent view), (2) after multiple comparisons between the two views, they tended to settle their gaze towards the preferred view as a function of the 5 min of testing time, and (3) they generated significantly more leg activity while looking at the observer's view (non-congruent) than the ego (congruent) view, expressing an increase in self-exploration in the context of the non-familiar view.

In order to untangle the confound between differences in spatial orientation and spatial directionality of the two on-line views presented in the first experiment, we conducted a second experiment, where both views of the legs portrayed a similar orientation (two ego views, see Fig. 2B); the two views being only different in relation to leg movements' directionality. Inversion of movement directionality was obtained by using a camera with a left/

right inverted tube. Again, infants were recorded for 5 min in front of the display. The side of the view was counterbalanced among subjects of each 3 and 5 months old group (n=10). Overall, in the second experiment, infants continue to express a differentiation between the two views of their legs: (1) they tended to look significantly longer at the reversed view (i.e., the incongruent view); (2) following frequent comparisons between the views, they tended to settle their gaze towards the preferred view as a function of the 5-min testing time; and (3) they generated significantly more leg activity while looking at the reversed-ego (incongruent) than the ego (congruent) view, expressing an increase of self-exploration in the context of the incongruent view, which varied only in terms of movement's directionality.

To assess further movement directionality as a spatial determinant of the infants' apparent differentiation of the two views, a third experiment was conducted, where the two views presented to the infant varied in orientation, as in experiment 1, but this time keeping movement directionality congruent with the infant's own movements in both views (see Fig. 2C). Remember that, in experiment 1 orientation and movement directionality were confounded. Again, infants were recorded for 5 min in front of the display. The side of the view was counterbalanced among subjects of each 3 and 5 months old group (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 or for 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.

Evidence of a body schema by 3 month olds

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, we performed two further experiments (Morgan and Rochat 1997). Again, 3-, and 4–to 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 both orientation and movement directionality of either legs constant, but altered their relative position on the screen. In a *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 (see Fig. 3).

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 min. Order of presentation was counterbalanced among subjects of each age group.

The rationale of this experiment was the following: if infants perceive the contrast between the normal and reversed conditions, it was predicted that they would tend to look and kick differentially across these two conditions. Results of this experiment show that infants from at least 3 months of age manifest differential looking

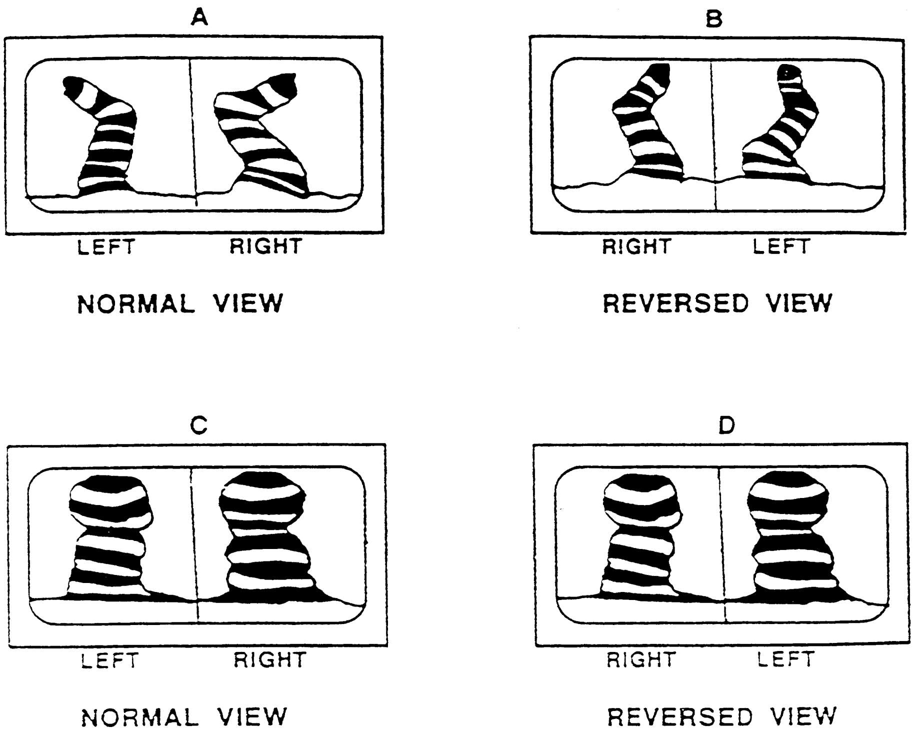

Fig. 3A–D The legs as they appeared to the infant on the TV in both conditions of experiments 4 and 5 (Morgan and Rochat 1997). **A** Normal view (experiment 4), **B** reversed view (experiment 4), **C** normal view with bulky socks (experiment 5), **D** reversed view with bulky socks (experiment 5) and kicking behavior across the two conditions. For both groups, infants tend to reduce their looking and leg activity when presented with a reversed relative location of their legs on the screen. These results suggest that young infants are sensitive to differences in the relative movements and/or the featural characteristics of the legs (i.e., the relative bending of the legs at the knees and ankles) across the two conditions.

In order 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, infants were tested successively in the two conditions, wearing bulky socks to cover the bending of the legs. In contrast to the preceding experiments, the results showed, for both 3 and 5 months old groups (n=10 infants in each), 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 onwards, infants develop an early sense of self, which 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 pre-conceptual self, which develops rapidly in the course of the first months, announcing and preparing for later self-recognition.

Sense of self-agency by young infants

Now I would like to present briefly more observations on young infants, which we recently collected at the Emory Infant Lab (Rochat and Morgan, in press; Rochat and Striano, manuscript submitted). These observations further demonstrate that, by 2–3 months, infants develop a sophisticated sense of their own body as an *agent* in the environment. They also show that infants are actively engaged in detecting and exploring objects' affordances as well as being in the process of recognizing and planning actions on objects.

In one study (Rochat and Morgan, in press), we presented 3- to 4-month-old infants with an on-line view of their own legs projected onto a large video monitor. In one condition, they only saw their legs dressed with black- and white-striped socks. The infants were seated reclined in front of the TV and could not directly see their legs. In different experimental conditions, infants saw either their legs (no-object condition) or their legs plus an object on the screen (object condition) (see Fig. 4).

In the no-object condition, a tie microphone was placed under the infant feet so that each time it moved its legs, it heard a rustling/scratching sound coming from an amplified speaker located centrally on top of the TV (see Rochat and Morgan 1995 for details). In the object condition, the microphone was placed inside the object, producing the rustling/scratching sound only when touched or kicked by the infant. The object consisted of a white disk with black polka dots supported centrally by a metal spring. The microphone was placed inside

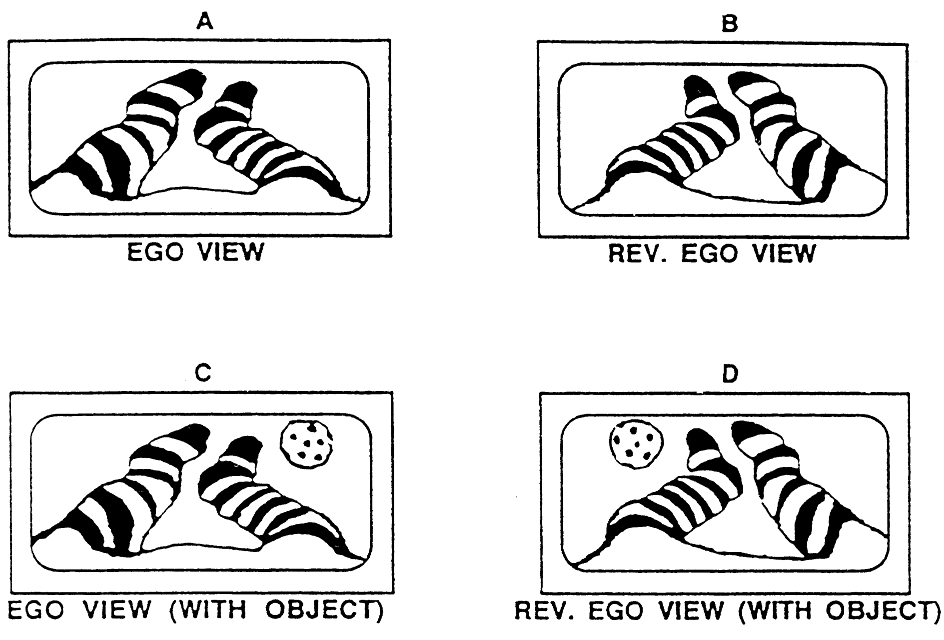

Fig. 4A–D The legs as they appeared to the infant on the TV in all 4 conditions of experiment 6 (Rochat and Morgan, in press). **A** ego view, **B** reversed-ego view (*Rev. Ego*), **C** ego view with object, **D** reversed-ego view with object the spring and only the polka-dot disk (6 cm in diameter) was visible on the screen. In order to contact and kick the object, the infant had to perform a full lateral extension of the ipsilateral leg.

In the no-object or object conditions, infants were presented successively for 2 min with two different views of their own legs: an ego view or a reversed-ego view (see Fig. 4). Each view was provided by different cameras placed above and slightly behind the infant. The ego view corresponded to the view that infants would have if they were looking down directly at their own legs. The reversed-ego view reversed the legs from left to right and was obtained by a special camera with a reversed tube. In the latter situation, when infants moved their right leg to the right, they felt it (proprioceptively) moving to the right, but saw it on the left side of the TV screen moving to the left. In other words, the reversed-ego view provided a conflict between seen and felt movement directionality of the legs.

In analyzing both looking time at the display and overall kicking activity while looking at the display, we obtained the following results. In the no-object conditions, infants spent significantly more time looking at the display and kicking with their legs when they were presented with a reversed-ego view than with an ego view. Interestingly, the reverse was true in the object condition: infants tended to look significantly longer at the display and kicked more while presented with the ego view than with the reversed-ego view. Overall, what these results mean is that infants attended the display differently in the presence or absence of the object. In the absence of the object, the infants were both proprioceptively and visually more engaged in the context of a conflictual presentation of their own legs on the screen (reversed-ego view). This latter view, which altered the familiar visual-proprioceptive calibration of the legs, appeared to be more interesting to the infant and associated with enhanced exploration than the congruent and familiar ego view. In contrast, infants appeared to look more and kick more with the familiar ego view when orienting their leg activity toward an object in space. When there is an *address* in space, where they can aim their leg activity, they prefer to look at the view corresponding to the familiar visual-proprioceptive calibration of their legs and that helps them to guide them successfully towards the object to obtain the sound. When merely contemplating their own legs the screen with no object, infants prefer to explore the incongruent view of their legs, which provides a novel conflict between visual and proprioceptive information.

These observations indicate that infants' attention did depend on the context in which they were in and the action they planned. They showed detection of what the particular experimental condition (object or no-object) afforded for action and detected the effectivities of their own leg movements in relation to the goal of producing an interesting sound. In addition, infants demonstrated that they were resourceful in relation to what they plan to do and the context of the task they were engaged in. Again, they focused more on what is perceptually familiar (ego view) in the context of a spatially oriented action required by the task. In contrast, they focused more on what is perceptually unfamiliar and novel when the task required only contemplation of the legs.

Parallel to perceiving, acting, and detecting the affordances provided by the experimental situation, these results also suggest that infants recognize different goals attached to a task: spatially oriented action in one condition and self-exploration in the other. In addition to perception, action, and the detection of affordances, infants also express an engagement in relation to two radically different goals: kicking an object or exploring novel visual-proprioceptive feedback of the legs. The infants appeared to function interchangeably in relation to these two goals, which correspond to *doing* (perceiving-acting, i.e., kicking) and *probing* (re-cognizing and representing, i.e., exploring novel, unfamiliar calibration of the legs in relation to familiar one).

More recently, we analyzed how newborn and 2-month-old infants monitor different types of auditory feedback that are contingent to different pressures they applied orally on a rubber pacifier introduced into their mouth for sucking (Rochat and Striano, submitted). The aim of this research was to document further the monitoring by young infants of the consequences of their own action and the exploration of their own body effectivities.

Infants sat in between two speakers. After a 90-s baseline, where they had the opportunity to suck and explore a soft-rubber pacifier introduced in their mouth with no contingent sounds, they were tested successively in two 90-s experimental conditions with different auditory feedback of approximately 75 db following each suck.

In one condition (analog + contingent), each time the infant applied a minimum amount of pressure on the pacifier, he or she simultaneously heard a trill of discrete computer-generated sounds, which were ascending and descending in pitch frequency. This ascending-descending pattern of sounds matched exactly and on-line the actual pressure applied orally by the infant on the pacifier. In other words, in this condition infants were provided with an auditory equivalent of the effort they generated orally on the nipple. There was a perfect spatiotemporal overlap of the positive pressure variation recorded on the nipple and the sound frequency change infants heard via the speakers.

In another condition (contingent only), each time the infants applied a minimum amount of pressure on the pacifier, they heard a 2-s trill of discrete sounds with randomly distributed pitch frequency. This pattern of sounds was contingent with the infant's sucking, but did not match the actual pressure variation orally applied by the infant on the pacifier. In other words, in this latter condition, infants were provided with a temporally equivalent, but spatially incongruent (non-analog) auditory feedback of the effort they generated orally on the nipple.

Following testing in these two conditions, infants were tested in a second baseline with the pacifier introduced in their mouth for sucking, but with no auditory feedback.

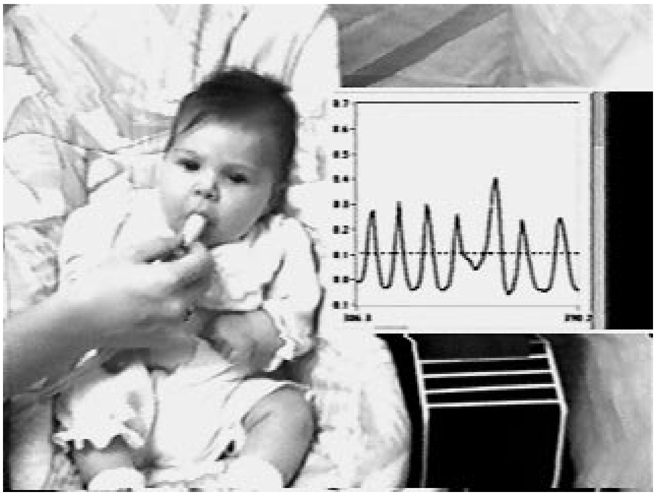

Fig. 5 Video image of a synchronized and mixed-frontal view of the infant with the on-line graphic representation of the pressure (pounds per square inch) applied on the pacifier by the infant, as recorded by the computer. The *horizontal dotted line* represents the pressure threshold for auditory feedback in the experimental conditions (analog + contingent or contingent only)

Infants' oral activity was recorded via an air-pressure transducer connected to the pacifier. The transducer itself was connected to a computer, which recorded on-line sucking and other positive pressures applied by the infant on the pacifier. Based on the recording of positive pressures applied by the infant on the pacifier in the different conditions, we analyzed sucking frequency, width, and amplitude over testing time (see Fig. 5).

The results indicated that 2-month-old infants do differently modulate their sucking and oral exploraton of the pacifier, depending on the auditory feedback. In comparison with the contingent-only condition, in the analog+contingent condition, 2-month-olds generated, overall, significantly lower-amplitude sucking and significantly more-frequent pressure on the pacifier which were just at threshold for obtaining an auditory feedback. Also, in the analog+contingent condition, 2-month olds tended to generate significantly more very long-lasting pressures above threshold on the pacifier. In contrast, newborns showed no signs of any differential sucking and oral activity on the pacifier in relation to the two auditory feedback conditions.

Based on these observations, we conclude that by 2 months, but not immediately after birth, infants start to engage in a differential perception-action coupling while exploring the contingent auditory consequences wich are either congruent or incongruent with what they are doing on the pacifier. By 2 months, infants start to discriminate among different auditory traces of their own actions. They have developed a novel sensitivity to their own effectivities, starting to explore and, possibly, to recognize themselves in the auditory consequences of their own action. The systematic exploration of such consequences are viewed as the potential mechanism underlying early objectification of the self as agent in the environment (Rochat 1995).

Conclusions: ecological self and the origins of self-recognition

The reviewed research suggests that, early on, infants pick up invariant information specifying their own body as a differentiated entity in the environment. This information is intermodal and pertains to the co-engagement of proprioceptive and other perceptual systems (e.g., vision or audition in the research reviewed above). As of at least 3 months of age, infants discriminate visual-proprioceptive information, which is either consistent or inconsistent with regular perceptual feedback they experience when, for example, feeling, hearing, or seeing moving parts of their own body.

Both temporal contingency and spatial congruence of visual, auditory, and proprioceptive feedback determine young infants' exploration of self-produced action. It is based on this exploration that young infants probably develop an early sense of themselves and of their own agency in the environment: a sense of the ecological self.

Based on our resesarch, we propose that infants are born with an ability to pick up perceptual information that specifies themselves as differentiated from other entities in the environment. The development of self-knowledge does not start from an initial state of confusion. Infants are born with the perceptual means to discriminate themselves from other objects and appear to use these means to sense themselves as differentiated, situated, and effective in their environment (the ecological self).

The sense of the ecological self is determined primarily by direct perception and action. It does not imply any explicit self-recognition and is not conceptual in nature. What characterizes infants' self-exploration when, for example, they watch themselves kicking in front of a TV, is the direct experience of visual-proprioceptive correspondances, not the reflection that it might be themselves live on the screen. If they prefer to look at a spatially incongruent view of their legs, it is because is violates the familiar visual-proprioceptive calibration of the body. For infants to recognize that it is their own legs they look at would take an additional reflective step, a step towards an *objectification* of the self. As for mirror self-recognition emerging by the second year, children need to objectify their own body, combining the direct perception of the embodied ecological self with the contemplation of a disembodied representation of the self (the "me" reflected in the mirror). One is experienced directly and the other indirectly as the product of a mental reflection.

Self-recognition is a process that emerges beyond infancy, but is based on the early development of an early sense of the ecological self, captured by current research in infancy such as the one presented here.

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