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EXPLORATORY BEHAVIOR IN THE DEVELOPMENT OF PERCEIVING, ACTING, AND THE ACQUIRING OF KNOWLEDGE*

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TRADITIONS IN THE STUDY OF CHILDREN'S EXPLORATORY BEHAVIOR

Interest in exploratory behavior, especially when such behavior is manifest as play, curiosity, or reactions to strangeness, is nothing new in psychology. Its role in the development of young mammals was recognized by the early

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behavioral biologists inspired by Darwin, such as Romanes; by the baby biographers a little later; and by pioneer psychologists such as G. Stanley Hall. It has been studied in primates, including human infants, intensively (e.g. Welker 1961). In Piaget's *Origins of Intelligence in Children* (1937; transl. 1952), it emerged as a mechanism of primary theoretical importance in accounting for a child's development. It took several decades for Piaget's theory of cognitive development to penetrate the thinking of American developmental psychologists, but as the shift away from behaviorist theories took place, new concepts relevant to exploratory activity were introduced. With each wave of conceptual change, newly oriented studies of exploratory behavior appeared. A brief mention of some of these changes will establish their significance in the rapid progress of developmental psychology in recent years.

One of the first concepts to be attacked and revised was the notion of motivation as a homeostatic process tied firmly to organic needs and drives, and linked to reinforcement in explaining behavior change. White (1959) in a much-cited paper urged that "competence" provided a natural motive in young children—a need to learn about the environment and how to deal with it. The notion was not revolutionary, since it was highly reminiscent of Woodworth's functional approach and his emphasis on a direct perceptual motive—an organism needs to "see clearly, to hear distinctly" so as to cope adequately with its environment (Woodworth 1947, 1958). But the climate of the times was finally right for reintroduction of such a motive. "Intrinsic" motivation was coming into its own. Berlyne (1966) proposed two types of exploration, one "specific" and one "diversive," motivated not by hunger or thirst or the like, but by something more like a need to know. These concepts were followed up with a large number of experiments by Berlyne and others, and led to further notions to be linked to exploration, such as "novelty" (e.g. Hutt 1970).

In the 1970s the literature of early childhood was enriched by large-scale studies of exploratory manipulation of objects (e.g. McCall 1974; Fenson et al 1976). The relevant concept that inspired these studies was cognition, as the study of cognitive development emerged with the new focus on cognitive psychology. Emphasis was placed on a change toward the end of the first year of a child's life from relatively random action on objects, to cognitively directed "functional" activities, such as drinking from a toy cup or talking into a toy telephone instead of banging them on somelhing. McCall suggested that early exploration was "largely an investigation of the raw sensory-perceptual feedback of the objects" (1974, p. 77), which changed progressively toward greater cognitive control and imaginative play with the object. Fenson et al (1976) similarly stressed emergence of new "cognitive capacities" following nonspecific manipulation:

> Although 9-month-olds generally showed the ability to relate to objects and 7-month-olds did not, at both ages play was nonrelational and nonaccommodative and was characterized by close visual and tactual inspection of individual objects, usually accompanied by mouthing and chewing and the application of more or less indiscriminate motor schemes (shaking, banging, turning the object over and over, and shifting it from hand to hand). . . . The emergence of relational acts in the latter part of the first year and the emergence of symbolic acts in the first half of the second year dramatically change the structure of the child's play, mirroring the development of important new cognitive capacities (pp. 234 ff).

It is interesting to read that the play mirrors the development of new cognitive capacities, rather than that the manipulative play has a key role in cognitive development, as Piaget would have suggested.

A quite different concept, the idea of "attachment" bonds belween an infant and a carelaker, led to a different line of research on exploration. Researchers studied not manipulation but the child's exploration of the larger environment as its capacity for self-initiated locomotion matured. Rheingold and her colleagues (Rheingold & Eckerman 1969; Ross 1974; Ross et al 1972) were the pioneers in this work. What happens to the child's intellectual growth when his physical growth enables him to enlarge his scope of observation on his own? The question is now being readdressed, and I return to it below. Rheingold thought of familiarity and novelty (as well as relationships with its mother) as having an important role in the child's ventures into new territory (Rheingold & Eckerman 1970; Rheingold 1985). Her research did not lead her to overstress the role of attachment and dependence on maternal help; she was impressed by the strength of the infant's urge to explore new territory on its own initiative. All this had to do with learning about the world.

Few psychologists were writing about action in the 1970s, but Jerome Bruner devoted a series of papers to the topic and made the development of skilled action in infancy the subject of a number of studies (Bruner 1968, 1973). Exploratory activities played a prominent role for him in understanding action, and so did intentionality (Kalnins & Bruner 1973). Bruner studied the "attainment of competence." "In the growth of such competence in infants, three themes are central—intention, feedback, and the patterns of action that mediate between them" (Bruner 1973, p. 1). Bruner's description of an infant's actions in capturing an object differed from earlier descriptions of reaching and grasping because he emphasized the intentional, unified character of the action. Bruner quoted Bernstein's model (Bernstein 1967) for programming an action, one that emphasizes neither reflexes nor random responses but "future requirements." [I return to this point below in considering the experiments of von Hofsten (1983).] Exploratory activity, even at a very early age, is controlled by some anticipation of an outcome, presumably an adaptive one. Bruner thought one of the principal steps in the development of any skill was an objectivized representation, or image ["a constructed space that is independent of action" (Bruner 1968, p. 47)]. But anticipation must have been there earlier, too, in some form. Indeed, in concluding a series of lectures on achievement of skilled actions, Bruner said that

> cognition—the achievement, retention, and storage of information—is inherent or immanent in the functional enterprises of organisms. . . . So, when we study the changing responses of the three-week-old infant to changes in the pay-off for sucking, we are studying not just sucking but the infant's mode of coping cognitively with a changing environment (1968, p. 68).

Bruner's emphasis on function, and on actions as systems, gave a new character to the study of even such simple exploratory behaviors as reaching for things. This emphasis exists in stronger form at the present time in work such as Thelen's on development of locomotion (Thelen 1984, 1987). Reaching and locomotion are not necessarily exploratory activities, but they must be regarded as prominent in the service of exploring the world and its furnishings, as I argue below.

THE CONCEPT OF AFFORDANCE AND EXPLORATION

Why, in view of this rich background of theory and research, should we turn again to the topic of exploration? Is there anything new to be said theoretically, or is there a new body of facts to be related? As Jane Austen made Mary Crawford say in *Mansfield Park,* "Every generation has its improvements." The years since 1975 have garnered a vast harvest of research in infant cognition and development, and a significant new concept has arisen. It is thus time to look at exploratory activity again, and to link it to *perceptual* development, to development of *action* (motor skill, if anyone prefers that term), and to *cognitive* development, all three.

The relevant concept is the notion of affordance, introduced by J. J. Gibson (1966, 1979). *Affordance* links perception to action, as it links a creature to its environment. It links both to cognition, because it relates to meaning. Meaning is in the world, as much as in the mind, because meaning involves the appropriateness of an organism's actions to its surroundings. The concept of affordance implies a special approach to psychology, particularly to perception—the ecological approach (J. J. Gibson 1979). An animal, human or otherwise, has evolved and lives in an environment and occupies an ecological niche that it is uniquely specialized for and with which it maintains reciprocal relations. Gibson emphasized the mutuality of animal and environment, as he did also the mutuality of perceiving and acting. The environment affords animals such necessities for existence as terrain, shetters, tools, and other animals. We perceive affordances of the ground to be walked on, of the cup to be drunk from, of the noises, fumes, and onrush of a truck in our path to be avoided.

> The *affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes,* either for good or ill. The verb to *afford* is found in the dictionary, but the noun

> *affordance* is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment (Gibson 1979, p. 127).

Elsewhere I have discussed the term further, with developmental applications (E. J. Gibson 1982). Here I want to link this notion to the development of exploratory activities. When and how do we come to perceive affordances of surfaces, things, places, and events? As a developmental psychologist, I want to know how a child comes to perceive the world so as to keep in touch with the things and events in his environment that afford actions like going places and making use of the objects and people that serve his needs. Perception guides his actions (I take that as given); it tells him what to do, where to go, and how to go where he wants to go. After a decade of research and thought on this problem, I have come to some (to me) rather obvious conclusions. First, nature has not endowed the infant with the ability to perceive these things immediately; babies spend nearly all of their first year finding out a lot about the affordances of the world around them. (Of course, we keep on finding out ever after, though not quite so assiduously.) Second, learning about affordances entails exploratory activities. I develop this idea more fully below and then trace the development of exploratory behavior in the light of recent research.

Implications for Perception, Action, and Cognition

The point of view of this essay is functional, in the old sense, but also in a modern sense that incorporates systems theory. I assume that both information about the environment and action occur over time in a sequence related by some common factor. A sequence of acts termed exploratory will have some outcome and will not be random. It will have a perceptual aspect, a motor aspect, and a knowledge-gathering aspect.

Why is exploratory behavior implicit in perception, in fact an essential part of it? The old view of perception was that "input" from stimuli fell upon the retina, creating a meaningless image composed of unrelated elements. Static and momentary, this image had to be added to, interpreted in the light of past experiences, associated with other images, etc. Such a view of perception dies hard, but die it must. There is no shutter on the retina, no such thing as a static image. Furthermore, perceiving is active, a process of *obtaining* information about the world (J. J. Gibson 1966). We don't simply see, we look. The visual system is a motor system as well as a sensory one. When we seek information in an optic array, the head turns, the eyes turn to fixate, the lens accommodates to focus, and spectacles may be applied and even adjusted by head position for far or near looking. This is a point long emphasized by functional psychologists such as Dewey (1896) and Woodworth (1958). It was developed in detail by Gibson—e.g. in his experiments on active touch

(1962). These adjustments of the perceptual system are often, especially in early life, exploratory in nature because the young creature is discovering optimal means of adjustment. But they may be exploratory even in a skilled observer, because they are used to seek information. We live in interaction with a world of happenings, places, and objects. We can know it only through perceptual systems equiped to pick up information in an array of energy, such as the optical array. Furthermore, time is required for the adjustment of the perceptual system, for the monitoring of the information being acquired, and for the scanning required by most perceptual systems to pick up information (perceiving an object by touching, for example, or locating a sound source through hearing). Information, accordingly, is picked up over time. Thus if a stable world is to be discovered, there must be temporal invariants of some kind that make constancy of perception possible. I take for granted that perceptual acts extend over time. Perceiving and acting go on in a cycle, each leading to the other.

Perception occurs over time and is active. Action participates in perception. Active adjustments in the sensory systems are essential. But action itself may be informative, too. Information about things and events exists in ambient arrays of energy. Actions have consequences that turn up new information about the environment. They also provide information about the actor—about where he is, where he is going, what he is doing. All actions have this property; but it is useful to distinguish *executive* action from action that is *information-gathering*. We tend to think of some perceptual systems and the activities that go on within them as primarily information-gathering. The visual and auditory systems, in particular, seem to have little or no executive function. (There are exceptions. The eyes, for example, are used socially in an executive fashion to signal approbation, displeasure, surprise and so on). Some systems, on the other hand, have on the surface a primary executive function, such as the haptic systems of the mouth and of the hand. The mouth is used for tasting and testing for substantial properties as well as for sucking, eating, and speaking. The hand is used for examining textures, substantial properties of objects, shape, and location, as well as for holding, carrying, and lifting. Because executive functions like lifting can be informative, the distinction between exploratory and executive actions has sometimes been questioned. But it is a useful distinction for a developmental approach. The possibilities of executive action are minimal in very young infants, but research in recent years has made it clear that exploratory activities are available and are used in functional ways even in the newborn.

Executive actions, such as reaching, grasping, and locomotion have their own role in perceptual and cognitive development because they change the affordances of things and places, providing new occasions for information-gathering and for acquiring knowledge about what Tolman referred to as the "causal texture" of the environment (Tolman & Brunswik 1935). Cognition, I suggest, rests on a foundation of knowledge acquired as a result of early exploration of events, people, and things. As the baby's perceptual systems develop, exploratory activities are used to greater and greater advantage to discover the affordances that are pertinent to each phase of development. As new action systems mature, new affordances open up and new "experiments on the world" can be undertaken, with consequences to be observed.

The active obtaining of information that results from the spontaneous actions of the infant is a kind of learning. To say that learning occurs only when actions are repeatedly "reinforced" is to blind ourselves to the most important kind of learning that underlies our accumulation of knowledge about the world and ourselves. Spontaneous self-initiated actions have consequences, and observation of these is supremely educational. Affordances of things generally have to be learned, with the aid of the perceptual systems and exploratory behavior. External reinforcement plays a small role, if any. Intellectual development is built on information-gathering, and this is what young creatures (not only human ones) are predestined to do. They have structures, action patterns, and perceptual systems that are either ready to start doing this at birth or grow into it in a highly adaptive sequence during the first year (in human infants). These activities continue as play through the preschool years and as deliberate learning in later life, but the serious role they fill is most obvious as they are coming into being. Cognition begins as spontaneous exploratory activity in infancy. Piaget said this long ago. But now research puts a new face on the story.

THE COURSE OF EXPLORATORY DEVELOPMENT: AN OVERALL PERSPECTIVE

A baby is provided by nature with some very helpful equipment to start its long course of learning about and interacting with the world. A baby is provided with an urge to use its perceptual systems to explore the world; and it is impelled to direct attention outward toward events, objects and their properties, and the layout of the environment. A baby is also provided with a few ready-to-go exploratory systems, but these change and develop as sensory processes mature and as new action systems emerge. There is an order in this development that has interesting implications for cognitive growth. As new actions become possible, new affordances are brought about; both the information available and the mechanisms for detecting it increase.

Exploratory development during the first year of life occurs as a sequence of phases that build the infant's knowledge of the permanent features of the world, of the predictable relations between events, and of its own capacities for acting on objects and intervening in events. The three phases that I am about to suggest are not stages, in a Piagetian sense. They overlap, change is not "across the board," and absolute timing varies tremendously from one infant to another. They depend heavily in at least one case on growth in anatomical structure. Nevertheless, an order is apparent that gives direction to development and makes clear how perceptual and action systems cooperate in their development to promote cognitive growth.

The first phase extends from birth through about four months. During this phase the neonate focuses attention on events in the immediate visual surround, within the layout commanded by its limited range of moving gaze. Sensory capacities and exploratory motor abilities are geared to this task, and some serendipitous possibilities for preliminary learning about features of the grosser layout exist. Visual attention to objects is minimal, but discovery of some basic properties of objects is made possible by visual attention to motion and by the active haptic system of mouthing. Sounds accompanying events are attended to. It is most impressive that these early exploratory systems, rudimentary as they seem, appear well coordinated.

The second phase, beginning around the fifth month, is a phase of attention to objects. Development of the manual exploratory system makes reaching and grasping possible. By the same time visual acuity has increased, and stereoscopic information for depth is available. Objects, though presented in a static array, can be explored and their affordances and distinctive features learned.

The third phase, beginning around the eighth or ninth month, expands attention to the larger layout, which can only be explored as the baby becomes ambulatory. Spontaneous, self-initiated locomotion makes possible discovery of properties of the extended environment around corners, behind obstacles, and behind oneself. Affordances of places for hiding, escaping, and playing are open for investigation. Watching a two-year-old on a playground is a relevation of attention to affordances of things like swings, ladders, bridges, and ropes.

After the first year, other phases might be identified—e.g. exploring devices that have complicated affordances like mirrors, and tools that must be carried to other objects as well as manipulated. Research is still scanty in this area. There is also the whole domain of speech development, in which exploratory activity plays an extensive role during the first year (see chapters by Stark, and by Oller in Yeni-Komshian et al 1980). This domain I reluctantly leave to the experts.

Phase 1: Neonates Explore Events

Very young infants attend preferentially to visually presented movement (e.g. an object moving across the field of view, or a flickering light) Static objects or scenes generally arouse little interest. An infant's visual acuity for static two-dimensional displays is poor for the first several months and increases only gradually during the first year (Banks & Salapatek 1983). This handicap was long thought to incapacitate the young infant almost to the point of blindness and prevent it from learning much about the world. We know now that this is by no means the case; not only are other perceptual systems functioning, but the baby picks up information from motion in the optical array as it regards events taking place before it, such as a caretaker approaching, or things receding, disappearing behind other things, and reappearing as the baby is carried or wheeled about. I describe briefly what kinds of exploratory activity are possible over the first few months and then consider three basic questions about the meaning and value of this activity. First, is the neonate's activity externally directed; is it really exploring the world? Second, is this activity in any way controlled by the infant, or is it compulsory reflexive response to stimulation? And third, are there any cognitive consequences of the activity? Is a rudimentary foundation of knowledge being acquired, or is the baby merely exercising its receptor organs as it awaits maturation of cognitive competence? If it is acquiring knowledge, knowledge about what?

What can infants before the fifth month do by way of exploratory action? From birth, infants can scan the layout visually by moving the head and eyes, albeit relatively unskillfully. Studies of scanning movements of the eyes in newborns suggest that they are preprogrammed to "search" and are spontaneously active, rather than stimulated reflexly (Haith 1980). The evidence has been presented in detail elsewhere (Banks & Salapatek 1983; Gibson & Spelke 1983; Haith 1980). The eyes are sufficiently coordinated to maintain a gaze on a moving target, and on a static one when the baby is being moved itself (Owen & Lee 1986). Neonates are most likely to look at a moving object and are able to track it. Although visual pursuit and head movements are jerky at first, the movements of head and eyes are aimed and coordinated (Tronick & Clanton 1971). The neonate's visual field when the head is still and the eyes fixate a stationary display is limited peripherally, both vertically and horizontally (only 15–20° to either side of the line of regard), and is limited as to the distance of the target. However, the field is wider and the distance can be greater for a moving object of regard (Tronick 1972), and the head moves to keep the object in view (Bullinger 1977). Tronick concluded, after extensive research on looking patterns in infants 2–10 weeks old,

> The infant's effective visual field is directly related to the nature of events available for registration. Motion is a more effective producer of attention—more easily registered in the peripheral field, more compelling in the focal field. Initially, the field is quite small, but motion is already more effective in either the periphery or the center of the field. With increasing age, the areal limits increase, but only in relation to the stimulus conditions (Tronick 1972, p. 375).

Visual "capture" of a moving object improves during early infancy (Burnham & Dickinson 1981) and is affected by various conditions, such as the speed of the target. Very likely it is also affected by other aspects of events, such as accompanying sounds.

Events can usually be heard as well as seen, and the baby's exploratory head and eye movements may be elicited by such sounds as a human voice. The head turns toward a sound source, and the eyes open (Butterworth & Castillo 1976; Field et al 1980; Alegria & Noirot 1978). The looking and listening systems appear coordinated from the start and unite in attending to the same event. Further evidence for coordinated auditory-visual exploration comes from research using a looking-preference method. Spelke (1976) found that four-month-old infants presented with two filmed events placed side by side looked preferentially at the one matching a sound track, although the sound source was midway between the two. There is some evidence that infants in the second month look preferentially at the face of a person simultaneously articulating an appropriate speech sound (Kuhl & Meltzoff 1982) given a choice of two faces.

In addition to the eye-head exploratory system, neonates have a haptic exploratory system. The mouth is a versatile organ, used for tasting, sucking, vocalizing, and examining the textures and substantial properties of things placed in it. Rochat (1983) demonstrated that infants explore with this system soon after birth. He observed sucking and exploratory responses to an intra-oral stimulus in one-, two-, and three-month-old infants, and described the perceptual activity of the mouth and tongue as "a distinct pattern of oral behavior corresponding to movements and scannings of tongue and lips relative to the intra-oral stimulus" (p. 124). At one month, infants distinguished differences in the texture or substance of a nipple, but not in its shape. At three months, infants distinguished nipples that varied in global shape. Rochat concluded that there was a "distinctly perceptual function of the mouth, inherent in the exploratory response." This activity is not reflexive, since it is modulated in character and varies in response to context.

Like visual and auditory exploration, oral exploration is probably precoordinated with other systems to some extent. A study of hand-to-mouth activity in newborns (Butterworth et al 1985) showed that spontaneous arm movements consist in a direct motion of the hand to the mouth about 15% of the time; the mouth is held wide open from the start of the movement, apparently in anticipation of the hand. It might be thought that the mouth and the hand, because they are both haptic exploratory organs, have a similar function and substitute for one another. This is not the case at an early age, however. The hand only achieves exploratory skill at around five months, and it is used for transferring objects to the mouth for examination until the end of the first year. Rochat & Gibson (1985) compared discrimination of two substances (one hard, one soft) by neonates (newborns and babies two and three months old) when the object was placed in the mouth and when it was placed in the hand. The substances appeared to be discriminated in both cases, but the patterns of exploration were different. The hand squeezed the hard object more often; the mouth pressed harder on the soft one.

The visual system may be able to obtain some of the same information as the oral exploratory system in another form of precoordination. Meltzoff & Borton (1979) reported evidence that infants of 29 days could visually discriminate objects previously explored orally when the objects differed in shape and texture. This study has proved hard to replicate, perhaps because stationary visually presented shapes are poorly attended to by infants of this age. However, Gibson & Walker (1984) found that infants of one month, given a hard or a soft substance to explore orally, and subsequently given a visual preference test with two objects moving either in a pattern characteristic of rigid objects or in one characteristic of flexible, squeezy objects, prefered the novel substance. Type of motion produced by exerting pressure on different substances is both visually and haptically perceptible. Information for the different affordances may be represented amodally.

It seems likely that oral exploration of gustatory stimuli occurs in neonates, since there is evidence for some taste discrimination (e.g. preference for sweetened fluids); but the activity itself has been little studied. It was found in our laboratory (Andrea Messina 1985; unpublished manuscript) that infants of three months presented orally with a small plastic cylinder dipped in fruit juice tend actively to lick the cylinder. Habituation may be demonstrated using this spontaneous activity, and dishabituation may occur to a novel compound.

IS EXPLORATION EXTERNALLY DIRECTED? Now, consider the first of my three questions. Are these systems externally directed in early infancy? Or, as Piaget held, are young infants egocentric, not differentiating themselves from external, objective things and happenings? Can any factual argument be made that neonates can explore the world?

Evidence from the visual system alone supports such an argument. Infants from eight weeks up (perhaps earlier) have been found to track an object visually only when it moves relative to a background. If the background moves along with the object, tracking is disrupted (Harris et al 1974). The object is evidently seen as located in, and moving with respect to, a spatial layout. The baby is not just responding to motion as such (see also Owen & Lee 1986). Action of a limb in coordination with the tracking or fixation is even more convincing evidence that the event is placed in the external environment. The ability to reach for and grasp an object, in the sense of an executive action, does not mature until about the fifth month. But experiments have been reported which assert that neonates may extend an arm and even a hand toward a stationary object, occasionally managing to touch it, as if attempting to grasp the object. A picture of the same object did not elicit similar reaching. (Bower 1972; Bower et al 1979). Attempts to replicate these experiments did not find evidence of reaching or grasping at the object, nor evidence of reaching more toward object than picture, although the infants expressed interest through visual exploration (Dodwell et al 1976, 1979). But as early as 15 weeks, infants reach to nearer targets more often than farther ones, and look significantly longer at an object than at a picture of it (Field 1976). More recently, arm extensions and grasping by young infants during the presentation of *moving* target objects have extended these results. Von Hofsten & Lindhagen (1979) found, surprisingly, that by the time infants had mastered reaching for stationary objects, they also reached successfully for moving ones and caught them at a speed of 30 cm/sec. These infants were about 18 weeks of age. Von Hofsten later studied arm extensions of infants during the very first week of life in response to a moving object (von Hofsten 1982). While these infants certainly did not catch the moving object, meticulous analysis of the spatiotemporal characteristics of the infants' arm extensions as they followed the object with their eyes gave evidence of aim at the object. Von Hofsten concluded that this was an attentional, orienting response rather than an attempt to grasp, but that the coordinated action was unmistakably externally directed.

The coordination of two perceptual systems in response to the same external event is particularly convincing evidence of externally directed attention. It has often been argued that detection of an external event that creates a disturbance in the optic array and results in retinal stimulation is only evidence of sensitivity to proximal stimulation of the receptor and does not necessarily indicate perception of the distal source, the event in the world. But when two systems, such as the auditory and the visual system, cooperate in eliciting exploratory activity, with two different receptor mechanisms involved, such an argument does not apply. The two systems are both locating the event somewhere in the world, uniting in detecting its affordance. The same argument applies for visual-haptic coordination. Oral haptic exploration of an object followed by visual exploration that results in detection of the same property of the object, such as rigidity of substance, indicates perception of an external, objective property of the object, since the perception is not modality (i.e. receptor) specific. There is evidence for such recognition at one month of age.

The ultimate argument for perception of events as external distal happenings in the world is appropriate, adaptive response to them in the face of changing context. This brief survey of exploratory activity in neonates can be supplemented by evidence from a number of studies of response to an approaching object on a collision course. Bower et al (1971) and Ball & Tronick (1971) found that very young infants (2 months or less) responded defensively to an approaching object that filled the optic array with an accelerating expansion pattern. This response (head retraction, raising of hands, etc) did not occur for an expansion pattern on a "miss" course. Yonas (1981) has summarized the developmental course of this defensive behavior. It increases over several months in differentiation and organization, but it occurs in a primitive form soon after birth, providing an example of perception of the affordance of an external event at a very early age.

ARE INFANTS' EXPLORATORY RESPONSES REFLEXIVE OR CONTROLLED? The S-R psychologists in the first half of this century generally viewed activity of the neonate as composed of reflexes, compulsory responses to stimuli. Although Piaget would not willingly have allied himself with their view, he nevertheless felt that activity began with reflexes and that controlled spontaneous exploration developed only later as intentional activity. My view in this essay differs; early exploratory activities are immature and unskilled, but they do appear to be spontaneous and directed. They may be controlled appropriately very early by contextual factors.

Methods for studying perception in infants only began to bear fruit when experimenters realized that they could use natural exploratory activity to tell them whether the infants were or were not capable of extracting information from events presented to them. Two behaviors—turning the head and eyes to look, and exploratory mouthing—were found to be appropriate and useful indicators of perceptual competence (or lack of it). Looking responses have been used as indicators with preference paradigms (Fantz 1961), habituation paradigms (Horowitz 1974), and contingent-learning paradigms in which infants learned to turn their heads appropriately to look at an interesting display (Papoušek 1967; Siqueland & Lipsitt 1966). Sucking has also been used in contingent-learning paradigms in which infants learned to suck at high amplitudes to elicit an interesting visual or vocal event (Siqueland & DeLucia 1969; Eimas et al 1971). Innumerable ingenious variations of these paradigms have resulted in our present rich accumulation of data on infant perception. All these paradigms have been used successfully well before infants are capable of grasping and handling objects, and they demonstrate neonatal control of exploratory activity.

A few examples suffice to demonstrate control.[1] Siqueland & DeLucia

[1]Many other examples of early establishment of control of exploratory behavior could be given. For example, a spontaneous action system, kicking, can play a role in directed exploratory behavior. A ten-week-old infant learns in a few moments to double or triple the amplitude of kicks in order to view a mobile over its head in motion (Rovee & Rovee 1969).

(1969) performed experiments with infants from three weeks to one year of age in which high-amplitude nonnutritive sucking resulted in appearance of a projected slide of a cartoon figure, geometric pattern, or human face. Four-month-old infants quickly learned to suck at criterion rates to look at the slides, and reduced the rate when slides were withdrawn. After an extinction phase (no slides), the rate rose again at once on reintroduction of slides. Similar experiments with visual consequences ensuing upon control of sucking rate demonstrated "motivated exploratory behavior with infants as young as 3 weeks of age" (Siqueland & DeLucia 1969, p. 1146).

Very young infants not only want to look at interesting events, they like to see them as clearly as possible. They detect an out-of-focus presentation and show a preference for one in focus (Atkinson et al 1977). Kalnins & Bruner (1973) showed that infants would even act spontaneously to control clarity of a visual scene presented to them. They showed infants aged 5–12 weeks a color film whose clarity of focus was made contingent on sucking rate. When the baby sucked for a clear focus, the rate increased very fast and remained high as long as focus was maintained. When sucking resulted in a blur, no such increase occurred. When the condition was reversed, sucking rate dropped. The authors concluded:

> What is striking about the adaptation we have observed is its swiftness in establishment and its equally great swiftness in being transformed when conditions change. In all the above respects it seems reasonable to suppose that, just as the sensory-perceptual and sensory-motor capacities of the very young infant have been seriously underestimated because of failure to use the correct behavioural repertory for measurement, so too, and for the same reason, has the voluntarily-controlled problem-solving activity of the infant been similarly underestimated (p. 313).

The actions observed in these experiments do not savor of anything reflex or random, but rather show modulation due to observation of the consequences of exploratory activity of the kind that we expect of intentionally controlled behavior. This quality of the activity reminds us of control of attention in adults. As adults we can select what we choose to attend to. Can an infant explore the environment with sufficient competence to ignore one visually presented event and observe another selected one when the events are literally superimposed on one another, as adults are able to do (Neisser & Becklen 1975)? The question was explicitly addressed in an experiment by Bahrick et al (1981) with four-month-old infants. An intermodal preference paradigm (Spelke 1976) was used. Two films of interesting events were presented superimposed, while one soundtrack was played to influence the selective attention to one of them. If the baby could attend primarily to one film, ignoring the other, it should have become more familiar with that event. Following the superimposed presentation, the two films were presented side by side, in silence. If the baby looked preferentially now at the film that had been unaccompanied by sound, it might be inferred that it was selecting a novel event to look at. This was the case. Bahrick et al concluded that four-month-old infants can selectively attend to one complex visual event while ignoring another superimposed upon it, a remarkable example of controlled exploratory activity.

CONSEQUENCES FOR COGNITION What does this motivation and ability to observe external events buy the neonate in terms of acquiring knowledge about the world? Does he perceive anything that gives him knowledge of objects and the spatial layout of things? What can his limited exploratory skill and relative dependence on movement in the visual surround permit him to discover for founding a knowledge base? Despite poor visual acuity for stationary displays, little if any functional use of binocular disparity, and inability to handle objects and bring them close in front of the eyes, sensitivity to motion in the optic array provides a surprising amount of useful information for an actively exploring perceiver. Retinal disparity does not provide the only information about depth and about where things are in relation to the perceiver and to one another. Kinetic information is useful, and young infants do use it before they can use either stereoscopic or so-called pictorial cues for the solidity and distance of things (Yonas & Granrud 1984). As an infant moves his head or as things move around in the area accessible to his gaze, motion parallax provides optical information about depth. As one thing goes behind another, accretion and deletion at edges provide information about which item is behind the other. This information is used to determine that one surface is in front of another by infants at five months, according to a study using preferential reaching as a response indicator (Granrud et al 1984). Using the habituation method, younger infants (three months) were shown to discriminate one form from another on the basis of kinetic information (Kaufmann-Hayoz et al 1986). The form's outline was delineated by motion through a field of random dots, producing accretion and deletion of texture at contours. Habituated infants were shown to transfer recognition of the form's outline to a static black and white drawing of it by remaining habituated, and by dishabituating to the drawing of a different form. Thus kinetic information serves to reveal structure by way of contours at three months. Common motion of dots in the form's contours could also contribute to perceived unity of the figure. When a static-to-moving order of habituation was compared, no recognition was found. At this age, static forms are less likely to be attended to and perceived as a whole; perception of them may even depend on preceding detection by means of kinetic information.

Can infants use information provided by motion to detect three-dimensional solid form at this age? Kellman (1984) demonstrated that at 16 weeks they can. His subjects were habituated to a videotaped three-dimensional object rotating successively on two axes of rotation in depth, thus giving rise to a sequence of optical projective transformations. After habituation, they were tested with the same object rotating around a third, new axis, and with an object of a different shape. The infants generalized habituation to the same object, showing that they recognized it even in different transformations; but they dishabituated to the new one. By contrast, infants who were shown stationary views of the object taken from the same transformation sequences did not generalize to the new transformations of the same object, showing the importance of kinetic information.

Can infants obtain the same information by moving their gaze themselves so as to achieve kinetic optical information in the case of spontaneous visual exploration? Kellman & Short (1986) in a later experiment moved the infant in an arc around a static target object. The axes were alternated as before by changing the attachment of the object to the axis on which it was mounted. As before, when motion perspective was available in the optical transformations, the object's shape was recognized and discriminated from another, but not when only static views of successive transformations were available. Furthermore, the infants' looking times did not differ in the moving and static conditions, strong evidence that they perceived the object as stationary and themselves as moving. A third point to note from these experiments is that the infants were exhibiting object constancy, since they recognized the object as the same despite presentation of varied transformations. It is possible, though not so likely, that shape constancy may be perceived under static conditions at this age, but it surely is when optical motion is involved in presentations.

A question that has been little addressed in research on perceptual development is that of how perceived unity of objects comes about. There seems little doubt that infants perceived as units the objects presented under conditions of optical motion in the experiments just described, since there was generalization of habituation to new presentations that varied in the specific retinal image projected. What are the conditions for perceived unity? Kellman & Spelke (1983; Kellman et al 1986) investigated this question by presenting infants with partly occluded objects and testing whether the objects were perceived as whole and unitary by observing generalization of habituation to a complete, unoccluded object in contrast to the object broken so as to present a gap between the two parts that were visible during occlusion. In one condition of habituation, the object moved behind its occluder, translating either laterally, vertically, or in depth, but in another it did not. Infants of four months perceived the occluded object as a connected unit when it moved behind the occluder, but not when it remained static. Common motion of parts thus serves as information for unity of objects, and separates them perceptually from surrounding objects. It will be noted that the condition of common motion was present and may have played a role in the experiments on perception of the shape of moving figures and objects described above.

These points are underlined and extended in an elegant experiment by Kellman et al (1987) performed with four-month-old subjects. Another question is addressed as well. Kellman et al asked whether the infant could distinguish between its own motion and motion of an object in the layout, making use of their method of investigating perception of object unity. It is a fact described by J. J. Gibson forty years ago (Gibson 1947) that movement of an observer results in optical motion of a deforming character (e.g. expansion or contraction) over the total optical array, while motion of an object in the layout results in a local displacement relative to its background. An adult easily distinguishes the two, even when both occur together. The disturbance of the whole array specifies motion of the self, while the local displacement specifies motion of an object within the layout, relative to its background. Kellman et al placed the infant in a seat that moved in an arc around a partially occluded facing object, a stick. When the stick was moved to and fro behind the partially occluding screen, the baby could be moved conjugately. Would the baby perceive itself as moving separately from the stick, or would it perceive egocentrically, detecting only one movement to and fro? The babies did indeed differentiate self from object motion, since they perceived the object as a unit when it moved, whether they themselves were moved conjugately or not, and perceived it as broken when it did not move, again whether they were moving or not. They also looked longer at a moving stick, whether or not they themselves were in motion. This competence has important implications. Infants at 16 weeks show position constancy as regards the layout of things around them (that is, ability to locate themselves in relation to it), and perceive real object motion during self-movement. They use the motion of the object, at the same time, to establish the unity of a partly occluded object.

The kind of optical motion elicited by self-movement is generally referred to as "optical flow." It has great usefulness for guiding movement through an environmental layout because it can at the same time specify where things are as an observer moves and provide information about the observer himself (Gibson 1979). There is only scanty research to date on the development of the ability to use such information. Deliberate exploratory use of body movement that produces optical flow has not been studied in infants, although they have been informally observed to use appropriate head and torso motions to "see around" things in, for example, peekaboo games (E. J. Gibson 1969). A recent line of research has established that optic flow from head and body movements is used to monitor and maintain postural equilibrium by infants just beginning to walk (Lee & Aronson 1974; Stoffregen et al 1987) and even by considerably younger ones (Butterworth & Hicks 1977). Butterworth & Pope (1982) observed such an effect at two months. This use of optic flow is automatic, rather than exploratory, but it is another indication of competence in the perceptual use of optical motion at a very early age.

Another cognitive consequence of the neonate's competence in perceiving events involving movement is the opportunity for detecting sequential, potentially causal relations between events—what follows what, as Tolman would have put it (Tolman & Brunswik 1935). Causal relations between events, both self-perpetrated and entirely objective, are an important basis of knowledge about happenings in the world, and provide the foundation for discovering order and regularity. Piaget (1954) argued that the young infant's "feeling of efficacy" of his own actions was the beginning of causal perception. Certainly the earliest convincing evidence relevant to causal understanding lies in the neonate's quick detection of the consequences of his own actions when an outcome is made contingent on them, as described in the Siqueland & DeLucia (1969) and the Kalnins & Bruner (1973) studies. The infant perceives the relation of *affordance* between his own actions and the outcome. Habituation experiments using looking behavior frequently allow the infant subject to set its own criterion for trial length, a method referred to as "infant control" (Horowitz 1974); this procedure works as early as three months. The infant presumably learns to time its exploratory activities so as to control exposure of the displays offered by the experimenter.

What about observing order in the world in totally objective events? If two structurally and temporally related events are presented to an infant observer with sufficient repetition, will a potentially causal relationship be detected? This question is necessarily moot, since the implications of the word "causal" are fraught with philosophical ambiguities. However, a few experimenters have tried presenting infants with displays of a mechanical event similar to the spatiotemporal impact events used by Michotte (1963) to demonstrate direct perception of causality in adults (launching, entraining, etc). In Michotte's experiments, the event presented involved spatial contact of one moving object with another and transmission of force (momentum) from one to the other. A causal event maintained an invariant relation through conservation of momentum—as one object gained velocity, the other lost it. An infringement of this invariant relation achieved by some trick of the experimenter should be perceived as noncausal, while the original event should be perceived as causal. In any case, a violation of the invariant relation should be detected if causal relations can be perceived. An experiment by Leslie (1982) illustrates an application of this idea in an experiment with 13–38-week-old infants. Infants in one group were habituated to a filmed display of a red brick moving toward, colliding with, and launching a green brick (causal event). In another group, the subjects were habituated to a film of the red brick striking the green one, which then moved off only after a short delay (noncausal event). Following habituation, half the subjects were presented with a film in which the red brick collided with the green one, which remained stationary. The other half were presented with a film in which the green brick moved away from the red one, without any impact. All the films except the first were noncausal, showing either no exchange of momentum or a violation of conservation of momentum. Presumably the group that had first habituated to a direct-launching film should dishabituate to the others, if causal relations were detected, whereas the other (noncausal) habituation group should not. The highest level of dishabituation occurred when the direct-launching film was followed by the film in which the green brick moved away from the red without any impact (red brick didn't move). It is difficult to draw conclusions about perception of causality from this complex experiment. Leslie concluded that the infants distinguished a spatiotemporally continuous movement from a temporally discontinuous one. Leslie's experiments have since been extended to a more natural scene of a hand moving toward a doll to pick it up, with varied spatiotemporal conditions (Leslie 1984).

It is perhaps unreasonable to expect that a very young infant could perceive an objective causal relation directly, without experience. More likely, one learns the rule of conservation of momentum through observation of events involving two objects in a dynamic relation of transmission of energy. It has become fashionable to suppose that human beings, even as infants, are endowed by way of an evolutionary program with prior implicit knowledge of some natural laws of dynamics. However that may be, the neonate's natural tendency to engage in active visual exploration of events presents a magnificent opportunity to detect dynamic relations between moving objects in the environment. The information is available, and as the infant becomes able to differentiate the structure of a complex event he may perceive the affordances for dynamic change within it (E. J. Gibson 1984). Perceiving affordances for action precedes understanding of objective causal relations and possibly plays a role in it. Affordances begin to be perceived early, whereas the ability to distinguish causal relations from other types of events is a long-time cognitive development that has its foundation in early exploratory activity.

Phase 2: Attention to Affordances and Distinctive Features of Objects

Beginning around four to five months, the exploratory activities of infants take on a new aspect, one that appears revolutionary to observant parents and caretakers. An elaborate system for examining objects comes into its own. The appearance of revolutionary change is not deceptive, but that is not to say that there is no continuity of development. The new exploratory system depends on maturation of a number of contributing factors, each with its own time course when considered separately, but they come together at this point to make possible the discovery of a whole new set of affordances.[2] The

[2]This way of viewing the emergence of a radical new achievement is discussed in detail by Thelen (1987).

coordination of the various factors involved and the spontaneity and determination of the action greatly increase the apparent intentionality of an infant's behavior from this time. What are the parts that arrive at this conjunction? The major components are increasing capabilities of the visual system, and development of muscular components involved in reaching, grasping, and fingering. Visual acuity and motor components of tracking and fixating have improved greatly by two months of age (Banks & Salapatek 1983) and by four months are quite competent for visual exploration; at four months or thereabouts, stereopsis is generally mature, and retinal disparity can provide precise information for depth at close hand. At around three months, reaching out toward an object shows signs of readiness, but grasping takes longer and independent fingering longer still. The period between four and five months sees these components getting organized into a superb exploratory strategy that includes oral exploration (already quite competent) as well as visual and manual activity. Objects can be seized and brought before the eyes for close-up visual examination and to the mouth for proficient haptic search. This is the time when babies become interested in objects and reach for them, eager to examine them. The infant is no longer dependent on motion to provide information in an optic array, nor on actions of others to bring things close enough for oral exploration. As the hands become active and controllable, a whole new set of affordances is opened up for the baby's discovery; things can be displaced, banged, shaken, squeezed, and thrown—actions that have informative consequences about an object's properties.

There have been numerous studies of exploratory manipulation of objects during this period—classic older studies and more recent ones that emphasize the kind of information that can be obtained, and the coordination of modal information. Kopp (1974) summarized work of her own and earlier work on exploratory activities around eight months as follows:

> There is no question that manipulative activities do have attentional and informative value for infants. It has also been suggested that modulated motor behaviors free the organism to focus attention on the object of interest, with consequent additional information input. Nevertheless, it is obvious that a considerable amount of learning and information-processing does go on during infancy, mainly through use of the eyes (p. 635).

This observation foreshadows some questions that underlie much of the recent work on development of exploratory activities between five and nine months. Few studies question whether the baby's activities and perception are externally oriented in this period; very recent research confirms that they are (Keating et al 1986). No one questions whether they are intentional. It seems obvious that they are. The questions debated center on (*a*) what is the relation between various modal systems, or types of information, especially visual and haptic; (*b*) what is it that the baby is learning; and (*c*) whether exploratory activity in this period predicts future cognitive development. I do not summarize studies of detailed development of motor skill during this period, although skill obviously increases. Instead I consider these questions.

INTERMODAL ASPECTS OF EXPLORATORY ACTIVITY Some of the questions about intermodal relations are old ones. When do babies make use of sounds in search behavior (Uzgiris & Benson 1980; Freedman et al 1969)? Does touch teach vision, or does vision dominate everything else? Are modal systems "integrated" to build, finally, a coordinated schema (Piaget 1954)? Today the questions seem to be asked in a less general style and with more emphasis on defining the information, control of behavior, and cognitive outcome.

Intermodal exploration is not new to this period of growth, as we noted in surveying exploratory behavior in the earlier period; but with increasing skill and new coordinations available, it may be different. A number of studies have confirmed earlier findings that novel objects motivate exploration (e.g. Willats 1983; Ruff 1984), but will the recognition of novelty persist over a shift in the mode of the pick-up system? There was some evidence that it did in one-month-old infants (e.g. Gibson & Walker 1984), but availability of multiple systems may bring about specialization of modes of exploration as experience with them is gained. Studies have reported intermodal transfer in four- to five-month-old infants (Streri & Pêcheux 1986b; Streri & Spelke, in press). Streri & Pêcheux showed that five-month-old infants were capable of intra-modal tactual discrimination of shape by manual exploration (1986a) and then went on to examine cross-modal recognition of the object explored (1986b). They found evidence of generalization of habituation from visual exploration to manual, but not vice versa. Five months is about as early as active manual exploration can be expected in infants, and it is obviously far from its peak of skill at that time. It is noteworthy that Streri & Pêcheux (1986a) found that tactual habituation required much more time than visual (about three times as long), possibly because infants at this age may simply hold the object some of the time without actively exploring it. Even a month of experience with manual exploration may bring greater skill and change results, since other experimenters have found transfer from touch to vision at six months (Ruff & Kohler 1978; Rose et al 1981). The fact of transfer from vision to touch but not vice versa at five months suggests that skill in pick-up of information in one mode may facilitate the process in a less-developed mode, analogous to visual discrimination of a stationary form following observation of a dynamic, moving presentation of the same form in younger infants (Kaufmann-Hayoz et al 1986).

A developmental process of another kind may be at work here, as well. As infants acquire skill in manipulating an object, and bring it before the eyes for visual examination of its properties, opportunities occur for differentiating unique experiential qualities that arise via haptic versus visual exploration. Infants at about six months do not always show consistent novelty preferences in cross-modal experiments where touch precedes vision. There are modality-specific attributes of objects, such as color, and these specificities may begin to be differentiated about this time. Walker-Andrews & Gibson (1986) described experiments with 1-, 6-, and 12-month-old subjects that tend to support this suggestion. The 1-month-old infants were familiarized with a substance (rigid or deformable) orally and were then given a visual preference test with two objects that differed in type of motion presented, one moving rigidly, the other deforming. The infants looked reliably more often to the one exhibiting the novel type of movement. Twelve-month-old infants were given either a rigid or deformable substance for manual exploration, followed by a visual preference test presented pictorially (a movie of two objects moving appropriately). These older infants looked reliably more often at the familiarized type of motion, not the novel one. Infants of six months, with real objects to look at, tended to show a novelty preference, but not all did. Infants of 12 months, with a real object to look at, showed a shift toward a familiarity preference, though not as pronounced as when the presentation was pictured. It appeared that the older infants detected modality-specific properties that made the haptic and visual experiences different, but also recognized the similar affordance that both haptic and visual information specified and were concerned with *congruence* as well as novelty.[3]

The influence of modality-specific properties on exploratory activity and resulting novelty or familiarity preferences was the subject of research by Bushnell et al (1985). Earlier studies investigating the concordance of visual and tactual exploration produced conflicting results, but a study by Steele & Pederson (1977) suggested an explanation. Presented with a novel object following familiarization, an infant's exploratory activities, visual or tactual, may be guided by the type of new information introduced. If the new object differs from the old one in only one property, and that one modality-specific (e.g. color), an infant old enough to differentiate modal properties might be expected to apply only the most appropriate exploratory system. Bushnell et al investigated the differential sensitivity of six-month-old infants to modality-specific properties (color and temperature) combined in a single object, a plastic vial containing warm or cool water, covered with either red or blue paper. The infants were familiarized with a single vial, which they could examine both visually and haptically, and then given two test trials, one

[3]"Duality" of perception, detection of both similarity and differences, occurs in a somewhat analogous situation with three-dimensional objects and two-dimensional representations of them in six-month-old infants (Rose 1977; 1986).

familiar and one novel. The novel trial was a vial differing in only one respect, either color or temperature, from the familiarized vial. When temperature was the property changed, there was a significant increase in both touching and looking; but when color was changed, there was no increase in either type of exploratory behavior. These infants had at six months a coordinated pattern of looking and touching that was applied when a novel "tactual" property was introduced, so visual and haptic attentive processes were not differentiated in this respect. The coordinated exploratory pattern is just at its peak, and the little vials afford handling, which in this case was accompanied by looking as well. The curious fact that a color change elicited no fresh burst of exploration is not totally unexpected. Color receptivity is mature well before six months, but color does not appear to be an important factor in defining affordances of objects at this stage and was not differentiated as specifying anything important. Indeed, when one considers the action repertory of a six-month-old, what could color signify? Finding and securing something warm to the touch is a different matter. This does not mean that visual information is not important—optical specification of substance, shape, and where something is located certainly is important. Perception is selective at six months, but not in purely sensory respects; exploratory activity is geared to affordances of objects.

There is evidence that exploration is refined and differentiated with respect to object properties during the period from 6 to 12 months. Ruff (1984) performed experiments on 6-, 9-, and 12-month-old infants, studying their manipulative exploration of objects varying in shape, texture, and color, and making detailed observations of specific behaviors during visual and haptic examination (e.g. looking at an object while rotating it) and mouthing (e.g. taking an object out of the mouth and turning it or looking at it before mouthing it again). The general method was to allow the infants to become familiarized with an object and then present them with one differing in a single property. There were age differences, such as a decrease in mouthing and an increase in fingering between 6 and 12 months, and the influence of specific object characteristics was particularly apparent. For example, more fingering (rubbing fingers over the object) occurred when texture changed. Mouthing and transferring from hand to hand were prominent with shape change. The older infants dramatically increased the amount of rotation for a shape change, thus enhancing the opportunity to observe new object features both visually and haptically. In short, the infants appeared to maximize opportunities for picking up information about a specific change, varying their actions for different object properties. There was no suggestion that one method of exploration or one sensory system had priority, but rather that differentiation of exploratory methods was developing in relation to distinctive properties of objects.

The question about differentiation of specific (including modality-specific) properties can be asked with respect to affordances. Does an infant learn to differentiate affordances of objects as this period of active manipulation goes on? Some objects afford banging (especially if they are rigid, make a sharp impact on a rigid surface, and create a noise), some are squeezable because they are elastic and yielding, changing shape when pressed. Gibson & Walker (1984) noted the appropriate occurrence of such differential exploratory activity in 12-month-old infants presented with rigid or elastic objects in the dark. Palmer (1985) asked this question in a program of research with infants 6, 9, and 12 months of age. The babies were presented (in the light) with objects differing in texture, size, and other properties that afforded varied actions or had different consequences (e.g. a bell with and without a clapper). There was indication of exploration, both visual and haptic, relevant for acquiring knowledge of and exploiting appropriate uses of the objects (but not necessarily imitative of adult uses). The specificity of actions relevant to properties of objects increased during the 6- to 12-month interval. The evidence suggested that as manual exploration becomes more expert, it becomes less redundant with visual exploration of an object, the two exploratory systems being used to supplement one another with respect to modality-specific properties.

Along with maximization of actions suited to object properties, motor skills of manipulation increase—for example, skill in using two hands in parallel for manipulation (Willats 1985) and skill in catching moving objects (von Hofsten 1983; von Hofsten & Lindhagen 1979). Von Hofsten showed that infants were capable of catching a moving object as soon as they could reach and grasp a stationary object, and that their reaches correctly predicted the velocity of the distal object. But motor skills improved, enabling capture of faster-moving objects along with more economical movements of the catcher. Affordances depend both on information available to the perceiver and on the developmental status of the perceiver's action system.

WHAT IS LEARNED? COGNITIVE CONSEQUENCES What is the infant learning during this period of object exploration about the things in the world around it? I have already suggested that active exploration of objects, leading to observable consequences and more specialized exploratory activities, has important results for learning about what an object affords, what can be done with it, its functional possibilities and uses. It also provides the optimal conditions for learning about distinctive features of objects—what figural features make them unique and how they resemble or do not resemble other objects. Such knowledge is the basis, potentially, for classifying things. I once thought (E. J. Gibson 1969) that learning the distinctive features of sets of objects (like faces) and pictured things (like letters) was the principal means of perceptual learning. I would now put this notion in a perspective that includes active exploration and observation of consequences leading to detection of affordances. Functional properties may be recognized by acquaintance with an object's distinctive features. Simply learning about identities of things is important, too. Recognition of things as the same when they are re-presented, as having a certain identity and uniqueness, is cognitively extremely economical. Abstractions about the dimensional properties by which objects differ (e.g. size, color, and weight) become apparent as the process of differentiating and identifying objects goes on, a useful kind of knowledge in its own right. In short, the cognitive consequences of this phase of intensive exploration of the objects at hand are enormous. The process of learning to identify objects, learning what can be done with them, and learning how categories of objects that share affordances can be formed furnishes the world with meaningful things.

All this knowledge is about things, however. Does learning about objects and their properties have any cognitive consequences for the understanding of events and causal relations? I think it may. As Leslie (1982) pointed out in studies of detection of causal relations by young infants, perceiving that one object propels another or "launches" it implies perceiving two movement components as distinguishable. Events may be perceived very early as dynamic changes over time, but much then remains to be learned—i.e. how to differentiate the structure of events and the roles of objects within them. Perceiving the role of an object implies detection of a potential affordance by means of active exploration. Discovering the uses of tools is a case in point. Using even a simple tool is at a minimum a two-step event—an action that serves as a means to a further step of reaching something desirable, perhaps. Piaget's observations of his own children included many such cases.

A recent study by Willats (1985), in the Piagetian tradition, investigated learning to pull on a piece of fabric underneath an object in order to bring the object within reach. The fabric supporting the object can be thought of as a simple tool, to be used as a means to a desired end. Willats presented babies at six, seven, and eight months with a toy placed on a reachable cloth, the toy either 30 or 60 cm distant. At six months, few infants showed evidence of intentional use of the supporting cloth by pulling on it, although they often retrieved the toy in the nearer position as a result of playing with the cloth in an exploratory fashion. By eight months, nearly all the infants rapidly retrieved the toy in both conditions with a single pull, or with rapidly executed short ones. The infants (the same ones, observed longitudinally) had learned the affordance of the cloth as a tool, and thereby gained knowledge about the function of supports in potential events.

ASSESSMENT AND EVALUATIVE USES OF EXPLORATORY ACTIVITY It is often reported by people who work with a retarded population that these individuals lack normal exploratory motives and do not spontaneously seek out new information as we expect normal children to do. Attempts to teach them the uses of unfamiliar objects seem more successful when routines resembling classical conditioning or repetition with application of external rewards are adopted. One can surmise that, in evolutionary terms, exploratory activity insures cognitive development. This observation has led to research comparing exploratory activities in normally developing infants and infants at risk (e.g. preterms) or infants with delayed development linked to genetic or other defects.

Studies of preterm infants tend to find a negative relationship between premature birth and exploratory activity, but only when qualified by the degree of risk involved. Ruff et al (1984) compared 30 preterms, aged nine months, with 20 nine-month-old full-term infants. The preterm infants were divided into high- and low-risk groups on the basis of respiration at birth, neurological patterns, and neurobehavioral assessment. The low-risk group resembled the full-term infants in patterns of exploratory activity. The high-risk group differed from both the other groups, engaging in less handling of objects and less fingering, rotation, and transferral of objects from hand to hand. A summary exploration score correlated very significantly with measures of cognitive functioning at 24 months. It is possible, as Ruff et al (1984) speculate, that the less infants learn by active exploration of object properties, the less they will engage in categorization of objects, which in turn could lead to retardation of language development.

A study by MacTurk et al (1985) compared infants with Down Syndrome (mean age 9.2 months) with nondelayed infants (mean age 6 months) on tasks involving manipulation of complex commercial toys. They reported that the nondelayed sample displayed a significantly greater number of exploratory and social behaviors, while the Down Syndrome infants looked at the toys more frequently without manipulation. The nondelayed infants exhibited more persistence in achieving some outcome afforded by the toy, such as securing a small object from a hole or behind a barrier, or producing sounds from the object. Nevertheless, both groups exhibited persistent, goal-directed behaviors. Behavior of the Down group appeared to be organized around looking, while social behavior apparently played a greater role for the nondelayed group.

A study by Loveland (1987) provides a detailed analysis of exploritory activity in older Down Syndrome children (mental age 16–32 months) in a task exploiting discovery of the affordances of a mirror. This process requires perceptual learning that takes place in the course of exploration, and eventually results in knowledge such as rules governing what to do to locate objects reflected in the mirror. Exploration must eventually involve more sophisticated strategies than the manipulatory activities characteristic of infants in the second half of their first year. Nevertheless, Loveland's results parallel those from studies of exploration in younger children. The exploratory activities engaged in when searching for a toy reflected in the mirror do not differ spectacularly between the Down sample and a nondelayed comparison group, but strategies of exploration are different. When presented with the reflection of their mother or a toy in the mirror, the nondelayed children looked back and forth comparing the person or toy with the image significantly more often than the Down Syndrome children. Exploratory patterns characteristic of object manipulation occurred in both groups, but the mirror task is essentially one of spatial exploration and involves moving in the layout and observing changing relations in the mirror in relation to the self. This behavior is more closely related to Phase 3, ambulatory exploration (below), which begins only after exploration of objects has been going on for about four months.

Studies such as these appear to support the conclusion that exploratory activities have important cognitive consequences, expanding the child's knowledge of the world as his repertoire and competence in using exploratory strategies increase.

Phase 3: Ambulatory Exploration—Discovering the Layout

By nine months, an infant is highly competent in looking at, listening to, mouthing, touching, and manipulating objects—all active modes of discovering their properties. But what he can learn is severely limited by his dependence on caretakers to move him from place to place. He can explore his surroundings visually only to the degree that he can turn his head and trunk, although from being carried or wheeled about he may learn some of the consequences of changing position, such as what happens when one moves around a barrier. Nevertheless, a kind of cognitive revolution must result when an infant's horizons are expanded by the acquisition of self-initiated, self-controlled locomotion. A new field of knowledge is opened up and a whole new set of skills must be mastered. A new kind of activity that is both exploratory and performatory becomes available for learning about the larger world.

GUIDING LOCOMOTION A primary function of perception is the guidance of locomotion. For the crawler, who proceeds with his weight distributed on four limbs except during brief forward pushes, there are two major perceptual requirements: steering around obstacles and through apertures between objects that may clutter the layout, and detecting a safe surface of support for traversal.

Steering Must steering around obstacles and aiming for openings be learned from scratch when a baby makes her first trips crawling around the layout? Certainly not entirely. We know from a considerable body of research on the "looming" experiment that even pre-reaching infants show avoidance responses as objects approach them on a collision course (Bower et al 1971; Yonas 1981). They may retract their heads, raise their hands, and blink. The behavior does not occur if the object approaches on a "miss" course (Ball & Tronick 1971). The information for the event of imminent collision is a contour expanding in magnitude at an accelerated rate. The expanding flow pattern specifies an approaching obstacle, in the case of the looming experiment an object approaching the subject, as might a vehicle bearing down on a pedestrian. This expansion pattern is not produced by locomotion of the subject, but a similar flow pattern would be produced by locomotion at a constant rate toward an object in one's path. In the latter case, the advancing perceiver must stop, or shift direction toward an aperture or open space. It seems reasonable to suppose that there is transfer on the basis of the expanding flow pattern from early avoidance behavior to locomotion, but it is also likely that a certain amount of exploratory practice in changing course would be required before precision steering is attained. I know of no research on the question.

What about aiming for the gaps between things? An experiment by Carroll & Gibson (1981) with three-month-old infants contrasted the usual looming situation (a solid obstacle approaching) with a similar situation in which a contour identical with that of the obstacle surrounded an aperture. In the case of the obstacle, approach coincided with increasing occlusion of background, while in the case of the aperture, approach coincided with disocclusion, opening up a "vista" (J. J. Gibson 1979, p. 234). Avoidance responses occurred, as would be expected, to the obstacle, but not to approach of the aperture. Instead of retracting the head, babies tended to release head pressure as the aperture came near. Something more is involved in locomotion toward and through an aperture, however. Its size must be estimated. Is it big enough to get through? Is the gap wide enough for this particular body? Such a judgment requires knowing the width of one's own body, in relation to the aperture. This is an important affordance, which must be perceived in analogous situations by adults (e.g. is the ring big enough for the finger; is the opening big enough to get one's hand through?). It seems highly likely that exploratory activity would result in increased skill in this locomotor situation, but research on the problem is only beginning (Palmer 1987).

We know little about steering through a cluttered environment [but see J. J. Gibson (1979) for the rules guiding locomotion]. Aiming toward the center of the flow pattern during locomotion specifies direction of locomotion, and we know that even adults cannot walk in a straight line toward a straight-ahead goal for more than a few seconds with eyes closed. Small children can do this even less well (remember the game of "Pin the tail on the Donkey"?), so they may be even more dependent on optic flow patterns for aiming toward a goal. As yet, there is no research on acquiring the skill in the early stages of walking. Babies solve a detour problem when they must reach around a barrier to secure a toy before they can crawl around it for the same objective (Lockman 1984), so there is some domain specificity linked to putting a new action system to use, despite potential transfer from a familiar affordance. Exploratory trials with the new action system are bound to play a role in developing the new skill.

What the ground affords Besides keeping on the path to a destination and steering around obstacles and through openings, locomotion over a ground surface requires monitoring of the surface. Does the ground extend ahead, without bumps, drop-offs, or holes? Is it firm and rigid? How do infants engaging in their first solo trips find out what the surface affords for traversal? Earlier studies with the visual cliff (Gibson & Walk 1960) showed that most infants with the ability to crawl will avoid crossing over a simulated drop-off, even though a firm, rigid glass surface extends over it. Optical information specifies a drop-off, and the conflicting haptic evidence for a solid supporting surface is generally insufficient to tempt the infant to move out on it. But what of opaque surfaces that are unfamiliar? The problem has been investigated in a series of experiments with crawling and newly walking infants (Gibson et al 1987). The infants were presented with walkways stretching ahead of them. A baby was placed, seated, at one end of the walkway with the mother serving as the baby's destination at the other. The surface of the walkway could be changed so as to vary its properties. Rigidity of the surface was the major variable. Bipedal locomotion, as compared with crawling, imposes constraints on properties that underlie the affordance of a surface for traversal. The surface rigidity—its resistance to deformation—is such a property. It is potentially specified both optically and haptically, so both visual and haptic exploratory activity could be observed in infant subjects. A rigid surface (strong plywood) was compared with a waterbed, gently agitated. Both were covered with the same patterned fabric. Maintaining upright posture and walking was difficult on the waterbed, although crawling was perfectly feasible. The question was whether the infants capable of bipedal locomotion would explore the surface and detect the difference in affordances, as compared with those only capable of crawling.

Observations of exploratory behavior showed that the walking infants differentiated the two surfaces by longer periods of haptic and visual exploration. They also differentiated them by a longer delay of locomotion, more displacement and evasive activity, and by choosing to walk (rather than crawl) more often over the rigid surface than over the waterbed. The crawlers, however, did not differentiate the two surfaces, except by somewhat longer visual exploration. Infants at both stages of locomotor development did actively explore these surfaces and other unfamiliar surfaces presented in further experiments, but the walking infants also observed the consequences of their exploration in relation to the constraints imposed by bipedal locomotion.

Standing up and walking What are the constraints imposed by maintaining equilibrium when standing upright, and when moving forward with only one foot on the ground? How does perception facilitate this remarkable feat? Again information in flow patterns plays an essential role, activating compensatory movements that maintain stability. Experiments in a "moving room" subjected infants to optical flow simulating the flow pattern characteristic of falling forward or backward. Infants newly standing alone and even pre-locomotor infants use optical flow to maintain their posture (Lee & Aronson 1974; Butterworth & Hicks 1977). Recent research has shown that flow in the peripheral area of the optic array is critical for compensatory postural adjustment (Stoffregen et al 1987). The affordance of peripheral flow for maintaining stability appears to be differentiated from the affordance of central radial outflow for steering in adults and children over two years, but the differentiation may not be complete much before this time and may depend on exploratory locomotion and practice in walking.

Schmuckler and Gibson (Schmuckler 1987) have investigated the performances of novice and more experienced walkers both standing and walking to a destination where optical flow is imposed in a moving hallway. Subjects were two groups of infants under two years of age, with either a mean of three months experience or a mean of over five months experience walking. They walked to their mothers at the end of either an uncluttered hallway, requiring minimal steering, or a hallway in which two sets of obstacles had to be circumnavigated. Compensatory responses to imposed optical flow were significantly greater with both groups of infants in the case requiring steering. It would seem that a considerable period of exploratory locomotion is needed to perfect skills of upright walking in a cluttered environment such as generally characterizes even a newly walking infant's route in exploring an unfamiliar place.

WHAT IS AROUND THE CORNER This is the time when an infant turns its attention to the layout of the world that contains itself and other objects and provides the background for events. The furnishings of the layout, unless they are animate or vehicular, generally stay where they are, providing stable landmarks no matter what the small human's viewing point. A child may learn from being carried about that even though he is moved around, the room and what it contains are fixed. But he can learn it far better when he crawls around the chair, peeks out from one side or the other, and moves himself to obtain continuously changing perspectives. He can observe the layout and search 360 degrees around him, and he may become much more aware that the area in which he is moving extends behind him. Optical flow patterns are generated by one's own movements in the layout. These flow patterns provide a kind of interface between the self and the world, because they contain information that specifies both at the same time, permitting "coperception" of the self and the layout. Differentiation of oneself from the surrounding layout has occurred long before this, if it is not innate (Kellman et al 1987), but now multiple opportunities are available for perceiving that *I* am *here, you* are *there,* and *I* can *go* there, a kind of differentiation that underlies learning important cognitive and linguistic distinctions (Loveland 1984).

There is an exhaustive literature on so-called "perspective-taking," inspired by pioneer studies of Piaget and Inhelder. Earlier work assigned development of the ability to appreciate another person's point of view (that it was different from one's own and that what might be visible or occluded for that person was not the same as for oneself) to a rather late age, but as better ways of testing the activities and knowledge of younger children were found, the age was progressively lowered. McKenzie et al (1984) found that six- and eight-month-old infants could locate an anticipated event from a novel direction after rotation, and did not search always in a constant direction relative to themselves. The rotations were 30 or 60 degrees to the right or left of the child's original position. Butterworth & Cochran (1980) presented evidence that infants detected something about what someone else can see from changes of the other's gaze direction, and searched for the visual target; but up to 18 months exploratory scanning was often improperly directed when the other person looked behind the infant. Observing another person changing gaze direction, young infants will search for the target of the gaze peripherally, but generally not accurately behind themselves. The ability to act so as to take account of what someone else can see (for example, turning a picture so that someone else can see it although it is then occluded from oneself) is apparently perfected only after skilled locomotion has been attained. Locomotor exploration of the layout undoubtedly plays a role in this development.

COGNITIVE MAPPING Attaining different perspectives is a consequence of locomotion; as one moves continuously around the layout, one's point of observation is continuously changing, providing different views of a room or a scene. Exploratory locomotion is identifiable with such continuously changing perspectives, and thus forms the foundation for detecting what path leads where, what object or landmark is nearest what other, what wall or object occludes another and will shortly be occluded by one's own body or some barrier about to be passed. J. J. Gibson wrote many years ago that "knowing the possibilities of locomotion *outside* the limits of momentary vision, that is to say the *cognitive mapping of the extended environment,* can be explained in part by the recurrent, constant, or invariant properties of such stimulation [continuous change of points of observation] which are discovered during exploratory behavior" (Gibson 1958, p. 193). Research on acquisition of cognitive maps by toddlers bears on whether knowledge of places presently out of view depends on previous exploration of the territory.

Finding a once-seen-but-now-hidden target by advancing toward it along the shortest route has been used as a test of a cognitive map. What conditions must be satisfied to make this achievement possible? Rieser and his colleagues performed experiments on this question with toddlers and older children. The situation usually involved showing the subject a target from one point of observation and then moving the subject to a position from which the target was hidden. The subject was then required to move through the expermental space to the target, or to point to it. The task required a "spatial inference" for accurate response. Children of 18 months could do this by moving to a target in a simple layout (Rieser & Heiman 1982). Children of 24 months could point in the correct direction more often than chance when they had been walked through an experimental layout, even though there were no landmarks available (Rider & Rieser 1987). But the younger subjects made many errors. Exactly what kind of learning goes on when children are not given an opportunity for free ambulatory exploration is not clear. Most of the studies allowed their subjects no opportunity of this sort, and furthermore presented them with homogeneous featureless environments, such as a circular or perfectly square area with symmetrically placed doors or windows. The ability to make inferences in such situations (e.g. inferring the shortest route, or the direction of a concealed target) not surprisingly increases with age. The reason for this could be the dawning of a new cognitive faculty, but it could also be the need for spontaneous exploratory walks through real environments, observing the continuities of paths and the reversibility of vistas.

Few of us as grown-ups are competent at finding a building in a new neighborhood without preliminary exploration. Special devices like maps and street numbers can help us, but the problem for the toddler is a more immediate one. Menzel (1973) showed that chimpanzees develop a cognitive map of a well-known terrain and proceed to targets via economical routes, but in this study the terrain had previously been well travelled daily for months. Familiarity with an environment enhances even very young children's ability to locate a target (Acredolo 1979). Rider & Rieser (1987) found that their youngest subjects made errors in locating unseen targets because they "aimed their responses in the direction of the visibly open, most direct route to the target." That such behavior should precede inference about shortest routes, especially without previous free exploration, seems almost inevitable.

An experiment by Hazen (1982) examined directly the relationship between self-initiated exploration of a playhouse of three rooms and later competence to find a route through it by reversing a previously learned one or by selecting a detour to a goal. The subjects were children of 1.8–2.4 years, and children of 3.0–3.8 years. Half were given the opportunity to explore the playhouse rooms freely on their own before performing the route-finding tasks. Older children were better at performing the tasks, but the main finding was that active exploration of the playhouse was related to accurate knowledge of its spatial layout. Sheer quantity of exploration (passive and guided exploration included) was not associated with such knowledge; what mattered was the extent to which the children had explored on their own. Perhaps the active explorers were detecting landmarks, which have the affordance of indicating what path leads to another landmark and thus which way to go.

CARRYING: EMERGENCE OF A NEW AFFORDANCE The achievement of bipedal locomotion brings with it entirely new potential affordances to be learned by making possible a quite new activity—carrying things to a destination. Theories of the evolution of bipedal locomotion in man have sometimes proposed that the advantage of being able to carry food, young, materials for shelter, tools, etc greatly favored the emergence of walking on two legs. Observing the joy of a novice walker in carrying small objects around, often handing them to someone and then retrieving them to transport again, the possibility does not seem fanciful. Research has not yet been focussed directly on carrying things in young walkers, but a few suggestive observations have been reported. In experiments with the moving hallway, Schmuckler and Gibson (Schmuckler 1987) had young walkers move back and forth along the hallway carrying a colored golf ball (sometimes the young walker collected several to carry) to a parent at one end. The task consisted entirely in carrying the ball to the parent, handing it to them, and going back to the other end for another to carry in the same way. This simple "game" proved astonishingly motivating.

In research on exploring new territory where a number of toys could be found, Jones (1983) found that young walkers would leave their mothers to go off after toys. Rather than stopping to play with the toys, they frequently picked them up and carried them to the parent and then went after another, to follow the same routine. The pure motive of carrying something somewhere because a new affordance has emerged no doubt wears out fairly soon, but it seems to go through a self-motivating exploratory stage that permits a child to refine her perceptions of what she can carry—how large an object, what substances are feasible to transport, how heavy the burden can be, and so on. Anecdotal evidence abounds that toddlers sometimes attempt to carry a toy or a piece of furniture almost as large as themselves. Whether the stories are true or not, exploratory carrying is a sure way of learning about the affordance of "transportability" of objects and how much effort must be put into the act—once again a cognitive advantage that leads eventually to expertise.

Carrying is especially interesting to the developmental psychologist who wishes to relate detection of new affordances to developing cognition because it suggests a spiralling process, beginning with perception of the simplest affordances, such as separability and contactability, then moving on to chewability and graspability, then to reachability, to hideability, and eventually to all the refinements of transportability. With each new coil of the spiral, new properties of surfaces, objects, and events are perceived as consequences of exploratory activity, building an ever richer cognitive world. Detecting new affordances provides the means of differentiating the properties of things.

EXPLORATION IN THE SERVICE OF ACQUIRING KNOWLEDGE

The Grounding of Knowledge

In the final accounting, what is the significance of exploratory activity and its perceptual consequences? May it not be the essential ingredient for building a foundation of knowledge about the world? Or does intelligence emerge as a separate force that pulls action—even exploratory activity—along behind it? I have not discussed the latter idea at all, but the notion that intelligence develops and action somehow follows along has been fairly prevalent during the so-called "cognitive revolution." Beliefs about and representations of the world and the self presumably come first and actions follow after them. This notion is clearly opposed to the points I have been trying to make. Perhaps knowledge eventually becomes a system of representations and beliefs about the world (and oneself as an inhabitant of it), but it seems to me that representations and beliefs must be grounded by detection of the surfaces, events, and objects of the layout—the "stuff" of knowledge must somehow be obtained from the world. Furthermore, as living beings we act in the world and necessarily interact with the events and furnishings of the layout surrounding us. Our knowledge cannot consist of general abstract properties alone but must relate to the affordances for action that the world provides, not only in general beliefs but also in intimate everyday situations whose ever-changing circumstances demand great flexibility. I have been trying to show that the young organism, as it grows, has the capability to discover what the world affords and what to do about it. The foundations of the organism's knowledge evolve in an orderly fashion, with something new around the corner in each phase in a kind of spiralling evolution. What kind of knowledge could result, other than flexible means of interaction?

Predications About the World

The knowledge that results from learning affordances for action through exploratory activity and observation of its consequences is, in the beginning, probably entirely utilitarian. Meanings may be confined to situations where interactions are occurring and then can reoccur. It seems to me that this utilitarian, early, simple knowledge constitutes the beginning of ability to make predications about the world. For example, objects rest on a ground (but can be lifted from it, if they are the right size and substance). Ground is always underneath them. Some things are in front of other things. Things can be bumped into. Things can move in the surrounding layout. Some things make sounds. Some of these things are responsive (can eventually be categorized as animate). One can oneself control these responses by one's own actions (cooing, smiling). These are simple examples, but with expanding exploratory and action systems they may become much more elaborate as means available through grasping, manipulation, and later locomotion open up new possibilities of learning affordances.

Controlled manipulation accompanied by increasingly mature capabilities of visual observation provides a mechanism for differentiating affordances and qualitative properties of things and thus furnishes the material for categorizing, yielding more refined and more general predications. Locomotion with ensuing exploration of places and territories firms up incomplete knowledge and makes possible predications about the objectivity and permanence of the layout and the movability of oneself and others. Events, both external and self-perpetrated, present the opportunity for learning about consequences of movement, impact, and applying pressures, and thus provide the foundation for discovering causal relations.

I am not suggesting that predications of the kind I have illustrated have been formulated as anything like verbal propositions. Rather, knowledge has been attained that can function as a basis for further categorization and inference. Learning a vocabulary and a syntax for verbal representation of predications and events is an achievement that presupposes knowledge (something to talk about). It may well have rules of its own, but I doubt that these rules determine or even select what the infant first attends to and discovers about its early environment (cf Gelman 1986). I see little profit for the scientist in arguments about the mental representation of knowledge that cannot be talked about, but I think it must be conceded that such knowledge exists, even in adults, and certainly in the preverbal child.

Other questions—e.g. how knowledge is organized—are well worth asking and have a good chance of being answered. An important one has to do with the generalizability of knowledge, sometimes referred to as "domain specificity." After an infant has discovered an affordance pertaining to one action system, will it transfer appropriately across action systems? Is the affordance of a substance detected by mouthing detected as the same when the hands become active in exploring it? Is the differentiation of an aperture and an obstacle by a three-month-old in a looming situation generalized immediately to guiding locomotion by a crawler? I doubt that such transfer is automatic in early life, because new action systems bring new affordances, and some exploratory practice with them seems essential. But the role of practice would diminish as maturation winds down. Proliferation of tasks, however, increases as possibilities of action increase, bringing new opportunities for generalization. So do tasks proliferate with social expectations of caretakers, and these may engender a new kind of domain specificity as "training" by society begins. Still more affordances must be learned and the question of flexibility of generalization over domains can reappear on a new level.

Ontogenesis of Perceptually Based Knowledge

The course of development of perceptually based knowledge (knowledge based on exploratory perceptual systems) is an orderly one, as I have tried to show. As the phases of development evolve in the individual, with a focus in each phase, there is a progressive fanning out. New exploratory systems develop and new action systems emerge, making new tasks (e.g. carrying something somewhere) possible. Still, one sees evidence of earlier phases implying the later ones, as in the case of the aperture-obstacle distinction. The process does not look like disconnected shoots growing out in different directions, but rather like a spiralling course, an echoing of earlier abilities of affordance detection plus strengthened opportunities for discovering new meanings. Perhaps a system of meanings begins its evolution thus.

Differentiation is the key process in the kind of development I have been describing—differentiation of organs of both perception and action, and differentiation of perceived affordances. But the process is always related to the environment—its resources and its constraints. In the case of the looming experiment in the three-month-old, the information in the optical array, an expanding occluding contour increasing at an accelerated rate, has the affordance of imminent collision, calling for such avoidance behavior as the child can muster (head retraction, raising of hands). When a crawler's own locomotion produces an expansion pattern of an object in its path, the information has the affordance of potential imminent collision, but not in the same way, because the crawler can stop or detour. Furthermore, the information, while similar, is not the same. In the case of the approaching object, the expansion pattern characterizes only a part of the total array; but in the case of the infant's advance by way of its own locomotion, the expansion encompasses the total array. The cases call for differentiation, and yet they are closely related; the consequences of failing to perceive the affordance are the same because important environmental conditions are the same. The system that must be referred to for understanding the organization of perceived affordances is not the child's own organism alone, despite its manifold relations between perceptual and action systems, but an organism-environment system. Understanding behavioral and cognitive development requires consideration of both as reciprocal entities, a requirement for both the developing child and the psychologist.

Summing Up

If I did not make my theme clear in describing what I have called the three phases of exploration, I hope the last few paragraphs have enlightened the reader. My objective was a quite general one, allied with an ecological approach to biological science. The young organism grows up in the environment (both physical and social) in which his species evolved, one that imposes demands on his actions for his individual survival. To accommodate to his world, he must detect the information for these actions—that is, perceive the affordances it holds. How does the infant creature manage this accomplishment? Has evolution somehow provided him with representations of the world, and rules for how to act? I doubt this very much. But I think evolution has provided him with action systems and sensory systems that equip him to discover what the world is all about. He is "programmed" or motivated to use these systems, first by exploring the accessible surround, then acting on it, and (as spontaneous locomotion becomes possible) extending his explorations further. The exploratory systems emerge in an orderly way that permits an ever-spiralling path of discovery. The observations made possible via both exploratory and performatory actions provide the material for his knowledge of the world—a knowledge that does not cease expanding, whose end (if there is an end) is understanding. I like these lines from T. S. Eliot,

> We shall not cease from exploration
> And the end of all our exploring
> Will be to arrive where we started
> And know the place for the first time.
>
> *Four Quartets: Little Gidding*

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