Ecological Approaches to Cognition

Essays in Honor of Ulric Neisser

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Chapter 1

Direct Perception and Representation in Infancy

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How to reconcile the rich, immediate experience of perception and action with the schematizing, reconstructing process of higher cognition? This fundamental question is at the core of Dick Neisser's research and theoretical enterprise. As a tribute, I would like to discuss this issue in light of my own recent research in infancy.

If Neisser is at the origin of the cognitive revolution, he is also among the few cognitive psychologists who take perception seriously. As we know, Gibson's influence on Neisser is enormous. It is under Gibson's influence that Neisser became the strong advocate of a more ecologically minded study of higher cognition. Since the theoretical and revisionist stance he took some 20 years ago when he published *Cognition and Reality* (1976), Neisser has spent a great deal of effort attempting to reconcile what is too often viewed as irreconcilable: Gibson's revolutionary insights on perception, with the new wave of research in cognitive science documenting higher thought processes.

A major challenge to Neisser's enterprise is whether Gibsonian views on perception as direct and deprived of reconstruction are reconcilable with the essentially schematic and reconstructive (decomposable) processes of higher cognition that are commonly accounted for by cognitive psychologists. In other words, the question is whether perceptual and representational processes, because of their specific nature, are mutually exclusive or, on the contrary, need to be considered jointly as two inseparable aspects of how the mind works. This question does raise the issue of how well founded Neisser's main theoretical attempt is.

Based on my own recent infancy research, I would like to validate Neisser's attempt to combine Gibson's views with current accounts of higher thought and representational processes. I argue that the attempt to reconcile the direct process underlying perception with the indirect reconstruction involved in higher cognition is necessary based on the fact that the mind works and develops at both levels from infancy. Infants from at least 3 months of age and possibly earlier appear to function at both a direct (perceptual) and indirect (representational) level. These two levels of functioning are neither irreconcilable nor are they reducible to one another. Rather, they are part of the mind's basic architecture as they define distinct processes that develop in parallel, coexist, and interact from the outset of development.

PERCEIVING AND PONDERING THE ENVIRONMENT

The basic misunderstanding between hard-core Gibsonians and mainstream cognitive psychologists rests on the fact that each of them attempts to assimilate two fundamentally distinct and parallel processes as one. Gibsonians spend most of their research efforts trying to demonstrate that perception is veridical and direct. Information-processing people, on the other hand, generate models of the mind that entail the indirect process of a reconstruction. In fact, I would like to suggest that hard-core Gibsonians and mainstream cognitive psychologists are not only talking a different language and reasoning from radically different premises, they are actually accounting for different mental processes that they erroneously construed as being mutually exclusive. Gibsonians are essentially interested in the tight coupling between perception and action that allows animals to move and do things adaptively in the environment. Cognitive psychologists, on the other hand, are interested in modeling the reconstructive process of the mind as it engages in memorizing, thinking, or solving problems.

It is hard not to object to the fact that Gibsonians tend to ignore fundamental aspects that are so much a part of mental life, including memory, imagination, and the conspicuous propensity we have to model and speculate about the environment and our place in it. Alternatively, cognitive psychologists that deal with perception in the confine of their computerized laboratories are obviously minimizing the wealth of information provided by the environment that Gibson insisted on and from which he elaborated his ecological optic (1966, 1979). Ensconced in their assumption of the mind as information storage and schematizing machine, cognitive psychologists commonly overlook the rich fit between the perceiver/actor and its environmental niche.

Gibson's ecological approach to perception points to the fact that in order to make sense of the world, one does not have to engage systematically in a

process of reconstruction from peripheral, meaningless bits of sensations to insightful inferences and schemas. Following Gibson, what animals perceive (humans included) is a meaningful environment, rich in information that they learn to pick up via perceptual systems that have evolved to detect them. The light bouncing back to a perceiver's eyes is structured and does not forcibly require higher mental processes to get organized and convey meanings. Gibson convincingly pointed to the fact that light forms a structured array, full of rich, meaningful invariants that are readily available to be picked up. This radical conception is fundamentally in reaction to the traditional, laboratory-based view of perception as a process of meaning attribution of the raw material provided by the sensorium.

What is truly revolutionary in Gibson's approach is that perception is for the first time considered independently from any interpretative (inferential), speculative, or higher order thought processes. Gibson's central contribution is his demonstration that perception does not (always) have to entail representation or some kind of mental reconstruction. In the light, there is information that specifies the perceiver's situation in the environment and what this environment affords him or her for action: whether there are eminent dangers, obstacles, or shelters.

Birds fly at great velocity in dense vegetation and land like lightning on a particular branch of a tree that supports their weight and affords stability. It is doubtful that birds engage in a process of reconstruction and possess a map of each tree and branch they choose to land on. The squirrel I just saw jumping from a high branch to another in my back yard did not noticeably ponder whether the next branch might or might not hold its weight. In regards to such behavior, humans are no exception. They also demonstrate tight perception–action coupling that does not require any pondering and noticeable process of reconstruction. When chased by a grizzly bear, we do perceive without much cogitation and potentially deadly reconstruction that a particular tree affords climbing, therefore safety. Nevertheless, what might be specific to humans is their ability to ponder what did happen, why did it happen, and what will eventually happen next, in addition to respond adaptively to immediate environmental situations, detecting affordances like birds, squirrels, or any other animals do.

Aside from direct perception in the context of adaptation, survival, fitness of a perceiver/actor to its environment, and the appropriate detection of environmental affordances, there is, at least in humans, representation and mental reconstruction (pondering) capabilities. Such process is by definition indirect as it entails the schematizing of events that have happened or will eventually happen in the environment. It is apparent that perceiving à la Gibson and pondering the environment often take place in parallel and are inseparable. For example, I am currently absorbed in trying to convey intelligible (if not intelligent) ideas while my fingers are racing on the keyboard of my computer. I am both cogitating and perceiving/acting adaptively in the ecological niche of my study. There is undoubtedly a double, irreducible process taking place here. At one level, me writing at my computer can be accounted for using Gibson's ecological approach to perception and action. This is the necessary process by which I detect the computer affordances in terms of the workspace it provides and what I perceive. It is also the process by which I track and control the letters that appear on the screen in conjunction with my fingers' movements. If this aspect of the overall writing process I am engaged in is necessary and complex in itself, it is obviously not sufficient to account for what is presently on my mind. There, the Gibsonian account becomes theoretically mute. What guides my perception and the control of my fingers on the keyboard is the meaning I would like eventually to convey to future readers. What I am thinking about right now is not how my fingers feel while hitting the keys or how the letters appear and pile up on the screen. I perceive all those things, but that is not what I am thinking about. What is on my mind is eminently representational and reconstructive in nature: laying down meaningful ideas that represent, in my own mind and because I am a psychologist interested in these questions, what is happening when we perceive and do things in the world.

Most of our activities in the environment entail both tight perception–action coupling and larger goals that are represented. A baseball example should convince anyone who shares Neisser's passion for the sport. It is not unusual to witness a runner moving swiftly toward first and second base while checking if the ball he just hit will make it above the fence to transform the hit into a homer. On one hand, he is controlling his gait accurately to step on each base while pondering and predicting whether the ball will make it beyond the fence. In addition to the tight perception–action coupling manifest in the player's behavior, there is also the representation of the game's rule that gives meaning to both his action and his pondering. At one level, the player is perceiving and running to control his gait. At another, he is involved in assessing the situation and predicting its outcome by looking at the ball's trajectory. In the meantime, all the rules of the game are in his mind.

Perceiving and pondering the environment are real processes that take place on different time scales. Actions that are tightly coupled with perception are based on information that is picked up online (literally in flight for the bird landing on a branch or the gannet plunging toward its prey as described by Lee & Reddish, 1981). In contrast, pondering and the processing of information in representation are, by definition, detachable from the online monitoring of action. Pondering entails such things as planning, predicting outcomes, comparing outcomes with anticipated

goals, and reflecting back on past events. In a sense, pondering and the processing of information in representation transcend the immediacy of ongoing perception–action couplings. Ultimately, they monitor actions (past, present, and future) in relation to larger, meaningful goals: safety for the man chased by the bear, intelligibility for the writer in his attempt to convey ideas.

In short, it appears that rather than contradictory, perceiving–acting in the environment and pondering–representing the environment are dual but complementary processes. There is indeed no reason to consider ourselves as either perceivers and actors in an information-rich environment or as theorists and schema crunchers, imaging, rationalizing, anticipating, and learning from past experiences. In actuality, we are both. Neisser's theoretical challenge, as I understand and value it, is to capture how these two processes relate to one another.

Next, I would like to suggest that such dual mode of functioning is an early fact of life and that even neonates engage in more than simply tightly coupled perception and action patterns of behavior. They already have rudimentary (functional) goals that organize their action beyond the immediacy of perception and mere sensorimotor responding. The remaining chapter is organized as follows:

I first try to show that much of the newborn's wakeful activity is oriented toward oral goals (i.e., ingesting food, contacting objects that afford sucking, bringing hands in contact with the mouth). These observations suggest that from birth, infants express rudiments of anticipatory behavior, hence early signs of pondering regarding future outcomes. Neonates are not confined to the online monitoring of perception and action but appear to express future-oriented behavior guided by unambiguous functional goals. However, the functional goals guiding newborns' behavior are yet limited and appear to expand drastically by the second month of life.

In the following section and based on some recent observations, I illustrate that by 6 to 8 weeks, a marked developmental change occurs with the emergence of new anticipatory behavior in relation to novel functional goals. Infants start to respond to people with mutual gaze and smiling, react to the sudden disruption of affective dialogue with the mother and, in general, display a renewed interest toward objects that furnish their environment. I try to show that they start to engage in new, systematic monitoring of the self, objects, and others. At this phase of development, infants drastically enlarge the range of functional goals that guide their perception–action systems as well as their pondering of the environment. Functional goals become increasingly objectified and external to the body (i.e., the oral zone).

Finally, in a last section I try to demonstrate that by 3 to 4 months and in parallel to marked perceptual and action development (e.g., the emergence of systematic reaching and progress in postural control), infants start to manifest unambiguous representational abilities. I present evidence that at this age, aside from directly perceiving affordances, infants start to ponder their environment in relation to future outcomes that are actively imagined and represented.

THE ORAL GOALS OF THE NEONATE

The mouth of the newborn is a primordial organizing force of early development. At birth and during the first 6 weeks of life, the wakeful activity of the infant seems to revolve mainly around the mouth. The propensity for oral contact is what appears to be an important, robust aspect of behavioral development during the first weeks of life. We have suggested elsewhere (Rochat, 1993; Rochat & Senders, 1991) that the behavioral propensity for oral contact constrains much learning in early infancy and defines important avenues of behavioral changes. This propensity for oral contact is deep-seated in the behavioral organization of the newborn and is probably part of the biological endowment of the child (i.e., not originating from postnatal experiences). For example, it is not unusual to witness bruised wrists and hands in newborns at delivery caused by intense sucking engagement in the womb. Ultrasonic recordings document such hand-to-mouth and sucking activity in the fetus during the last trimester of pregnancy (de Vries, Visser, & Prechtl, 1982).

Not that long ago, newborn behavior was considered as essentially confused (disoriented) and chaotic (disorganized). Pioneer infancy researchers, such as Spitz (1965) (but see also Mahler, Pine, & Bergman, 1975; Piaget, 1952; among many others and in the footsteps of the newborn blooming buzzing confusion suggested by James, 1890), presented newborn behavior as "random, unstructured, and . . . inconsistent" (Spitz, 1965, p. 54). Current research leads to a radically different view. It appears on the contrary that newborn behavior is, in some respects, remarkably organized and oriented toward meaningful aspects of the environment, in particular food.

We recently collected data on sucking by very low birth weight, premature infants that illustrate how well prepared and organized infants come to the world (Rochat, Goubet, & Shah, 1997). These observations also point to the predetermination of oral goals (i.e., feeding) that organize much of early behavioral development. In Rochat et al. (1997), we recorded sucking behavior by tube-fed premature infants at 36 weeks of gestational age. Sucking was recorded via the positive pressure variations infants applied on a rubber nipple introduced in their mouth 5 minutes before, during, and after nasogastric gavage feeding. What we found is that infant sucking increases significantly during gavage, indicating that mere stomach cues or temperature changes in the tube during feeding engage infant sucking, a complex activity that appears to be part of a larger action system, namely the feeding system.

This observation with very low birth weight (VLB) premature infants demonstrates how remarkably well organized infants come to the world, predetermined to tap into environmental resources such as the nipple as a source of nutrition. Interestingly, VLB premature infants are not yet physiologically mature enough to be fed orally due to the fact that the coordination between breathing and swallowing depends on soft palate growth normally occurring during the last weeks of pregnancy. This explains in part the necessity to feed premature infants enterally (via nasogastric tubing), delaying oral feeding. However, the enhanced sucking engagement we recorded indicates that infants are already prepared to respond in particular ways in relation to specific contexts (i.e., feeding). Again, what is remarkable is that young infants demonstrate that they do not behave in a vacuum but rather act adaptively in relation to predetermined environmental resources (i.e., the nipple). These resources represent functional goals that orient behavior at birth and are the primordial source of anticipation, possibly of representation.

Neonates spend up to 20% of their waking hours with their hand(s) contacting the oral region (Korner & Kraemer, 1972). Contrary to Piaget's (1952) assumption that hand–mouth contacts by neonates are merely accidental, with genuine hand–mouth coordination emerging only by the second month, recent research shows that these contacts at birth are rather systematic and anticipatory in nature. Butterworth and Hopkins (1988), performing a microanalysis of upper limbs and mouth movements in instances where neonates bring one of their hands to the oral region, demonstrated that this behavior did not appear to be driven by reflex mechanisms such as the Babkin and the rooting reflex. These authors reported instances where infants bring their hand directly to the mouth without prior contact to the perioral region. A fine grain analysis of hand trajectory reveals flexibility and variability, rather than spatio-temporal rigidity and fixedness as would be expected if this behavior was merely driven by a reflex mechanism. Interestingly, Butterworth and Hopkins described episodes in which newborns open their mouth in anticipation of contact. This behavior is illustrated in Fig. 1.1A displaying a picture I took of my daughter Cléo, 10 minutes after her birth, in which she engaged in hand-to-mouth transport. This snapshot reveals the unambiguous opening of the mouth in apparent anticipation of manual contact. It portrays precisely the observations and analyses reported by Butterworth and Hopkins.

In subsequent studies, we confirmed Butterworth and Hopkins' (1988) report, demonstrating further that hand–mouth coordination by neonates

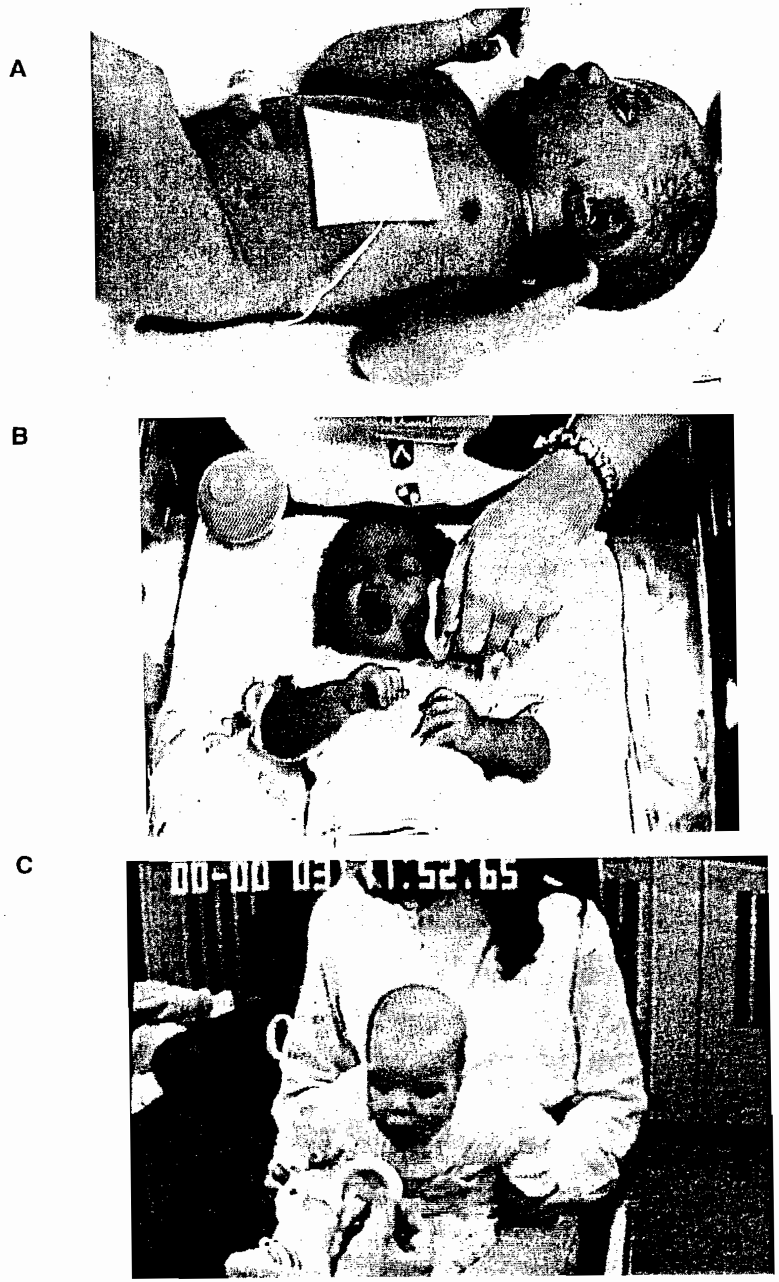

FIG. 1.1. Oral goals and engagement by young infants: Hand–mouth coordination in a neonate with mouth opening in anticipation of manual contact (1A); rooting response by a newborn infant with mouth open and tongue protrusion as the head orients toward the tactile stimulation (1B); oral capture of an object by a 4-month-old infant with both hands constrained, preventing her to reach (1C).

is controlled by sucrose delivery (Rochat, Blass, & Hoffmeyer, 1988). We found that following the delivery of a drop of water with 12% sucrose on the baby's tongue, and in addition to an engagement in mouthing and tonguing activities, infants systematically brought one hand to the mouth and maintained contact for long periods of time. Hand–mouth transports and contacts increase by 50% following sucrose delivery compared to pretest and posttest baselines (Rochat et al., 1988). In another study in which we attempted to capture further the underlying mechanism of hand–mouth coordination by neonates, we observed that following sucrose stimulation and the establishment of hand–mouth contact, upper limb movements tend to stop and overall calming takes place (Blass, Fillion, Rochat, Hoffmeyer, & Metzger, 1989). The coordinated action appears to be brought to completion once hand–mouth contact occurs. This fact is interpreted by Blass et al. as indicating that hand–mouth coordination in the neonate might serve the function of providing the infant with something to suck on, once the sucking (feeding) system is engaged. This interpretation is supported by a study in which immediately following sucrose delivery, the infant was presented with a rubber pacifier inserted in her mouth. Pacifier insertion is shown to suppress hand–mouth coordination typically following sucrose delivery. The pacifier appears to facilitate and bring to balance the newborn's sucking/feeding system (Blass et al., 1989). Once the pacifier is introduced into the newborn mouth, a dramatic inhibition of upper limb movements toward and around the mouth is observed, confirming the idea that hand–mouth coordination, at birth, is an integral part of the feeding/sucking system.

Once engaged, the feeding system appears to orient the newborn toward objects that afford sucking. This orientation probably underlies the neonate's mouth opening in anticipation of a manual contact illustrated in Fig. 1.1A.

Another example of oral anticipation is the robust rooting response of the neonate that is commonly assessed by pediatricians in their neurobehavioral testing of neonates immediately after delivery. As shown in Fig. 1.1B, the rooting response is not merely characterized by a head turn in the direction of the perioral stimulation. It also entails a mouth opening and sucking engagement with tongue protrusion in what appears to be the expression of an oral goal (Koupernik & Dailly, 1968). Typically, newborn rooting behavior, as for hand–mouth coordination, is brought to completion when a suckable object comes into oral contact and the infant is able to suck on it. As suggested by Prechtl (1957), head turning and rooting by newborns are a preliminary to food intake and are actions that subserve the homeostasis of the body's energy content. Again, this would suggest that the rooting displayed by newborns is not merely reducible to a tight (innate) coupling between perception (stimulus) and action (response), but rather is fundamentally goal-oriented and ultimately driven by the anticipation of an oral goal.

If oral goals (i.e., contacts with a suckable object) organize much of newborns' wakeful behavior, similar goals continue to determine the emergence of important behavior emerging by the second, and even the fourth month of life. I have documented that when 2-month-olds start to engage in systematic manual–haptic exploration of objects, they tend first to bring them to the mouth (Rochat, 1989). Up to approximately 4 months, the mouth remains the main locus of spontaneous object exploration (Rochat & Senders, 1991). Interestingly, when 4-month-old infants start to reach systematically for objects they see, they do so primarily to bring them in contact with the mouth. This is illustrated by Fig. 1.1C displaying a 4-month-old infant that is just starting to reach and to whom an object is presented for reaching with the mother holding both of her hands down to the side. Prevented to use her hands in order to reach and eventually transport the object to the mouth, the infant manifests the new strategy of leaning forward to directly capture the object orally. Obviously, the infant adaptively discovered new means to achieve the same goal. As Bruner (1969) did before us, we suggested elsewhere that the oral capture of the object is an important factor driving the emergence of systematic reaching behavior by the fourth month (Rochat & Senders, 1991).

The observations outlined indicate that immediately after birth, infants are not merely sophisticated responding machines endowed with the sensory power to discriminate the stimuli they are bombarded with. In contrast, they suggest that neonate behavior corresponds to sensorimotor movements that are organized in action systems that are driven by specific functional goals, in particular feeding and oral contacts. A major feature of early development is that from oral goals that appear to guide infants' behavior and anticipation during the first 4 to 6 weeks of life, new functional goals emerge that expand infants' perception, action, and attention to their environment. By 6 weeks, infants form novel expectations and appear to become newly attuned to external things and events beyond their own bodily sphere.

THE OBJECTIFIED WORLD OF THE 2-MONTH-OLD

There is a key developmental transition by the second month of life. Parents commonly report increasingly gratifying social exchanges with their infant who starts to smile and respond in reciprocal ways. I would like to illustrate that at this phase of development, infants drastically enlarge the range of functional goals that guide their perception–action systems, not only in relation to their caretakers, but also in relation to the self and to

objects. In general, the functional goals guiding the infant's perception, action, and anticipation emerge as increasingly objectified and external to the body. Infants appear to wake up to an objectified environment.

Infants, for example, start to use their hands not only to touch themselves and bring them to the mouth, but also to transport grasped objects for oral exploration (Rochat, 1989, 1993). By 2 months, the oral zone remains a focal point of infant behavior. However, it appears that the mouth becomes increasingly oriented toward an exploratory function, in addition to nutrition. Beside sucking, infants start to manifest more biting, tonguing, and lip movements while experiencing an intraoral object that is eccentric in comparison to the biological shape of the nipple in terms of shape and texture (Rochat, 1983). In our culture, solid food is commonly introduced starting the second month, this practice contributing to a change in the functional status of the mouth as an exploratory system in the context of feeding. It is via oral exploration (i.e., chewing, biting, and tonguing) that infants learn to process and select food that is either ingestable or not ingestable. In addition to the transit and extraction of liquid food via sucking, the introduction of solid food transforms the mouth into a checking and processing point from which food is either swallowed or rejected.

Relative to the whole body surface and aside from the finger tips and the inside of the hands, the mouth concentrates the highest density of tactile–haptic receptors. By the second month, infants tap increasingly and in new ways into the haptic power of the mouth. In addition to chewing and swallowing in the context of feeding, they start to use their mouth to explore nonedible physical objects. At birth, when infants are presented with a small object for grasping and once they have a good hold of the object, they will not tend to bring it to the mouth for oral contact and exploration (Rochat, 1993). As we have seen in the preceding section, this is not due to a lack of hand–mouth coordination. Rather, it is due to limited attention and interest for grasped objects that are not yet integrated in larger intermodal exploratory activities. Note however that immediately after birth, infants do engage in differential oral and manual responding when presented with objects varying in texture and elasticity (Rochat, 1983, 1987). This oral and manual exploration is still rudimentary and tightly linked to feeding, becoming more playful and gratuitous by the second month.

By 6 weeks, infants appear increasingly interested by objects for the sake of their novelty and the discovery of their affordances aside from feeding purpose. It is indeed during the second month that infants are commonly described by caretakers as opening up to the world, becoming more playful and interested, hence more interesting for those who spend time with them.

Aside from the anticipatory activity of the newborn discussed in the preceding section, neonatal imitation (Meltzoff & Moore, 1977), and few studies reporting categorical perception at birth (Bornstein, Kessen, &

Weiskopf, 1976; Slater & Morison, 1991), evidence suggesting that infants 1 month and younger can recognize objects and recall past events are sparse. Potentially representational activities by neonates are still limited to activities that are focused on the own body, and in particular to activities that are centered around the mouth (i.e., mouth opening, tongue protrusion). For 1- to 2-month-olds, evidence of object recall and recognition starts to abound. For example, infants are reported to look longer at an object matching the shape and relative elasticity of a pacifier they explored in a preceding oral familiarization (Gibson & Walker, 1984; Meltzoff & Borton, 1979). Interestingly, in a recent study Meltzoff and Moore (1994) reported that 6-week-old infants not only develop a new repertoire of oral imitation (e.g., tongue protrusion to the side in addition to midline), they also display remarkable attempts to explore and improve the matching between the modeled action and its imitation. This observation is not reported in newborns and points to a qualitative change in the imitative ability of the infant that appears to become more differentiated and objectified.

If by the second month infants show a marked increase in their propensity to engage with objects outside of their own bodily sphere, they do not lose track of themselves and their own body effectivities in the world. They start to show particular attention to the effect of their own action beyond the context of oral goals (i.e., feeding or oral contacts). For example, Lewis, Sullivan, & Brooks-Gunn (1985) attached to one wrist of 2-month-olds a cord connected to a music box that triggered interesting sounds and sights when pulled. Compared to a baseline period where the cord was not attached to the box, infants learned within 3 minutes to instrument the appropriate arm action to trigger the music box. The frequency of arm pulls are reported to increase significantly and infants displayed enhanced positive affects via significant increases in smiling. Interestingly, during a second (extinction) baseline, infants are reported to continue to pull at even a higher rate in an apparent attempt to obtain the reinforcing consequence. They displayed a marked reduction in smiling and a significant increase in an anger expression during this extinction phase. These observations suggest that infants at this age start systematically to explore themselves as agent of action and transformation in the environment. With this exploration, they learn new ways to impact on objects and develop expectations about what should happen next in particular environmental situations and following particular self-generated actions. In other words, they seem to be engaged in pondering the environment as well as perceiving and acting in it. I would suggest that there is more than direct perception as they act with a plan or some kind of a representation of future outcomes. It is doubtful that the accompanying emotional expressions of anger reported by Lewis et al. (1985) are automatic responses, but rather are revealing of the infant's anticipation of a planned

action that is violated by the surreptitious experimental manipulation of disconnecting the manipulandum. A similar example with infants of the same age will be discussed later in relation to the still face phenomenon.

In collaboration with Striano, we are currently collecting data that appear to confirm the observations of Lewis et al. (1985), but in a different experimental context. In an experiment that we just started, we are analyzing how 2-month-old infants monitor different types of auditory feedback that are contingent to each pressure they apply orally on a rubber pacifier introduced in their mouth for sucking. Infants sit between two speakers. After a 90-second baseline where they have the opportunity to suck and explore a soft rubber pacifier introduced in their mouth with no contingent sounds, they are tested successively in two 90-second experimental conditions with different auditory feedback following each suck.

In one (Analog + Contingent) condition, each time the infant applies a minimum amount of pressure on the pacifier, he or she simultaneously hears a trill of discrete computer generated sounds that are ascending and descending in pitch frequency. This ascending-descending pattern of sounds matches exactly and online the actual pressure variation applied orally by the infant on the pacifier. In other words, in this condition infants are provided with an auditory equivalent of the effort they generate orally on the nipple. There is a perfect spatiotemporal overlap of the positive pressure variation recorded on the nipple and the sound frequency change infants hear via the speakers.

In another (Contingent Only) condition, each time infants apply a minimum amount of pressure on the pacifier, they hear a 2-second trill of discrete sounds with randomly distributed pitch frequency. This pattern of sounds is contingent with the infant's sucking but does not match the actual pressure variation applied orally by the infant on the pacifier. In other words, in this latter condition infants are provided with a temporally equivalent but spatially incongruent (nonanalog) auditory feedback of the effort they generate orally on the nipple.

Following tests in these two conditions, infants are tested in a second baseline with the pacifier introduced in their mouth for sucking but with no auditory feedback. Infants' oral activity is recorded via an air pressure transducer connected to the pacifier. The transducer itself is connected to a computer that records online 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 are analyzing sucking frequency and amplitude over testing time.

The aim of this research is to document further the monitoring by young infants of the consequences of their own action and the exploration of their own body effectivities. In general, we intend to capture when infants start to discriminate among different traces of their own actions.

The basic idea guiding the research is that by 2 months, infants develop 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 is viewed as the potential mechanism underlying an early objectification of the self (Rochat, 1995).

I present next a sample of preliminary results obtained in the Rochat and Striano project. Figure 1.2 illustrates the oral response of a 2-month-old infant across the two baselines with no auditory feedback and the two experimental conditions with contingent sounds that are either analog (Contingent + Analog condition) or spatially incongruent (Contingent Only condition). The figure displays successive positive pressure variations applied by this particular infant on the pacifier in the successive conditions, each repeated twice in an alternate order.

As shown in Fig. 1.2, the infant displays remarkably fast learning of the auditory consequences of the oral pressures she applies on the pacifier. In comparison to the second baseline, the infant demonstrates a lower rate of sucking on the nipple during the first baseline. Very quickly this infant learns to use her mouth as an instrument to generate sounds aside from sucking and oral–haptic exploration of the pacifier as discussed in the preceding section. Aside from evidence of instrumental learning, the results obtained with this infant reveal two other interesting facts. In relation to the two auditory feedback conditions, she responded at a markedly higher rate in the Contingent + Analog condition where the sound matched her oral effort on the pacifier. The spatial congruence between what the baby does on the pacifier and the auditory equivalent produced by her action seems to determine her enhanced sucking engagement. Watson (1984) proposed that young infants' instrumental learning is enhanced when the consequence of the learned action is not perfectly contingent. Based on the results of the baby presented in Fig. 1.2, it seems that the learning is not only dependent on the timing of the consequence as, in both experimental conditions, there is perfect contingency (i.e., every time the infant sucks or applies pressure on the pacifier it produces a simultaneous auditory feedback). The only time the infant might have acted on the pacifier without a simultaneous auditory consequence is in the Contingent Only condition and during the 2-second burst of random sounds triggered by a preceding pressure. However, Watson's assertion should have predicted a reversed outcome compared to what this infant actually demonstrates. What appears to be an important determinant of the infant's oral–auditory exploration is not only the temporal link between the two, but the spatial congruence that matches the infant's haptic effort on the nipple and the simultaneous auditory perception of this effort. This is what makes the Contingent + Congruent experimental condition more engaging for this 2-month-old.

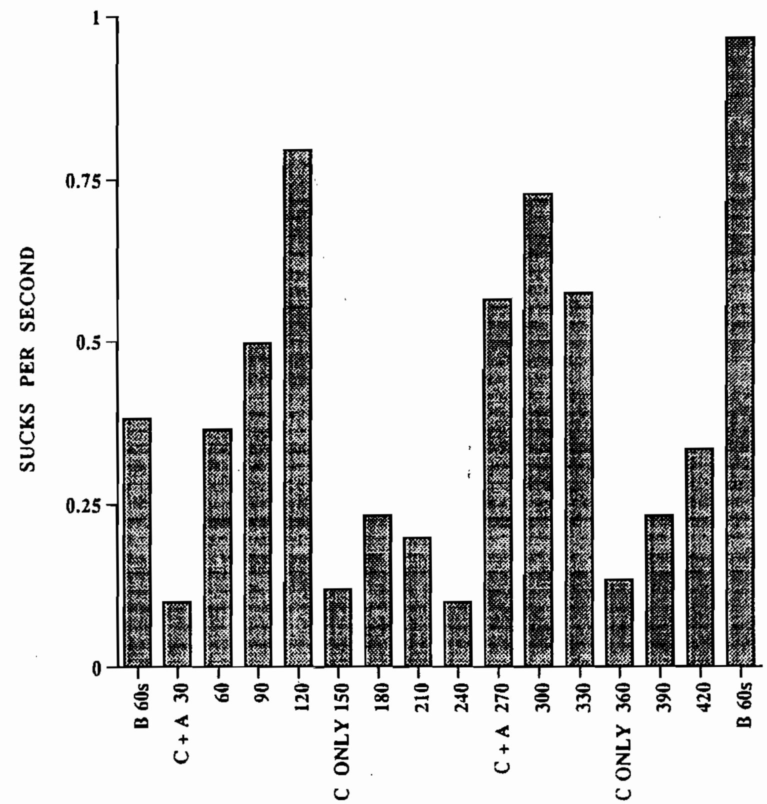

FIG. 1.2. Positive pressure applied on a pacifier (mean sucks per second) as a function of time (sec) and successive experimental conditions: no auditory feedback (beginning and end baselines (B)), contingent and analog auditory feedback (C + A), and contingent only auditory feedback (C only).

Finally, another remarkable fact is what can be observed in the second baseline at the end of the graph presented in Fig. 1.2. Similar to what is reported by Lewis et al. (1985), the infant engages in renewed oral activity during this extinction phase. Again, this would suggest that after only 6 minutes of learning opportunity, the infant already developed expectation as to what should happen when sucking on the nipple. Although we did not videotape the infant's facial expression, both the mother and the experimenter who witnessed the testing session reported that the baby became perturbed and more agitated, displaying an overall facial expression change during the extinction phase of the second baseline. It is doubtful that this reaction was due to fatigue, the infant engaging in more oral activity at during this last phase of the experiment. We intend to document precisely these reactions in subsequent testing by videotaping infants' facial expressions as Lewis et al. have done.

In summary, we interpret these preliminary observations as evidence that the infant displays in her oral activity more than mere instrumental learning. She engages in a differential perception–action coupling while exploring the contingent auditory consequence that is either congruent or incongruent with what she is doing on the pacifier. In addition, this particular infant demonstrates some probing of the situation and anticipation of an outcome (i.e., results of the second baseline). Again, these observations reveal that very early in development and in the context of expanding new goals, infants learn both: to act adaptively in coupling with perception and to anticipate outcomes.

As mentioned previously, by the second month infants open up not only to the world of objects but to the world of people. They start to reciprocate and share attention in bouts of turn taking, displaying what Trevarthen (1993) described as primary intersubjectivity. The study of 2-month-olds interacting with their mother is revealing of both their developing perceptual skills and representational abilities. A phenomenon that has been widely documented by 5- to 6-month-old infants (Muir & Hains, 1993; Toda & Fogel, 1993; Tronick, Als, Adamson, Wise, & Brazelton, 1978) is the still face, where the mother is asked in the middle of a playful interaction with her infant to adopt a neutral, frozen (static) expression while staring at her child. As already described, infants are systematically reported to show distress, including dramatic gaze aversion and smile reduction. It is not yet clear what exactly determines this robust response of the infant and more research is needed, particularly with infants in their second month as they start to develop interactive skills.

A lean interpretation of the still-face phenomenon is that it is essentially determined by the sudden removal of crucial perceptual cues by the mother that disable the infant in monitoring ongoing social exchanges. The mother becomes suddenly still, silent, and is commonly asked to refrain from touching her infant (but see Muir & Hains, 1993, demonstrating the stress reduction factor of touch in a still-face situation). Dynamic visual, auditory, and tactile cues are indeed suddenly and conspicuously absent in the still-face situation. Interestingly, and based on our own recent observations at the Emory Infant Lab, mothers have a very difficult time adopting a steady still face while interacting with their infant. They report an uncontrollable urge to interact and intervene when their child starts to show distress, notwithstanding the difficulty of maintaining a serious facial composure in front of their contact-craving infant.

Another way to look at and try to account for this phenomenon is to postulate that beyond the sudden absence of crucial perceptual cues, infants react to the situation because they do not expect their mother to behave in such a way. Obviously, this interpretation does not dismiss the importance of the sudden removal by the mother of perceptual information that might directly specify social exchanges and reciprocity with her infant. It does, however, assume that infants do anticipate certain behavior in their mother or any other caretakers, probing their reactions as a function of what they do and the social context they are in (e.g., whether they are entertained, fed, put to sleep, or changed).

I would like to share another set of preliminary observations that seem to go in the direction of this latter interpretation. These observations come from two different ongoing research projects with 2-month-old infants, started recently in collaboration with Blatt and Querido at the Emory Infant Lab. In one study, we place the infant in front of a female experimenter for approximately 3 minutes of free play interaction in which the experimenter tries to engage the infant with high-pitch voices and fun faces to make him or her smile, without engaging in any touching. Between bouts of lively interaction, the experimenter adopts a still face for up to 30 seconds or until the infant starts to show marked distress and first signs of fussing. During each still-face episode, the experimenter displays one of three different facial expressions that are commonly described as perceptually discriminated by infants of this age and even younger (e.g., Field, Woodson, Greenberg, & Cohen, 1982): a) an emotionless facial display corresponding to the neutral face used in existing still face studies; b) a happy face with frozen ("say cheese") smiling expression; and c) a sad face with inverted U mouth, puckering lips and broken eyebrows.

First observations of infants in this situation indicate that they react differentially to the still-face situation depending on the experimenter's facial expression. In the neutral, regular still-face display, all infants react according to what is documented in existing literature: marked gaze aversion and smile reduction. In contrast, it appears that infants show persistence in gazing at the experimenter when she adopts either a happy or sad still face, with maybe more gaze at the happy expression. Again, these observations are preliminary and more analyses are required to confirm these first results. However, such results are promising, in support of the idea that infants are probing the experimenter during still-face episodes. This probing depends on the static emotional cues that are available. Happy or sad faces appear to be meaningful for the infant in the social context they are in and therefore are potentially less disruptive. In contrast, the neutral emotionless expression is meaningless for the infants to the extent that it does not fit any of their expectations about people and how they usually react while interacting with them. This interpretation is reasonable considering that it is not the mere sudden immobility of the experimenter that triggers the reported stress in infants, but what they read in the facial expression of the person they are interacting with. This reading goes beyond direct perception, probably tapping also into a rudimentary representation of what an adult person is, or at least should be in relation to them (highly expressive, whether happy or sad, but never neutral or emotionless in intimate, playful interactions).

In a second ongoing project, infants are placed in front of the experimenter who engaged in a repetitive, ritualized peek-a-boo routine following a 30-second period of free-play interaction. This routine includes three distinct phases: a greeting phase ("Hi baby, look at me") with the experimenter leaning forward, closer to the infant; a hiding phase with the experimenter bringing both hands in front of her face and saying "Peek-a-boo!" and a release phase with the experimenter removing her hands from her face and moving away from the infant while saying softly "Aaaaaah!" This routine has fixed sequences in a crescendo–decrescendo overall pattern or script. This pattern of tension and release is often described as a feature young infants are particularly sensitive to in their interaction with others (Stern, 1985).

After a 30-second period of free play and interaction, the experimenter engages in a series of seven successive peek-a-boo routines over a period of approximately 1 minute before resuming free play. This sequence is repeated twice in two different conditions. In one condition, the peek-a-boo script is organized in the order of the three sequences just described (Normal condition). In another condition, the three sequences of the peek-a-boo are randomly organized and distributed over the seven repetitions of the script (Scramble condition). The experimenter wears an inconspicuous earphone, listening to a tape of successive random sequences of the peek-a-boo routine she follows, adopting the same tone of voice as in the Normal condition. In the Normal condition, the experimenter is attuned to the infant's attention and relative engagement with her, prior to starting each peek-a-boo routine. In contrast, in the Scramble condition, the experimenter follows the prerecorded order and hence is not attuned to the infant's ongoing attention. Furthermore, the scrambled order breaks the regularities of the crescendo–decrescendo pattern, removing the opportunity for the infant to develop expectancies based on some representation of the script.

We just started this research but preliminary observations are again promising. Two-month-olds appear to react differently in the scramble compared to the normal condition. The infants seem to smile less and to be generally less engaged. If these observations are confirmed by future analyses, this would again suggest that by 2 months, when infants start to reciprocate and respond socially, they do not merely express the direct perception of people's social (playful) affordances. They also start to read meaningful social events, elaborating specific expectations about people's behavior in a social (playful, interactive) context. They rapidly pick up complex regularities in the interactive flow with caretakers, developing expectations in routines that are offered by adults to entertain the infant. Interestingly, these routines (e.g., peek-a-boo, paddy cakes) are structured to be easily picked up and represented by the infant: not too long, punctuated by tension and release, with a mix of sharp sounds and interesting visual events that are particularly engaging for the infant. These routines are widely used and compulsively rehearsed by adults. The generalized use by adults of such infant appropriate routines scaffolds young infants' ability to anticipate and represent social events, beyond the direct perception of social affordances.

ACTION DEVELOPMENT AND REPRESENTATION BY 3- TO 4-MONTH-OLD INFANTS

By 3 to 4 months, infants manifest an increasing sense of their own agency in relation to objects, as well as unambiguous representational abilities. Recent infancy literature provides abundant evidence that by 4 months, infants predict outcomes of their own action on objects as well as the outcome of perceived events occurring independently of their own agency.

At the level of perception and action, this age is marked by the emergence of object manipulation. Infants start to contact and grasp objects they see (von Hofsten & Lindhagen, 1979) and develop fine manipulatory activities in conjunction with vision, including scratching, banging, and fingering of grasped objects (Rochat, 1989). In this novel propensity to bring objects in contact with the hands and to engage in protracted manual, oral, auditory and visual inspection, infants discover novel affordances and new effectivities of their own body. They learn what objects afford for manual action, aside from sucking, chewing, biting, and tonguing with the mouth. This is obviously an important development that enlarges the infant's possibilities for action and opportunities to learn objects' affordances. It is also a source of learning about the ecological self (Neisser, 1991): a sense of self as a situated agent in the environment.

When infants start to reach and do things manually with objects, it provides them with enhanced opportunities to plan actions and to learn about the outcome of their own actions. We have seen in the preceding section that from birth and clearly by 2 months, infants already demonstrate some anticipation of the consequences of their own actions. However, 3-to 4-month-old infants develop new perceptuo-motor activities (i.e., reaching) that provide rich opportunities for the parallel development of novel anticipation and probing: particular contact, particular manipulation, and specific effect on objects with new visual, haptic, and auditory consequences (e.g., the anticipation of a particular sound and shiny movements of a metal rattle that the infant might grasp and shake in front of her eyes).

As proposed by Piaget (1952) many years ago, eye–hand coordination, and in particular the emergence of systematic reaching behavior, corresponds to more than an important landmark of perceptual and motor development. It also corresponds to the emergence of planning and clearly intentional action. When infants start to reach, they do not only express eye–hand coordination and the detection of an object's reachability, they also manifest intention to do particular things with them such as banging them, pushing them, or bringing them to the mouth (Rochat & Senders, 1991). Again, aside from direct perception and action, planning, anticipation, and representation underlies early reaching behavior (see for example the research of Clifton, Rochat, Litovsky, & Perris, 1991, demonstrating anticipation and representation in 6-month-old infants reaching for various-sized objects in the dark).

I would like to briefly present more observations on 3- to 4-month-old infants we recently collected at the Emory Infant Lab (Rochat & Morgan, in press). These observations demonstrate that by 3 months, infants develop a sophisticated sense of their own body as agent in the environment. They also show that infants are actively engaged in detecting and exploring objects' affordances, as well as in the process of recognizing and planning actions on objects.

As part of a larger research program on self-perception and exploration in infancy (Rochat & Morgan, 1995a, 1995b), we presented 3- to 4-month-old infants with an online view of their own legs projected onto a large video monitor. In one condition, they saw only their legs dressed with black and white striped socks. The infants were seated in a reclined position in front of the TV and could not see their legs directly. In different experimental conditions, infants saw either their legs (No Object condition), or their legs plus an object on the screen (Object condition). In the No Object condition, a tie microphone was placed under the infant's feet so each time she moved her legs, she heard a rustling/scratching sound coming from an amplified speaker located centrally on top of the TV (see Rochat & Morgan, 1995a 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 centrally supported by a metal spring. The microphone was placed inside the spring and only the polka dot disk (6 cm in diameter) was visible from above 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 minutes with two different views of their own legs: an Ego view or a Reversed Ego view. Each view was provided by different cameras placed above and slightly behind the infant. The Ego view corresponded to the view infants would have 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 spend significantly more time looking at the display and kicking with their legs when they are presented with a Reversed Ego view compared to 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 compared to the Reversed Ego view. Overall, what these results mean is that infants attended to the display differently in the presence or absence of the object. In the absence of the object, infants are more engaged both proprioceptively and visually in the context of a conflictual presentation of their own legs on the screen (Reversed Ego view). This latter view that alters the familiar visual–proprioceptive calibration of the legs appeared to be more interesting to the infant and associated with enhanced exploration compared to the congruent and familiar Ego view. In contrast, infants appear to look more and kick more at the familiar Ego view when orienting their leg activity toward an object in space. When there is an address in space where they aim their leg activity, they prefer to look at the view that corresponds to the familiar visual–proprioceptive calibration of their legs and that will help them to guide them successfully toward the object to obtain the sound. When merely contemplating their own legs on the screen with no object, infants prefer to explore the incongruent view of their legs that provides a novel conflict between visual and proprioceptive information.

These observations indicate that infants' attention did depend on the context they were in and the action they planned. They show detection of what the particular experimental condition (Object or No Object) affords 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 are resourceful in relation to what they plan to do and the context of the task they are engaged in. Again, they focused more on what is perceptually familiar (Ego view) in the context of a spatially oriented action that is 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.

In parallel to perceiving, acting, and detecting the affordances provided by the experimental situation, these results also suggest that infants recognize different goals attached to the 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 the object or exploring novel visual–proprioceptive feedback of the legs. Infants appear to function interchangeably in relation to these two goals that correspond to doing (perceiving–acting, i.e., kicking) and probing (recognizing and representing, i.e., exploring novel, unfamiliar calibration of the legs in relation to familiar one).

The research example just provided pertains to observations of infant perceptions of their own action and their own effectivities on objects. I would like to provide further evidence of representation by 4-month-old infants who are not engaged in self-produced movements and in the perception/anticipation of their consequences, but rather who are placed in a situation where they observe and predict the outcome of events that occur independently of their own action. These kinds of situations remove the infants further from a doing mode and force them to adopt a more contemplative view on objects and events around them, probing them on the basis of representation rather than direct perception and concrete actions.

I will not rehash here the pioneer work of Spelke, Baillargeon and their collaborators showing that around 4 months, infants start to display specific anticipation regarding the outcome of partly occluded events (e.g., Baillargeon, 1995; Spelke, Breinlinger, Macomber, & Jacobson, 1992). The cleaver studies that these researchers have accumulated over the past 15 years demonstrate that early on, infants develop precise expectations regarding the behavior of objects that surround them. These expectations are interpreted as the expression of a core physical knowledge, or aboriginal collection of formal (represented) principles such as spatial continuity, objects' boundedness, and the principle of no action at a distance underlying physical causality (e.g., Spelke et al., 1992; but also Leslie, 1984).

I present some recent data in support of the view that as infants develop marked ability to do things with objects (e.g., reaching and manipulating), they also start to demonstrate unambiguous abilities to probe events beyond direct perception and the detection of affordances. These data demonstrate that by 4 months, infants are clearly capable of representing things they cannot perceive directly and can only infer from previous perception. In particular, the research provides evidence that by this age, infants can track mentally and hence represent invisible spatial transformations.

In a series of studies performed in collaboration with Hespos (Hespos & Rochat, 1997; Rochat & Hespos, 1996) we placed groups of 4- and 6-month-olds in front of a puppet stage on which a colorful Y-shaped object disappeared behind an occluder. As shown in Fig. 1.3, the object either fell vertically from the top of the stage behind the occluder (Translation

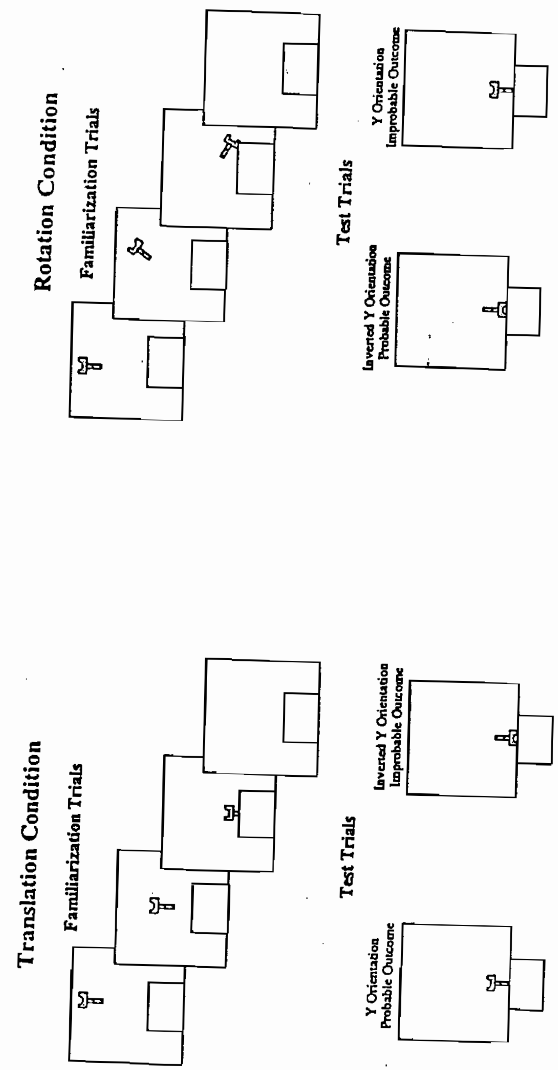

FIG. 1.3. Illustration of the familiarization trials in which the object disappeared either by falling (Translation Condition) or rotating (Rotation Condition) behind the occluder, reappearing during Test Trials either in a probable or improbable orientation outcome (Hespos & Rochat, 1997; Rochat & Hespos, 1996).

condition) or rotated behind the occluder disappearing at 4 o'clock (Rotation condition). Following six familiarization trials in each condition, the infant's visual attention was measured in two pairs of test trials in which following the object's disappearance, the occluder was lowered, revealing the object resting at the center of the stage in either a probable orientation outcome or improbable orientation outcome. The probable orientation outcome corresponded to how the object should have looked following its partly occluded trajectory. In contrast, the improbable orientation outcome corresponded to a 180° inversion of the object. In the improbable test trials, an Experimenter surreptitiously inverted the object from behind the stage prior to lowering the occluder. The rationale of such a procedure (i.e., violation of expectation paradigm) is that if infants formed accurate expectations regarding how the object should look behind the occluder, they should show enhanced visual attention to the outcome of the transformation that violated their expectation compared the one that is congruent with it. In other words, infants should look longer at the improbable compared to the probable test outcome. The rationale of this procedure has been validated by multiple infancy research in many different laboratories.

In three different experiments, each time with different infants, and with slight variations on the display that controlled for any potential residual perceptual cues specifying the movement of the object behind the occluder, we found that from 4 months of age, infants looked systematically longer at the improbable compared to the probable test outcome. These results are remarkably robust and point to sophisticated representational abilities by young infants.

If we admit that these results are the expression of specific expectations that call for more than direct perception, on what bases are these expectations formed and what do they tell us about the infant's ability to probe the environment? Based on our research, we conclude that at least by 4 months, infants are capable of generating dynamic mental imagery. This dynamic imagery or representation capability prolongs the information given by perception and allows infants to predict both visible and invisible spatial transformations. Infants demonstrate an implicit understanding that objects continue to exist when out of sight and behave in a spatially continuous way when moving behind an occluder. In our research, the infant saw the object disappear behind the occluder and managed to map onto invisible (represented) displacements the final orientation outcome of the object once it reappeared. As the object was still visible, they detected the object's characteristics, its starting orientation, motion, trajectory, and progressive occlusion. Once behind the occluder and in order to anticipate the final orientation outcome of the transformation, infants resorted to their imagination, in particular to some representational ability that enabled them to track mentally the object's spatial transformations as it moved behind the occluder. It is based on this mental tracking that infants discriminated between the probable and improbable orientation outcome.

Note that infants did take into consideration the motion and trajectory of the object and their longer looking at the improbable outcome was not merely based on the static matching of the starting and ending orientation of the object. A control group of infants familiarized with the object resting in the starting orientation looked equally at the object in either the probable or improbable orientation at the bottom of the stage in subsequent test trials. Furthermore, in the experimental situation, the novel (improbable) orientation outcome did match the starting orientation in the translation condition only. In the rotation condition, the improbable (novel) orientation was actually the same compared to the starting orientation (see Fig. 1.3). In other words, the Translation and Rotation conditions that each infant passed successively controlled for the eventuality of a mere static matching process (Rochat & Hespos, 1996).

Considering that infants did not merely memorize and compare the static orientation of the object at the top and bottom of the stage, and because no perceptual cues were available to track the object as it moved behind the occluder, the anticipation of its final orientation could only be based on mental tracking. Again, infants showed unambiguous representational abilities, and in the rotation condition demonstrated some rudiments of mental rotation that extended the information given by perception.

CONCLUSION: PERCEPTION, ACTION, AND REPRESENTATION DEVELOP IN CONCERT FROM BIRTH

What I tried to achieve in this chapter is to discuss and provide some evidence that from birth, infants demonstrate goal orientation and anticipation that implies some rudiments of representation in addition to finely tuned perception–action coupling and the direct perception of what objects afford for action. I argued that doing and probing in the environment are dual but complementary processes that are expressed from the outset of development. As suggested by Gibson (1979), the former might essentially be based on direct perception and the detection of veridical information specifying the environment. The latter implies schematizing, memory, and imagination, and is a fundamentally reconstructive process that cognitive psychologists have traditionally attempted to account for. The challenge is to reconcile these two processes, not to consider them as mutually exclusive and theoretically incompatible as Gibsonian or information processing people too often argue. Neisser's major effort of the past 20 years has been to face this challenge, and the observation of young infants validated this effort.

The relation between direct perception and representation, how they differ, interact, and eventually contribute to the acquisition of knowledge is not only an adult cognition problem. It is also a fundamental issue of cognition in infancy.

From birth, infants are both sophisticated perceiver–actors and future-oriented probers of their environment. They suck effectively and are quick to detect the suckability of objects they contact orally (e.g., Rochat, 1983, 1987). On the other hand, they act in relation to goals, anticipating oral contacts that bring to completion coordinated actions (e.g., Blass et al., 1989; Butterworth & Hopkins, 1988; Rochat et al., 1988). If there is direct perception in the neonates, it does not account for the control of all behavior at birth. Newborns already show signs of prospection and anticipation, their behavior organized toward goals that apparently bypass the immediacy of direct perception and its tight coupling to action.

By the second month, the codevelopment of perception, action, and representation becomes increasingly evident as infants start to manifest interests beyond their own bodily sphere and in particular toward objects and people. When they engage in socially elicited smiling, for example, they do not appear to do so merely in a direct (immediate) fashion but rather in reference to a meaningful reading of the person's emotional expression and what should happen next in their social exchanges. Similar expectations are expressed by 2-month-olds in the context of learning novel perceptual consequences of their own actions on physical objects.

If the research examples I used to describe the behavior of infants 2 months and younger might still leave some room for an interpretation in terms of direct perception and affordance detection, the examples of behavior by 3- to 4-month-olds are unambiguously linked to the infants' ability to prolong perception via the power of their imagination.

In conclusion, direct perception and representation are facts of the mental life of babies, as they are part of our adult life. The apparent co-existence and codevelopment of these two processes from birth underscores the importance of understanding how they relate and complement each other. This understanding is at the core of Neisser's project and the observation of young infants demonstrates how essential this project is.

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Chapter 2

Obstacles to Understanding: An Ecological Approach to Infant Problem Solving

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THE PROBLEM OF MOBILITY

This chapter focuses on a very basic and practical kind of problem solving—safely navigating the ground ahead. The problem of mobility is manifold. From their first crawling or walking steps, infants must find their way amidst myriad threats to balance control. The ground is covered with a variety of surfaces—slippery linoleum, deformable playpen mattresses, sloping driveways, and household stairs. Paths are cluttered with furniture, toys, and other obstacles. Interesting places to visit lurk around the corner or behind a door. All the while, infants' own bodies and skills are continually changing. Infants' top-heavy proportions gradually slim down, and the ratio of muscle mass to fat increases. Infants' proficiency at locomotion changes from week to week as babies master belly crawling, progress to hands and knees, cruise sideways along furniture, and finally walk upright.

Solving the problem of mobility in a real world environment is a continual decision process. Figuring out where to go and how to get there requires coordination of skills across a number of psychological domains and time scales: coping with the sheer biomechanics of moving the limbs in a gravitational field, contending with different ground surfaces and their effects on balance control, gathering perceptual information about the ground ahead and about infants' own propensities, searching out alternative means to traverse a surface or reach a location, and so on.