3

Infants' knowledge of object motion and human action

ELIZABETH S. SPELKE, ANN PHILLIPS, AND AMANDA L. WOODWARD

OVERVIEW

What is the intuitive conception of a human being, and how is it related to the intuitive conception of an inanimate material object? Is the system of knowledge underlying common-sense reasoning about human action distinct from that underlying common-sense reasoning about the motion of an inanimate object? What aspects of intuitive psychological and physical conceptions are inevitable and universal across cultures, and what aspects are variable and subject to change?

Studies of early cognitive development provide one approach to these questions. A wealth of observations of infants' actions on objects and interactions with people suggest that young infants distinguish people from inanimate objects and are sensitive to differences between human action and inanimate object motion. In addition, experiments have shed some light on infants' knowledge of how inanimate objects move, and the methods developed have begun to be used to probe infants' knowledge of how people act. The findings of this research suggest that infants begin to reason about human action during the first year and that the knowledge underlying this reasoning differs, in some ways, from the knowledge underlying reasoning about inanimate object motion. Ultimately, we hope that these studies will shed light on mature systems of knowledge of people and objects by illuminating their foundations in early development.

We begin by reviewing the methods and findings of studies of infants' reasoning about inanimate object motion. Because human action appears to violate some of the constraints on inanimate objects, we next ask whether infants are sensitive to violations of constraints on objects by considering briefly how they reason about shadows. Finally, we turn to infants' reasoning about human action. First, we describe a study investigating whether infants understand that human action cannot be predicted solely

on the basis of mechanical considerations. We then turn to the literature on social interaction and communication in infancy as a source of suggestions concerning infants' positive knowledge of human action, and we present the methods and findings from our own initial research on this topic.

REASONING ABOUT INANIMATE OBJECT MOTION

Recent experiments provide evidence that infants reason about the behaviour of inanimate objects by drawing on knowledge of constraints on object motion. Infants' knowledge has been revealed through the work of a number of investigators (see particularly Chapters 4 and 5), whose methods are based on the finding that infants tend to look longer at novel or surprising events than at familiar and expected events (Bornstein 1985; Spelke 1985; Baillargeon 1993). In many scores of studies, infants have been presented with events that either accord with or violate different constraints on objects, and their looking times have been measured (Ball 1973; Baillargeon 1986; Leslie and Keeble 1987; Leslie 1991; Baillargeon *et al.* 1990; Spelke *et al.* 1992; Wynn 1992; Xu and Carey 1992; S. Carey, L. Klatt, and M. Schlaffer, unpublished manuscript). With only a few exceptions, the findings of these studies are in broad agreement concerning infants' physical knowledge. Young infants appear to reason about objects in accord with three principles, each encompassing two constraints on object motion.

Figure 3.1 summarizes these principles and constraints. According to the *principle of cohesion*, objects are connected and bounded bodies that maintain both their connectedness and their boundaries as they move freely. This principle encompasses the symmetrical constraints of 'cohesion' (moving objects, unlike sand piles, do not disperse) and 'boundedness' (moving objects, unlike drops of water, do not coalesce). Evidence that infants are sensitive to this principle comes from a number of experiments (von Hofsten and Spelke 1985; Kestenbaum *et al.* 1987; Spelke 1988; Spelke *et al.* 1989; S. Carey, L. Klatt and M. Schlaffer, unpublished manuscript). An experiment by Spelke *et al.* (1993) serves as an example.

This experiment focused on infants' looking times for the outcomes of visible events in which an object either moved as a whole or broke apart. Three-month-old infants were familiarized with an object standing on a surface and were then presented with two alternating test events in which a hand grasped and lifted the top of the object. In one event, the whole object rose into the air, consistent with the cohesion principle. In the other event, the top half of the object rose into the air while the bottom of the object remained on the table, in violation of the cohesion principle (Fig. 3.2). Looking times for the outcomes of these events were measured,

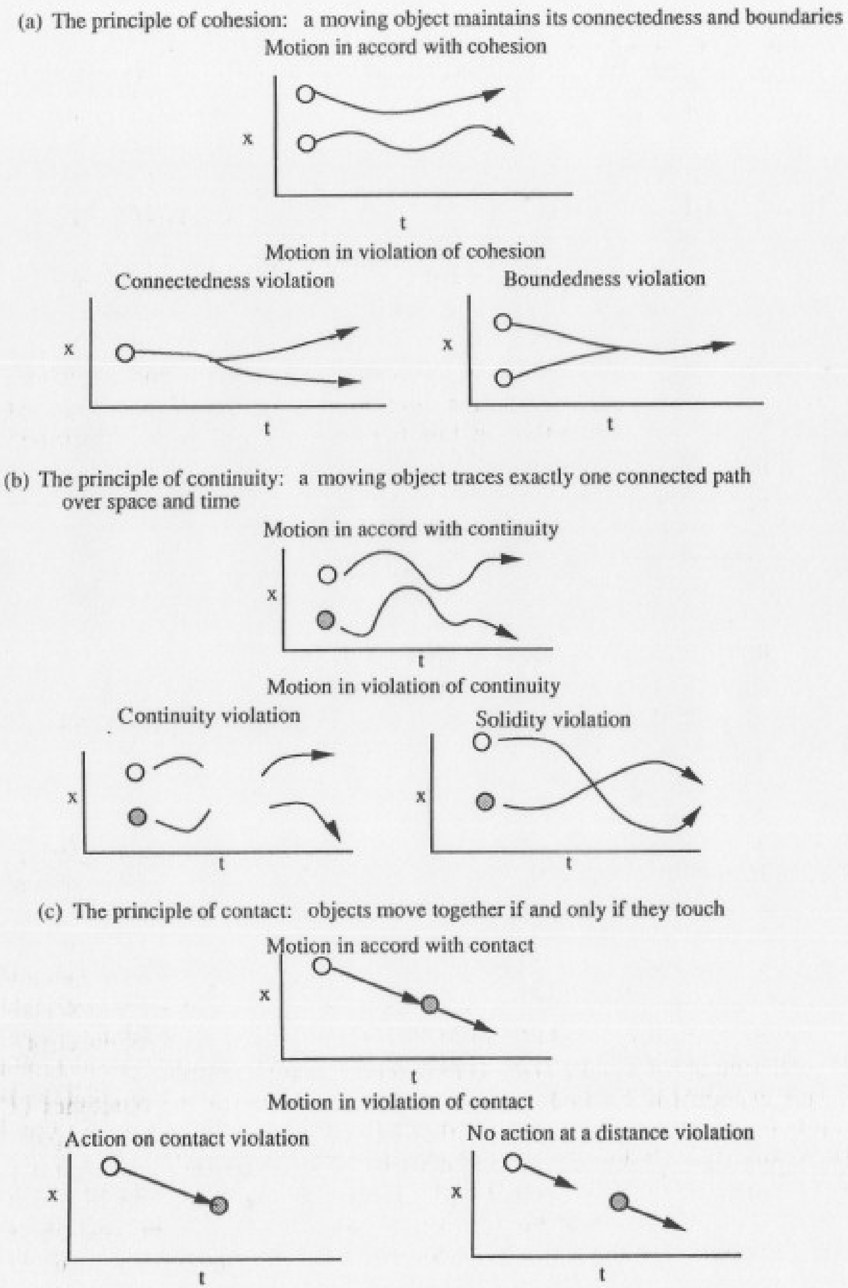

Fig. 3.1. Principles guiding infants' physical reasoning.

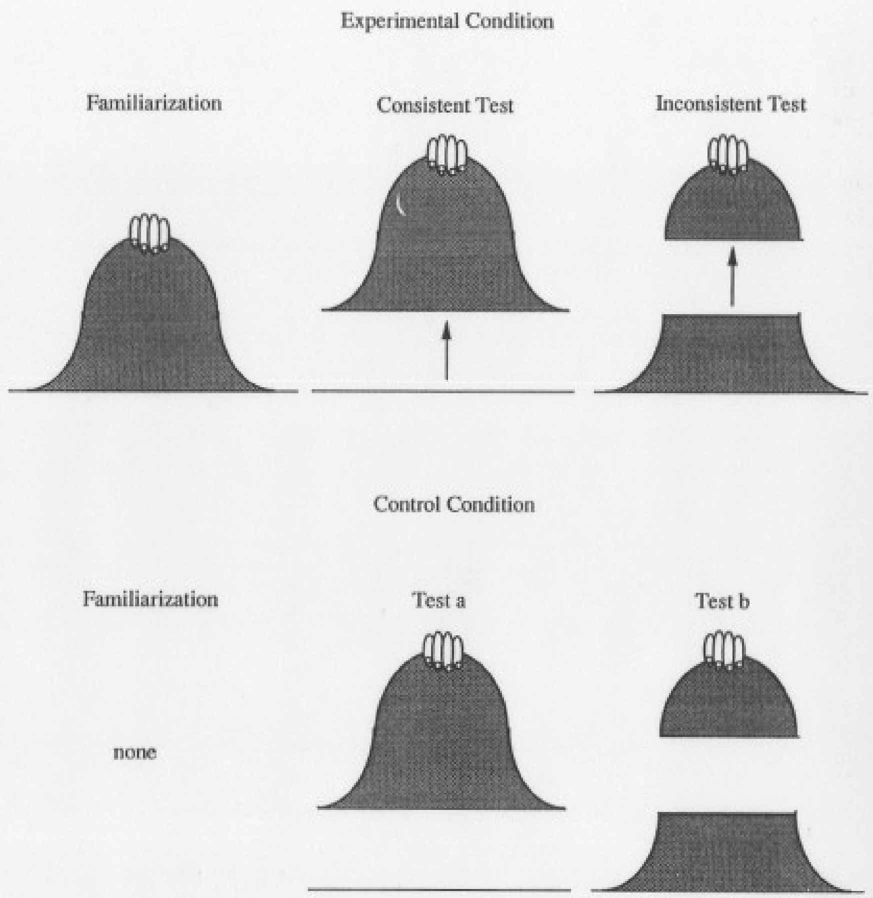

Fig. 3.2. Schematic depiction of the outcome displays for a study of infants' knowledge of the cohesion principle. Arrows indicate an object's previous path of motion. (After Spelke *et al.* 1993.)

beginning when all or part of the object came to rest in mid air and ending when the infant looked away from the display. These looking times were compared with each other and with the looking times of infants in a baseline condition, who were presented only with the static outcome displays. The infants in the experimental condition looked reliably longer at the inconsistent outcome display. This difference did not stem from an intrinsic preference for that display, because it was not shown by the infants in the baseline condition. Therefore the experiment provides evidence that young infants are sensitive to the cohesion principle.

The second principle guiding infants' physical reasoning is the *principle*

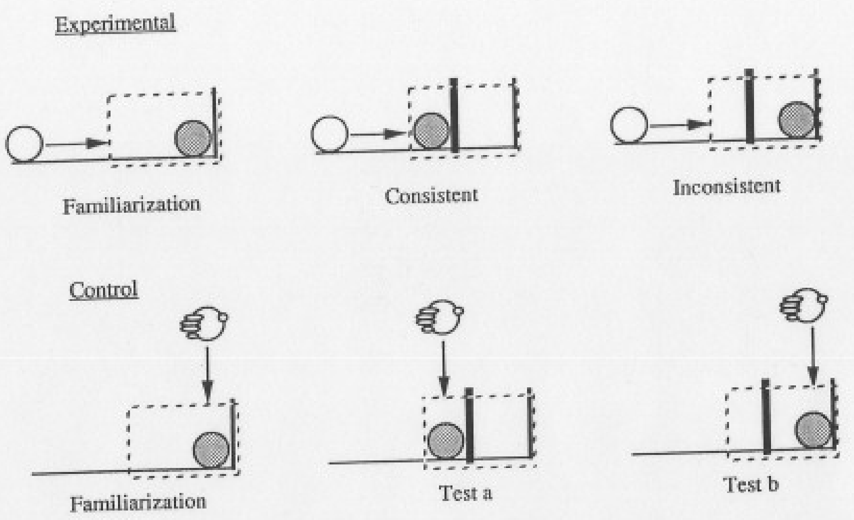

Fig. 3.3. Schematic depiction of displays for a study of infants' knowledge of the continuity principle. Arrows indicate the path of visible motion from an object's initial position (open circles) to the occluder (broken lines); shaded circles indicate the object's resting position when the occluder was removed. (After Spelke *et al.* 1992.)

of continuity: objects exist and move continuously, such that each object traces exactly one connected path over space and time (Fig. 3.1(b)). This principle encompasses the symmetrical constraints of 'continuity' (objects move on connected paths) and 'solidity' (objects move on non-intersecting paths, such that two distinct objects never occupy the same place at the same time). A number of studies provide evidence for sensitivity to this principle (Baillargeon 1986; Baillargeon and Graber 1987; Baillargeon *et al.* 1990; Baillargeon and DeVos 1991; Leslie 1991; Wynn 1992; Xu and Carey 1992; Spelke *et al.* 1994; M. M. Sitskoorn and A. W. Smitsman, submitted; Wilcox, Rosser, and Nadel, submitted) including the following study by Spelke *et al.* (1992).

The experiment focused on infants' looking times for the outcomes of events in which an object moved from view toward a hidden obstacle and reappeared on either the near or the far side of the obstacle. Infants aged just under 3 months were familiarized with an event in which a ball rolled on a horizontal surface, disappeared behind a screen, and then was revealed, by the raising of the screen, at the far end of the surface (Fig. 3.3). Looking time was recorded only after the raising of the screen, when the stationary object appeared at its final position. After interest in this event had declined, infants were tested with two events in which a barrier was

placed on the surface, the screen was lowered to cover the barrier, the ball was rolled as before, and the screen was raised to reveal the ball at rest either against the barrier (a novel position that is consistent with the continuity principle) or at the far end of the display (a familiar position that is inconsistent with the continuity principle because the ball could have arrived at that position only by passing through the hidden barrier or by moving discontinuously). Looking times for these two outcomes were compared with each other and with the looking times of infants in a control condition, in which the same outcomes were preceded by uniformly consistent events in which the ball was lowered to its final position. The infants in the experimental condition looked reliably longer at the inconsistent event outcome. The equal looking times of infants in the control condition suggested that this difference did not reflect an intrinsic preference for that outcome display. Therefore the experiment provides evidence that young infants are sensitive to the continuity principle.

The third principle guiding infants' reasoning, and the focus of this chapter, is the *principle of contact*: objects act upon each other if and only if they touch (Fig. 3.1(c)). This principle encompasses the symmetrical constraints of 'action on contact' (objects act upon each other if they come into contact) and 'no action at a distance' (objects do not act upon each other if they do not come into contact). Research by Leslie and his colleagues provides a wealth of evidence that infants reason about object motion in accord with this principle (Leslie 1982, 1984; Leslie and Keeble 1987) (for reviews, see Leslie (1988) and Chapter 5 of this volume), and their findings are corroborated by research from other laboratories (Borton 1979; Oakes 1993; Van de Walle and Spelke 1993; Chapter 4 of this volume); for partly contrary evidence see Oakes and Cohen (1990). We illustrate these findings by describing what may have been the first study of infants' knowledge of the contact principle (Ball 1973).

Children ranging in age from 9 weeks to 2 years were presented with an event in which two objects moved in succession behind a screen under spatio-temporal conditions that elicit, for adults, an impression that the first object set the second object in motion (Michotte 1963) (Fig. 3.4). After familiarization with this event, the screen was removed and the children were presented with fully visible events in which the first object either hit the second object (consistent with the contact principle) or stopped short of it (inconsistent with that principle). Looking times for the two test events were compared with one another and with the looking times of children in a no-familiarization baseline condition. Relative to baseline, the subjects in the experimental condition showed a reliable preference for the inconsistent event. A reanalysis of Ball's data (Spelke and Van de Walle 1993) provides evidence that this preference was significant not only for the sample as a whole but for the subset of children who were less than

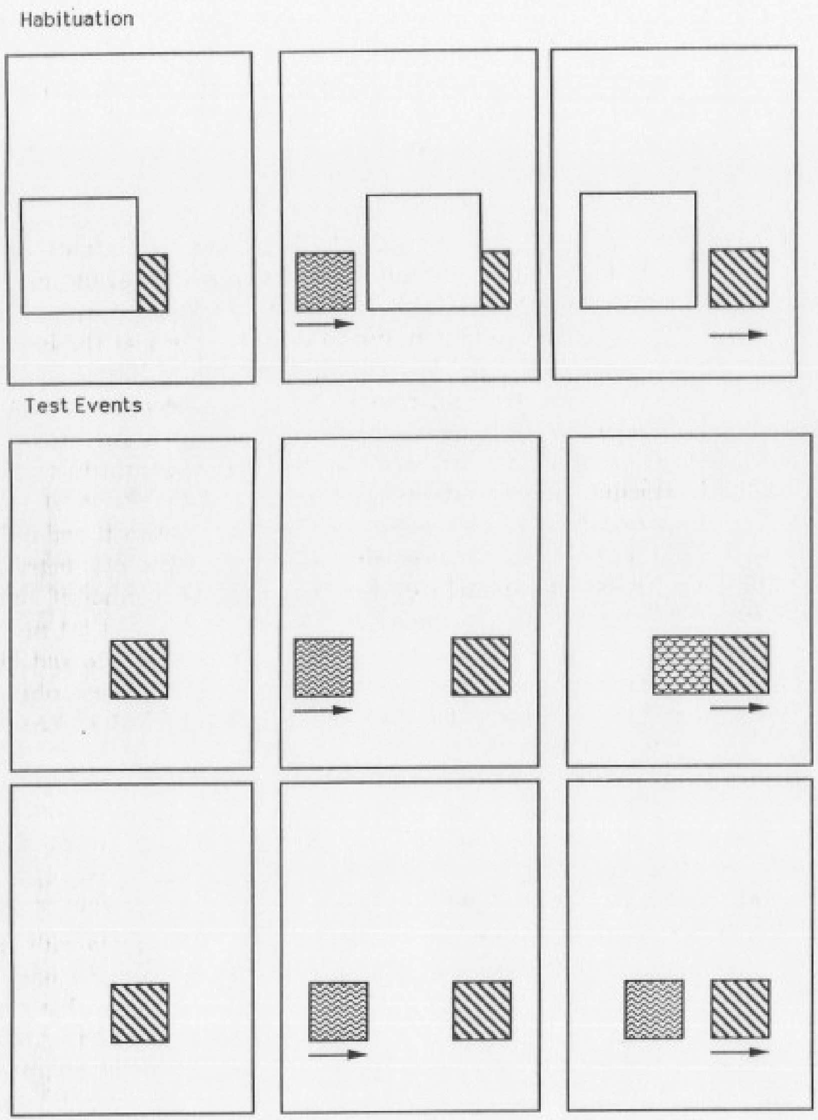

Fig. 3.4. Schematic depiction of displays for a study of infants' knowledge of the contact principle at the beginning (left), middle (centre), and end (right) of each event. (After Ball 1973.)

7 months old. A recent study obtained the same preference with 6-month-old infants (Van de Walle *et al.* 1994). Infants evidently inferred that the two objects met behind the screen, in accord with the contact principle.

In summary, young infants appear to know that inanimate objects move cohesively, exist and move continuously, and act upon each other on contact. Infants exhibit their knowledge in a variety of situations involving both visible and hidden objects. Indeed, a comparison across different studies reveals a convergence between infants' reactions to events involving visible objects and infants' reactions to events involving hidden objects. For example, infants apply the contact principle to both hidden events (Ball 1973; Borton 1979) and visible events (Leslie and Keeble 1987; Chapter 4 of this volume).

The convergence of findings from studies presenting different events and using different methods suggests that knowledge of the principles of cohesion, continuity, and contact is relatively robust and general in infancy. Nevertheless, these principles do not apply to all perceptible entities. In particular, the contact principle is violated by animate objects, including people, and by shadows. We ask next whether infants are sensitive to violations of this principle.

REASONING ABOUT SHADOWS

The motions of shadows violate all the constraints that infants apply to objects. Shadows do not move cohesively or continuously: when a shadow moves off the edge of a surface, it neither maintains its connectedness nor traces a continuous path; when two shadows move together on a surface, they lose their boundaries and coincide in space and time. Shadow motions also violate the contact principle: a shadow moves with the object that casts it and not with the surface on which it is cast. One series of studies has begun to investigate whether infants attend to shadow motions and appreciate that these motions differ from the motions of objects (J. Rubenstein, G. Van de Walle, and E. S. Spelke, in preparation).

The first experiment investigated whether infants perceive and attend to shadow motions. Infants aged 5 and 8 months were familiarized with a stationary display consisting of a shadow, a ball that appeared to adults to cast the shadow, and a box on which the shadow appeared to be cast (Fig. 3.5). (The shadow was actually produced by a hidden object and hidden lighting inside the box, camouflaged by shading on the visible surfaces in the display.) Infants were then tested alternately with the same stationary display and with an otherwise identical display in which the shadow moved laterally (Fig. 3.5(a)). Each of the 12 infants in this study

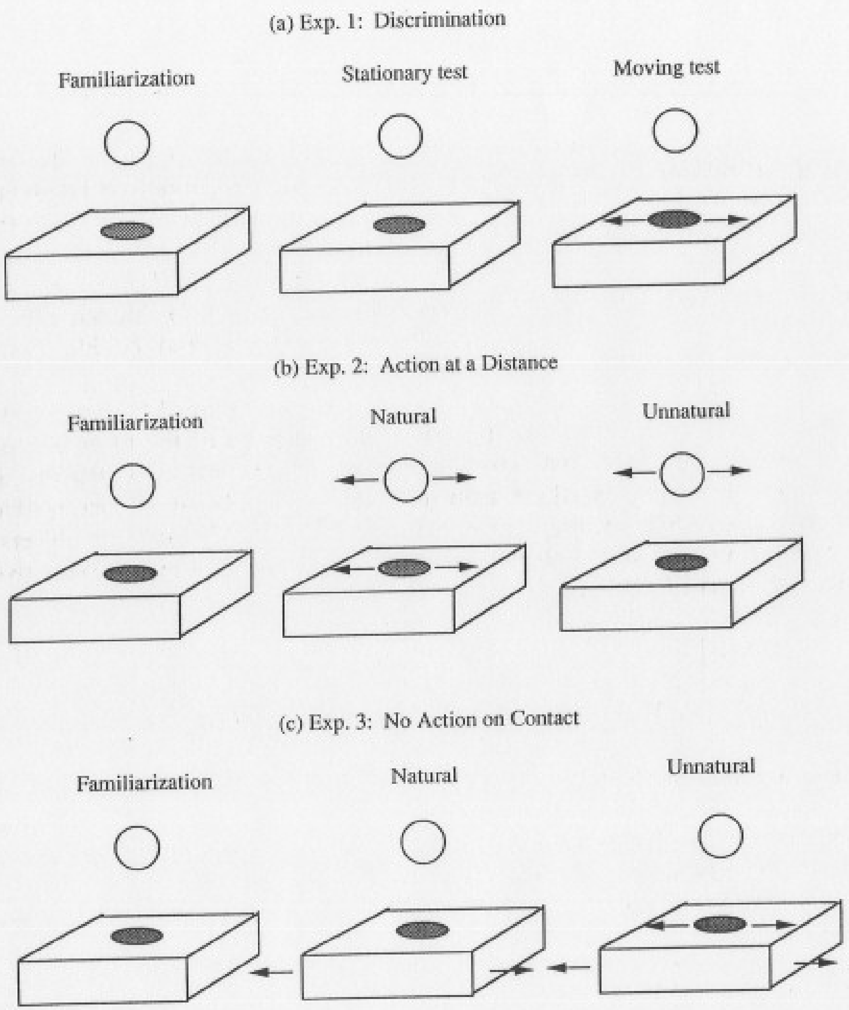

Fig. 3.5. Schematic depiction of the events for studies of (a) infants' sensitivity to shadow motions, (b) infants' knowledge that shadow motion violates the constraint of no action at a distance, and (c) infants' knowledge that shadow motion violates the constraint of action on contact. Arrows indicate the direction and extent of motion of the shadow and objects. (After J. Rubenstein, G. Van de Walle, and E. S. Spelke, in preparation.)

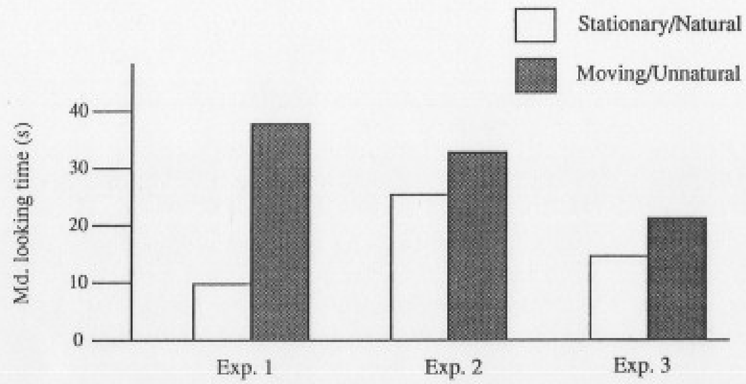

Fig. 3.6. Median looking times at displays in which a shadow is either stationary or moves and in which its motion is either natural and inconsistent with the constraint of action on contact or unnatural and inconsistent with that constraint. (After Rubenstein, G. Van de Walle, and E. S. Spelke, in preparation.)

looked longer at the display in which the shadow moved (Wilcoxon $z = 3.06$, $p < 0.005$) (Fig. 3.6), providing evidence that they detected and attended to the shadow's motion.

The next experiment began to probe infants' understanding of shadow motions, by investigating whether 5- and 8-month-old infants appreciate that a shadow moves with the object that casts it even when the object and shadow are spatially separated. Infants were familiarized with the same stationary display as in the first study and then were tested with two events in which the ball moved (Fig. 3.5(b)). In one event, the shadow moved with the ball—a natural motion for shadows, in violation of the constraint of no action at a distance. In the other event, the shadow remained at rest—an unnatural motion for shadows, in accord with this constraint. Thirteen of the 16 infants in this study looked longer at the *natural* event in which the motion of the shadow violated the contact principle (Wilcoxon $z = 2.10$, $p < 0.02$) (Fig. 3.6). This finding suggests that infants incorrectly inferred that the shadow would remain at rest, in accord with the constraint of no action at a distance.

The third experiment investigated whether infants appreciate that a shadow does not move with the surface on which it is cast. Infants were familiarized with the stationary display and then were tested with two events in which the box moved (Fig. 3.5(c)). In one event, the shadow remained at rest—a natural motion for shadows, in violation of the constraint of action on contact. In the other event, the shadow moved with the box—an unnatural motion for shadows, in accord with this constraint. Eleven of the 16 infants looked longer at the natural event in which the shadow remained at rest (Wilcoxon $z = 1.79$, $p < 0.05$) (Fig. 3.6). Infants appeared to infer that the shadow would move with the surface, in accord with the constraint of action on contact.

Taken together, these studies suggest that 5- and 8-month-old infants make false inferences about the behaviour of shadows. To the extent that the motions of detached shadows are familiar to infants, all the motions that they have seen have violated the contact principle. Nevertheless, infants appear to react to such motions as novel or unnatural, relative to shadow motions that accord with the contact principle. These findings suggest that infants overextend principles governing object motion to other perceptible entities. The tendency to overextend knowledge of material objects appears to persist well into childhood, leading to systematic errors in children's judgments about shadow phenomena (De Vries 1987).

Studies of infants' reasoning about shadows raise questions concerning infants' reasoning about human action. It has been proposed that infants categorize an entity as self-propelled, and therefore animate, by applying principles governing the motions of inanimate material objects to the entity and testing for violations of those principles (Premack 1990; see also Steward 1984; Gelman 1990). The above studies may pose difficulties for this view. Although infants attend to the motions of shadows, at least in certain visual displays, and although shadows disobey all the constraints that infants apply to material objects, infants nevertheless appear to overgeneralize mechanical constraints to shadows. This finding casts doubt on the thesis that infants test all perceived motion patterns for violations of mechanical constraints. It remains possible, however, that infants distinguish people from inanimate objects in their reasoning about action and motion, and that they appreciate that human action is not subject to all the constraints on inanimate objects.

REASONING ABOUT HUMAN ACTION

Like inanimate objects, people move as connected and bounded wholes on continuous and unobstructed paths. Unlike inanimate objects, however, people do not appear to act in accord with the contact principle. Although human action may be as constrained by the contact principle as is inanimate object motion at a neurophysiological level, it is not so constrained at the level of perceptible objects. People and other animals have perceptual systems that allow them to detect and respond to objects at a distance, steering a course around distant obstacles and toward distant goals. People have motivational systems that direct their actions and cognitive systems that allow them to make plans, choose actions, and pursue enduring goals. People communicate, influencing one another's actions, intentions, and states of knowledge; therefore one person's actions can be coordinated with the actions of other people, whether or not the people are in immediate contact. All these factors enable people to behave in ways that are not predictable from a consideration of their immediate physical environment.

Table 3.1 *Possible principles underlying reasoning about human action*

Principles that apply to the motions of all material objects

1. Cohesion: people move as connected bounded wholes
2. Continuity: people move on connected unobstructed paths
3. Gravity: people rest and move on supporting surfaces

Principles that are specific to the actions of animate objects

4. Self-propelled motion: human action is not constrained by the contact principle
5. Social responsiveness: people respond contingently to the actions of social partners
6. Social reciprocity: people react in kind to the actions of social partners
7. Communication: people supply social partners with information
8. Emotion: people's actions are influenced by their motivational and emotional states
9. Goal-directedness: people act to attain goals
10. Perception: people's actions are guided by their perceptions

The existence of perceptual, motivational, cognitive, and communicative systems has both a negative and a positive consequence for reasoning about human action. On the negative side, one cannot infer what people are doing by analysing the contact relations among objects. For example, if an action by one person appears to cause a reaction in a second person, one cannot infer that the first person touched the second. On the positive side, one can often infer a person's actions by drawing on information about the person's perceptions, emotional states, goals, and interactions with other people. For example, if a person looks desirously at one object while ignoring a second object, he or she is more likely to act on the first object. If one person smiles at a second person, the second person is likely to smile as well. Table 3.1 provides a list of candidate principles for reasoning about human action, drawn from our own intuitions and from a number of theoretical proposals about initial concepts of persons or animate objects (Gelman 1990; Premack 1990; Mandler 1992; see also Chapters 5, 6, and 7 of this volume). We focus in turn on each of the principles that are specific to reasoning about animate objects, asking first whether infants appreciate that human action is not predictable from an analysis of contact relations.

DO INFANTS SUSPEND THE CONTACT PRINCIPLE IN REASONING ABOUT HUMAN ACTION?

To investigate whether infants apply the contact principle to events involving people, we conducted an experiment that was patterned after the study by Ball (1973) described above and that used events involving people or large inanimate objects (Woodward *et al.* 1993) (Fig. 3.7). In the experimental condition with inanimate objects, 7-month-old infants were presented with videotaped events involving objects 5 and 6 feet high with bright contrasting colours and patterns, and distinctive meaningless shapes. Each object was moved from behind by a hidden person walking at a normal pace. First infants were familiarized with an event in which the objects moved behind a large central occluder. On each trial, one object moved fully into view on the left side of the television screen and disappeared behind the occluder, and then after an appropriate time interval the second object began to move in the same direction and disappeared at the right side of the television screen. This event was then repeated in reverse, beginning when the second object moved into view on the right and ending when the first object disappeared on the left. Repetitions continued until the infant looked away from the display, ending the trial. A succession of familiarization trials were given until the infant's looking time declined to half its initial level, and then the infant was presented with two test events involving fully visible objects undergoing the same configuration of visible motion. In one event, the two objects came into contact at the centre of the display and their motion changed at the point of contact. In the other event, the moving object stopped short of the stationary object, which began to move after a short pause such that the objects' changes in motion were separated in space and time.

The events for the experimental condition with people were the same, but they involved a man and a woman who walked naturally. Like the objects, the people began moving and reversed direction out of the infant's sight, beyond the edges of the television screen; therefore their behaviour did not indicate whether they could change their motion spontaneously. In the familiarization event, the man held both arms up close to his body and moved toward the half-hidden stationary woman, who faced leftward toward the man at the start of the event and turned her head and body to face rightward when she began to move. In the test event with contact, the man collided with the woman, making contact along most of the upper body and appearing to set her in motion. In the test event without contact, the man walked forward in the same posture but stopped short of the woman, who appeared to begin moving spontaneously. As for the events with inanimate objects, each event with people was then repeated in reverse and presented continuously for as long as the infant looked at it.

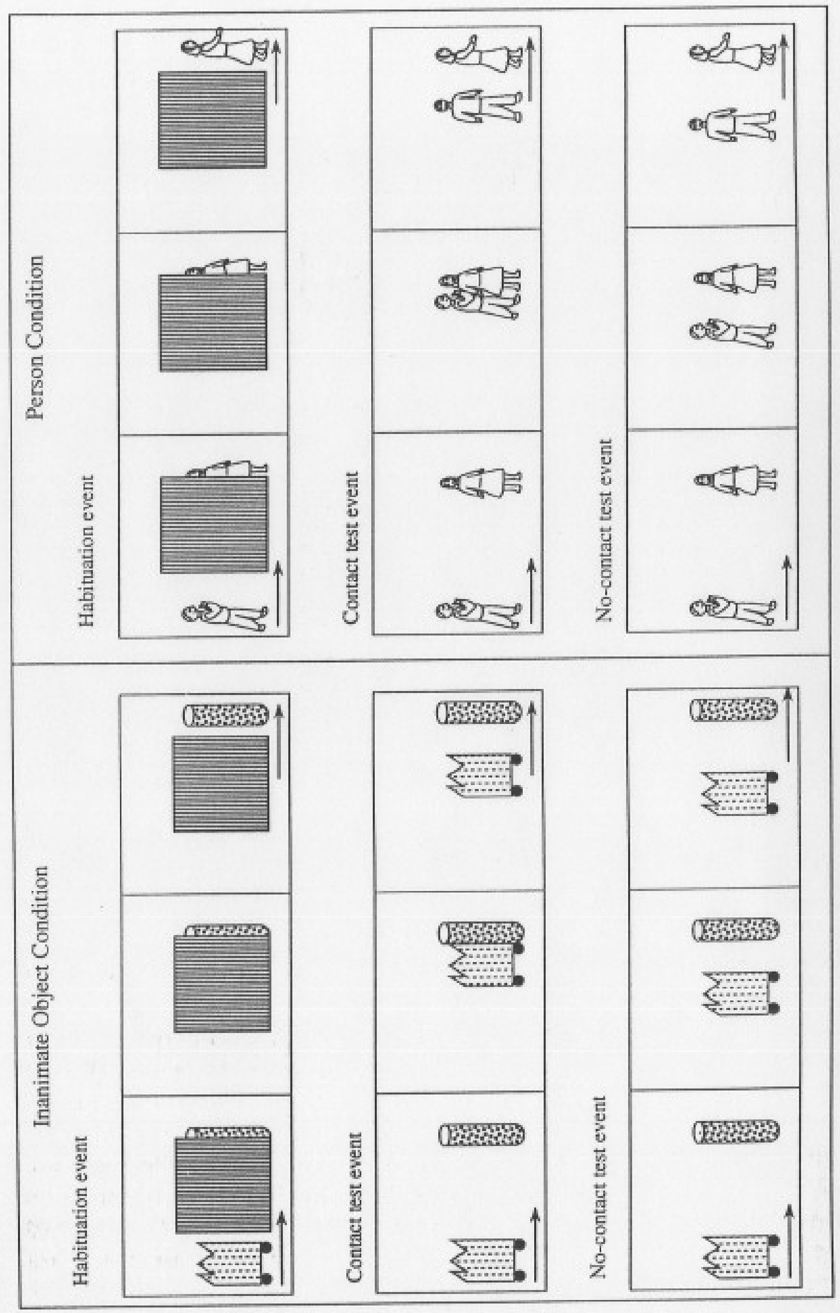

Fig. 3.7. Schematic depiction of the events for a study of infants' inferences about the contact relations between inanimate objects or people. (After Woodward *et al.* 1993.)

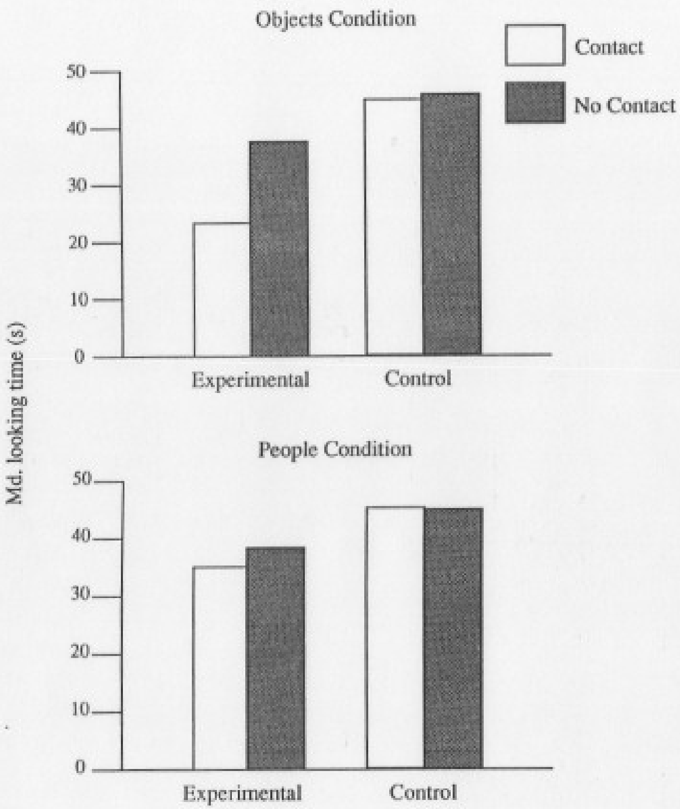

Fig. 3.8. Median looking times for events in which inanimate objects or people change their motion with or without contact. (After Woodward *et al.* 1993.)

To test for differences in the intrinsic attractiveness of the test events, additional groups of infants participated in two control conditions, one with inanimate objects and one with people. The infants in the control conditions viewed the same test events as their counterparts in the experimental conditions, but first they were habituated to neutral displays in which the objects to appear in the test events were shown standing still on the two sides of the screen.

Infants' looking times for the two test events were compared in each condition. The infants in the experimental condition with inanimate objects looked reliably longer at the no-contact event (Wilcoxon $z = 2.25$, $p < 0.02$) (Fig. 3.8); 12 of 16 infants showed this preference. In contrast, the infants in the other three conditions showed no preferences between the two test events (each Wilcoxon $z < 1$). In the experimental condition with people, six

of 16 infants looked longer at the no-contact test event; in the control condition with inanimate objects, seven of 16 infants showed this preference; in the control condition with people, eight of 16 infants showed this preference.

Further analyses compared the looking preferences of infants in the different conditions. Because of high variability in all the conditions, the difference between looking preferences in the experimental and baseline conditions with inanimate objects was only marginally significant (Wilcoxon–Mann–Whitney $z = 1.49$, $p < 0.07$, one-tailed). Thus the present study weakly replicates Ball's (1973) original finding. (An experiment by Van de Walle *et al.* (1994) provides a stronger replication.) The difference between looking preferences in the experimental and baseline conditions with animate objects did not approach significance (Wilcoxon–Mann–Whitney $z < 1$). In contrast, the looking preferences in the experimental condition with inanimate objects differed from those in the experimental condition with people (Wilcoxon–Mann–Whitney $z = 1.68$, $p < 0.05$). This effect is not attributable to differences in the intrinsic attractiveness of the test events with people versus objects, because the preferences in the two control conditions did not differ ($z < 1$).

These findings provide evidence that 7-month-old infants do *not* apply the contact principle to people. In the presence of information for a causal relationship between two perceptible entities, infants tend to infer contact between the entities if they are inanimate objects but not if they are people. In this respect, infants appear to reason differently about people and objects. As suggested by Premack (1990) and Gelman (1990), infants appear to appreciate that people are capable of self-propelled motion.

Our findings accord with the findings of experiments using other methods (Legerstee 1992). Research from the laboratory of Poulin-Dubois (D. Poulin-Dubois, A. Lepage, and D. Ferland, unpublished manuscript) compared the reactions of 9- and 12-month-old infants to a robot and an unfamiliar person both when they were standing still and when they were undergoing self-propelled motion. Children at both ages reacted with most negative affect in the condition in which the robot appeared to move itself around the room. Their reaction may reflect the expectation that the robot would not move spontaneously; the absence of negative affect in the condition in which the person moved suggests that this expectation is not applied to an unfamiliar person. In addition, an experiment by Carlson-Luden (reported by Golinkoff *et al.* (1984)) compared the abilities of 10-month-old infants to learn to push a lever in order to set either an inanimate object (a picture) or a person in motion. Although infants learned to make the picture move by pushing the lever, they did not learn to make the person wave and smile. A similar pattern was observed with younger infants in an experiment by Legerstee (1994). Legerstee compared the reactions of 4-month-old infants to events in which a person or an inanimate object disappeared behind a door. Whereas the infants responded to the disappearance of the object by touching the door, they responded to the disappearance of the person by vocalizing to the person without contacting the occluder. All these experiments suggest that infants reason differently about the motions of people than about the motions of inanimate objects.

Although infants appear to suspend the contact principle in reasoning about human action in the above studies, none of these studies sheds light on infants' positive understanding of human action. Infants may suspend the contact principle because they appreciate that human action is directed to goals or guided by perceptions, or because they appreciate that humans communicate and interact at a distance. Alternatively, infants may lack any positive conception of human action; they may view human behaviour as unpredictable. We turn to other research to distinguish these possibilities.

COMMUNICATION AND SOCIAL INTERACTION IN INFANCY

Research from a large number of laboratories has charted the development of infants' social interactions. Although not all of this research was conducted with our questions in mind, it provides a place to look for suggestions concerning infants' understanding of human action. We review parts of this research as it bears on infants' understanding that human action is socially responsive, coloured by emotion, directed to goals, and guided by perception.

People interact

By the time that they are a few months old, infants participate in well-orchestrated contingent interactions with their parents (Brazelton *et al.* 1974; Stern 1974; Trevarthen 1977, 1979; Tronick 1981; Field 1982; Stevenson *et al.* 1986; Cohn and Tronick 1988). Therefore early conceptions of human beings may involve an understanding of the ways in which people interact. Three aspects of human interaction that are accessible in principle to young infants are contingency (humans react to one another), reciprocity (humans respond in kind to one another's actions), and communication (humans supply one another with information). A variety of studies of early social interactions suggest that infants are sensitive to these properties. In each case, however, clear evidence that infants understand the social character of human action has been difficult to obtain.

A number of researchers have investigated infants' understanding of humans as socially responsive actors using the 'still-face' procedure (Tronick *et al.* 1978; Field *et al.* 1986*b*; Cohn and Elmore 1988; Gusella *et al.* 1988; Ellsworth *et al.* 1993; Muir and Hains 1993). In this procedure, an experimenter or parent interacts with the infant for several minutes and then stops reacting to the infant and stands motionless with a neutral facial expression. By 3 months, infants show decreases in smiling and increases in grimacing in the still-face phase of the procedure (Field *et al.* 1986*b*; Gusella *et al.* 1988). This effect does not appear to reflect a simple reaction to the cessation of an interesting event, because changes in smiling are reduced if infants are presented with an inverted face (Rach-Longman and Muir 1990) or with an interacting inanimate object that elicits equally high levels of attention (Legerstee *et al.* 1987, 1990; Ellsworth *et al.* 1993). Nevertheless, infants appear to show similar reactions in a still-face procedure involving a person who responds contingently to their actions and one who responds non-contingently (Muir and Hains 1993). Therefore it is not clear whether infants' emotional reactions to a still face reflect their expectation that people will behave contingently.

Further studies provide evidence that infants are sensitive to the contingent character of social interactions. Young infants can learn about contingencies, both those involving people (Pelaez-Nogueras and Gewirtz, 1993) and those involving inanimate objects (Watson 1972; Rovee-Collier *et al.* 1989). Moreover, young infants who are presented with a video image of a socially interactive adult have been found to show greater positive affect if the adult's behaviour is contingent on their own actions than if it is not (Hains *et al.* 1992). Like the still-face studies, these investigations fall short of establishing that infants have definite expectations about the behaviour of their social partners. Nevertheless, they provide evidence that infants are sensitive to the contingent responsiveness of a social partner and respond to their partners with appropriate social expressions.

Studies of games such as 'peek-a-boo' and give-and-take routines in which babies and their adult partners switch roles may serve to investigate whether infants have expectations about the reciprocal character of human interactions. Infants begin to play these games systematically at about 9 months of age (Bruner 1975; Trevarthen 1979). Research by Ross and Lollis (1987) suggests that infants at this age understand the roles involved in games such as peek-a-boo and work to maintain their reciprocal structure. In their longitudinal study, babies were taught two-person games involving objects in which the infant and an adult experimenter each played a specific role. After the baby was engaged in the game, the adult stopped fulfilling her role. Even at 9 months, infants responded to this break in the action in ways that suggested that they understood the structure of the game: they looked back and forth between the adult and the objects and were likely to repeat their turn or assume the turn of the adult. These findings suggest that 9-month-old infants expect their partners to continue to act in their reciprocal role. To our knowledge, however, no experiment has investigated infants' sensitivity to the reciprocal character of interactions in which they do not participate. In particular, we do not know whether infants who see one person engage in a given action predict that his or her social partner will also engage in a similar or complementary action.

Studies of imitation may serve to investigate younger infants' understanding that people respond in kind to one another's actions. Even newborn infants imitate the facial movements and emotional expressions of an adult (Meltzoff and Moore 1977, 1983; Field *et al.* 1982, 1986*a*; Vinter 1986; Reissland 1988; Legerstee 1991) and they respond with interest to an adult who imitates their own actions (Field 1977). In addition, an analysis of mother–infant dialogues provides evidence that maternal vocalizations increase the likelihood of infant vocalizations (Stevenson *et al.* 1986). Meltzoff and Moore (1992) have speculated that early imitation is an information-seeking activity, by which infants attempt to elicit actions from a social partner. If this interpretation is correct, then imitation would appear to reflect a tacit understanding that humans interact reciprocally.

A third characteristic of human interactions is that they involve the transfer of information from one person to another. Bates and colleagues (Bates *et al.* 1979; Bretherton *et al.* 1981) have suggested that infants first understand the communicative aspect of human interaction at about 9 months of age. At this age, three types of behaviour appear that suggest that infants intend to communicate: (1) they persevere in the face of failure to transmit their message and vary the form of the message until they succeed (see also Scollon 1976); (2) when requesting an object, they shift their gaze from the object to their addressee as if to check whether the message was understood; (3) they begin to use ritualized gestures in their interactions (Bates *et al.* 1979). Although Bretherton *et al.* (1981) interpret these developments in terms of the emergence of an 'implicit theory of interfaceable minds', that interpretation can be questioned on two grounds. On the one hand, it is possible that younger infants understand the communicative character of human interactions but lack the resources to act upon this understanding in the above ways. Some studies of naturally occurring social exchanges involving young infants may suggest an earlier understanding of communication (Tronick 1981). On the other hand, it is possible that 9-month-old infants still lack this understanding and have learned a set of routines for manipulating the actions of others (Shatz 1983).

People experience and express emotion

Young infants are sensitive to expressions of emotion. One-day-old infants show discrimination of happy versus sad living faces (Field and Walden 1981), and 5-month-old infants show discrimination between vocal

expressions which are happy versus sad (Walker-Andrews and Grolnick 1983) or happy versus angry (Walker-Andrews and Lennon 1991). These abilities appear to reflect more than a sensory analysis of emotional displays, because 4-month-old infants show no discrimination of happy and sad faces when the faces are presented upside down (Oster 1981), 5-month-old infants generalize from one set of actors portraying happy or sad emotions to new actors portraying these emotions (Caron *et al.* 1988), and 5-month-old infants are able to match facial expressions with their congruent vocal expressions (Walker 1982). Moreover, young infants respond appropriately to certain emotional expressions. Two-month-old infants imitate facial expressions of happiness, sadness, and surprise (Field *et al.* 1986*a*), and react in systematic and appropriate ways to maternal expressions of joy, sadness, and anger (Haviland and Lelwica 1987). At slightly older ages, infants respond with negative emotion to their mothers' depressed affect (Tronick *et al.* 1986), and they respond appropriately to the emotional content of praise or prohibition even if the speech is not in their native language (Fernald 1993). From an early age, then, infants appear to be sensitive to the emotional tone of a voice or an expressive face, and they react appropriately to these signals.

For adults, emotional expressions convey information both about the state and probable actions of the person expressing the emotion and about the objects towards which the emotion is expressed. A person who evinces disgust at one object and pleasure at another object is more likely to approach the latter object. Moreover, if someone expresses disgust or alarm while looking at an object, this behaviour suggests that the object may be unpleasant or dangerous. Studies of pre-school children's memory of emotional events suggest that they are also aware of these linkages (Liwag and Stein 1993). Are infants able to use a person's emotional expressions as information about his or her probable actions? Conversely, can they use a person's actions as information about his or her probable emotional state? Research by Wellman and Woolley (1990) shows that 2.5-year-old children can predict the emotional state (happy versus sad) of a character in a simple story from a consideration of the character's actions and their consequences. For example, children at this age predict that a character who wants her mittens will be happy if she finds them and sad if she does not. Given this ability, it seems reasonable to expect that children can use information about emotions to predict behaviour, but this question has not been addressed directly for toddlers or infants. However, there is a large body of evidence relevant to infants' use of emotional expressions in reasoning about states of the world – research on 'social referencing' in infants.

By the end of the first year, infants tend to look at the faces of their parents when confronted with an ambiguous situation, and they use information from a parent's facial and vocal expressions to regulate their behaviour (Campos and Stenberg 1981). In a variety of settings, infants' approach and avoidance behaviours towards people and objects are influenced by the positive and negative messages that their parents express toward those objects. In particular, a parent's emotional expressions influence the degree of interaction of 10-month-old infants with a stranger (Feinman and Lewis 1983) and the probability that 12-month-old infants will cross a visual cliff (Sorce *et al.* 1985) or touch an unfamiliar toy (Hornick *et al.* 1987; Walden and Baxter 1989; Rosen *et al.* 1992). Some researchers report similar effects in younger infants, although their findings are less clear. In a study by Walden and Ogan (1988), 6- to 9-month-old infants avoided a toy which had been the target of a negative emotional expression by a parent, but they did not check the parent's expression reliably. More dramatically, Pelaez-Nogueras (1993) was able to condition social-referencing type responses in 4- to 5-month-old infants. However, it is not clear whether infants' conditioned responses draw on the same underlying understanding as does the social referencing of older children.

Studies of social referencing provide evidence that older infants are sensitive to emotional expressions in other people, and that this sensitivity guides their actions on objects. The findings of these studies cannot be explained in terms of a direct effect of a perceived expression of emotion on the infant's own affective state, because the changes in infants' actions that occur in response to the expressions of another person are specific to the objects to which the person's expressions are directed (Hornick *et al.* 1987; Walden and Ogan 1988). Nevertheless, none of these studies reveals whether infants use information from a person's emotional reactions to an object to predict how the person will act towards that object.

People pursue goals

Because human action is goal directed, it is often possible to predict what a person will do from behavioural evidence concerning his or her intentions and goals. Do young children appreciate the goal-directed character of human action, and do they use behavioural information about a person's goals to predict his or her future actions?

There is ample evidence that 2.5-year-old children understand human action in terms of goals and intentions. By this age, children predict the behaviour of story characters from information that they are given about the characters' goals (Wellman and Woolley 1990), they talk about the behaviour of themselves and others using intentional action verbs (Huttenlocher and Smiley 1990) and mental verbs such as 'want' or 'think' (Bretherton *et al.* 1981; Shatz *et al.* 1983), and they interpret new verbs as referring to intentional as opposed to accidental acts (Tomasello 1993). Studies of

children's memory of unfamiliar actions suggest that, when there is a clear goal, children as young as 15 months remember the structure of a person's actions in relation to that goal (Bauer and Shore 1987; Bauer and Mandler 1989; Travis 1993). For example, young children are more likely to remember an action that was instrumental in completing a goal than an action which was irrelevant to that goal (Travis 1993). Observations of 9-month-old infants' persistent requests for action on the part of others invites the interpretation that they are also aware of others' goals (Bates *et al.* 1979; Bretherton *et al.* 1981); for a contrary interpretation of this evidence see Shatz (1983). The 9-month-old infant's developing understanding of pointing (Murphy and Messer 1977) invites a similar interpretation. To our knowledge, however, there is no direct evidence bearing on infants' ability to understand human action as goal directed. Methods by which this question may be addressed are suggested in Chapter 7.

People perceive

Human action is guided by perception: people move so as to approach perceived goals and avoid perceived obstacles. Although perception itself is an internal process, behavioural signs of perception such as the direction of gaze are an important part of the information that adults use to predict what other people will do. Are infants sensitive to the linkage between action and perception, and can they use information about what people perceive to predict their actions?

Two-year-old children have some understanding of the conditions under which adults are able to witness events and of the effects of witnessing an event on adults' knowledge and behaviour. For example O'Neill (1993) found that such children's instructions to their mothers about retrieving a hidden object varied depending on whether the mother had seen the object being hidden. The children's verbal instructions were longer and more specific when the mother either left the room or was blindfolded during the hiding of the object than when she was present and witnessed the hiding. These children appeared to appreciate that the mother could not act, unaided, to retrieve a toy she had not seen.

Two experiments suggest that younger children also have some understanding of linkages between looking and acting. First, 16- to 19-month-old children's word learning is reliably influenced by a speaker's direction of looking. When an experimenter introduced a new object and offered a name for the object, children learned the object's name if the speaker looked at the object while speaking but not if she looked away (Baldwin 1991). The infants evidently used the direction of the speaker's gaze as information about what the person was talking about. Second, both 10-month-old and 18-month-old children who are facing away from the mother have been found to turn more often to look and smile at her when she was previously seen to be looking at the infant than when she was previously seen to be reading a magazine (Jones *et al.* 1991). Careful analyses of the timing of the infants' actions suggested that infants were not responding directly to the mother's own signals or to an internal state of affect engendered by the mother's attention. Rather, the infants appeared to appreciate that the mother was more open to communication when she faced the infant. Nevertheless, these studies fall short of showing that infants can use information about a person's direction of gaze to predict what the person will do.

What of younger infants? When 3-month-old infants view a photograph of a face in a frontal orientation, their response to the photograph is reliably influenced by the face's direction of gaze. Infants respond with more negative emotion if the eyes are directed away from the infant than if they are directed to the infant (Ehrlich 1993). Evidently, young infants are sensitive to some of the information indicating what a person perceives.

Studies of infants' ability to follow the gaze of another person suggest that gaze direction is meaningful for infants. When infants interact with a person who looks at an object, they tend to follow the person's direction of gaze to the object (Scaife and Bruner 1975). The ability to follow an adult's line of regard increases in accuracy over the course of the first year. At 6 months, infants turn to look at an object in the direction that the adult is looking, but they typically look at the first object that they encounter in that direction, even if the adult is looking at a more distant object. By 12 months, infants follow the adult's line of regard to the correct object (Butterworth and Grover 1988). These looking patterns may reflect changes in infants' understanding of gaze direction and perception.

In summary, infants appear to be sensitive to a variety of aspects of human action. However, it is not clear what knowledge underlies this sensitivity or whether infants can use this knowledge to infer what a person will do. These questions have proved difficult to answer using studies of infants' spontaneous social and communicative behaviour. We have begun to approach them using different methods in which infants observe fully visible or partly hidden events in which they do not participate.

DO INFANTS MAKE POSITIVE INFERENCES ABOUT HUMAN ACTION?

Our first experiment (A. Phillips, A. L. Woodward, and E. S. Spelke, in preparation) used the same method as in previous studies of physical reasoning to investigate whether infants can infer the hidden actions of a person by drawing on information about about the person's affect and

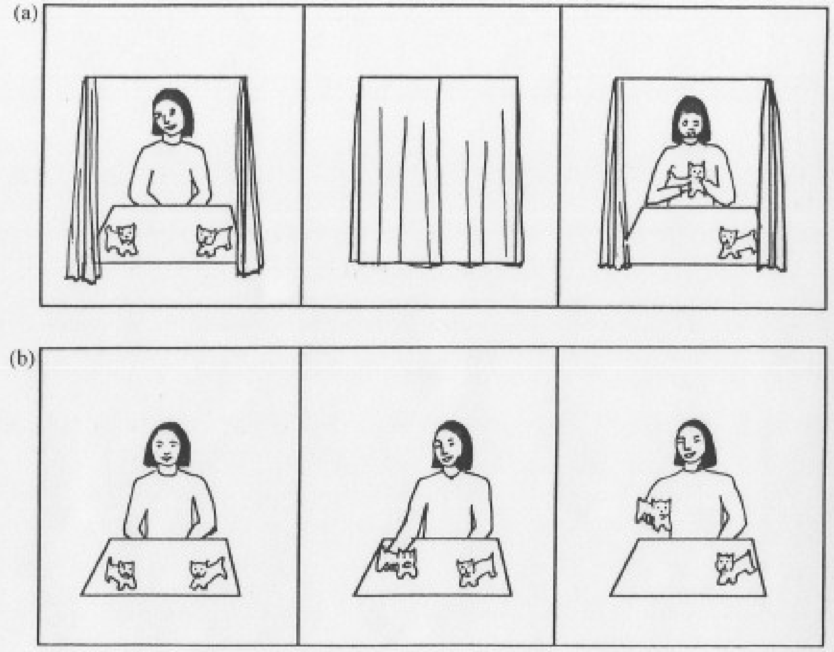

Fig. 3.9. Schematic depiction of the events for studies of infants' knowledge that the direction of a person's action is predictable from the direction of his or her gaze. (After A. Phillips, A. L. Woodward, and E. S. Spelke, in preparation.)

expression. First, infants were presented with an actor, a table, and two stuffed animals in two corners of the table (Fig 3.9(a)). On each of a series of familiarization trials, the actor looked at the child, established eye contact, and then looked away towards one of the toys (for half the children, this was the toy on the left) with an expression of joy and interest. After the infant had looked at this display for 3 seconds, a large curtain was drawn, occluding the entire stage. When the curtain was opened a few seconds later, the actor's head was centred, she was looking down, and she was holding the toy at which she had been looking. Looking time to this outcome display was recorded, and trials were continued until the infant's looking time had declined to half its initial level.

A test sequence followed, consisting of two events presented on six alternating trials. Both test events ended with the same outcome display: the curtain opened to reveal the experimenter holding and looking at the toy that was opposite the one that she had looked at and acted on during familiarization. In one test event, the experimenter began by looking and smiling at this toy; this event was consistent with the principle that people act on things that they see and approach things that they like. In the other test event, the experimenter began by looking at the toy at which she had looked during the familiarization period. Because the experimenter looked desirously at one object but picked up a different object, this event appeared to be inconsistent with the principle that human actions are guided by their perceptions and desires.

The first experiment was conducted with 8- and 12-month-old infants. The younger infants showed no preference between the two test events (Wilcoxon $z < 1$) eight of 16 infants looked longer at each event outcome. In contrast, the older infants looked reliably longer at the event outcome in which the actor held the toy at which she had not been looking (Wilcoxon $z = 2.07$, $p < 0.02$); 11 of 16 infants showed this preference (Fig. 3.10(a)). However, the change in looking preferences from 8 to 12 months was not significant (Wilcoxon–Mann–Whitney $z = 1.15$), nor was the preference for the inconsistent outcome across the two ages combined (Wilcoxon $z = 1.45$, $p = 0.07$). Therefore the findings of this experiment provide evidence that one-year-old children infer that a person will reach for the object at which she is looking with positive affect, but they do not clearly suggest how this tendency develops between 8 and 12 months.

The next experiment investigated infants' ability to infer a person's actions from behavioural signs of perception and emotion when both her actions and her gaze direction are continuously visible. Infants aged 8 and 12 months were presented with fully visible events in which an actor looked and smiled at one object while reaching for that object or for a different object (Fig 3.9(b)). As in the previous study, infants were familiarized with an event in which the actor looked at and reached for one toy, and then they were tested with events in which the actor reached to the second toy either while looking at that toy (consistent) or while looking at the first toy (inconsistent). The actor looked and reached at the same time, and she did so repeatedly on every trial for as long as the infant watched the display. Infants' total looking times for these events were recorded and compared. The results were weaker than those of the previous study: infants showed no differential looking at the consistent versus the inconsistent events at either 8 months or 12 months, (both Wilcoxon $z < 1$) (Fig 3.10(b)). The change in looking preferences from 8 to 12 months was not significant (Wilcoxon–Mann–Whitney $z < 1$), and an analysis of the two ages combined revealed no reliable preference between the events (Wilcoxon $z < 1$). Nevertheless, 11 of 16 12-month-old infants looked longer at the inconsistent event compared with eight of 16 8-month-old infants. Combining the results of the two experiments revealed a strong preference at 12 months for the events in which the person reached for one object during or after the time that she looked and smiled at another object (Wilcoxon $z = 2.52$, $p < 0.01$). Although no such preference was observed

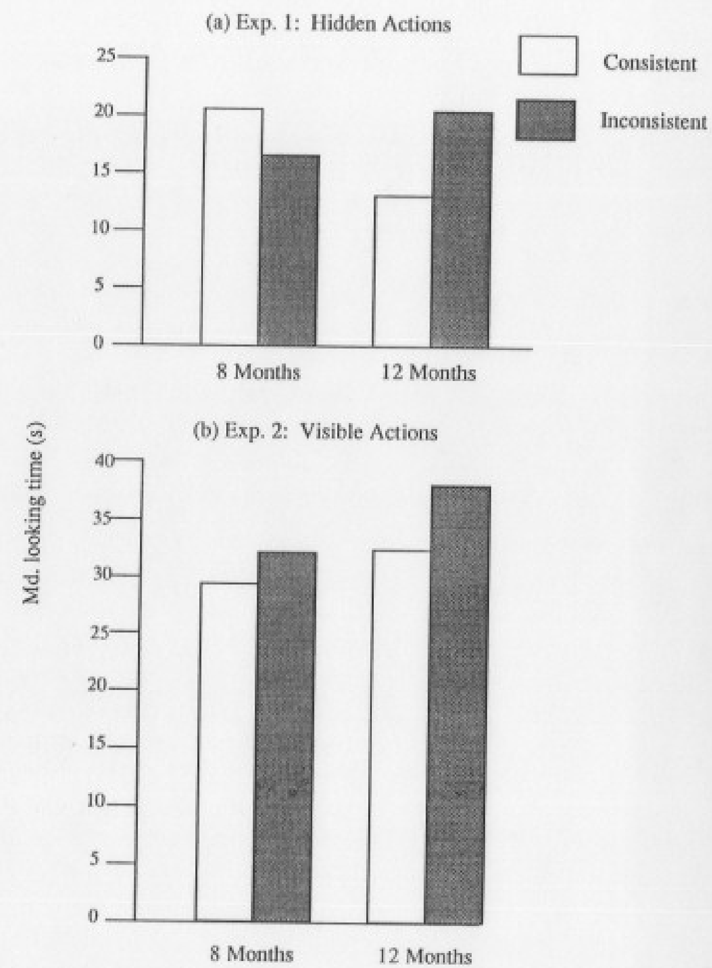

Fig. 3.10. Median looking times at (a) the outcomes of events or (b) fully visible events that are consistent or inconsistent with the principle that the direction of action follows the direction of gaze. (After A. Phillips, A. L. Woodward, and E. S. Spelke, in preparation.)

at 8 months ($z < 1$), the combined analyses still revealed no significant change in preferences between the two ages ($z = 1.26$, $p > 0.10$).

These studies provide evidence that 12-month-old infants infer a person's behaviour from information about her line of regard and emotional expression. This effect was not obtained for 8-month-old infants, but the difference in performance of the two age groups never attained significance. It is

Table 3.2 *Number of infants preferring the inconsistent versus consistent event outcomes who followed or did not follow the actor's line of regard*

Preference on test trials	8 months		12 months	
	Followers	*Non-followers*	*Followers*	*Non-followers*
Inconsistent	5	0	8	2
Consistent	2	3	4	1

possible that the 8-month-old infants' performance was heterogeneous, such that some infants were able to make this inference whereas others were not. This possibility is strengthened by the evidence that the ability to follow line of regard improves between 6 and 12 months (Scaife and Bruner 1975; Butterworth and Grover 1988).

To assess whether sensitivity to line of regard influenced infants' performance in our studies, we conducted a further analysis. On each of the first six familiarization trials of the first experiment, we coded whether an infant followed the actor's direction of gaze.* Infants were scored as correctly following line of regard if they looked first at the toy to which the experimenter turned; they were scored as incorrect if they looked at the other toy first. Infants who had more correct than incorrect trials were counted as 'followers'. The looking preferences of the followers and the non-followers in the test trial were then compared (Table 3.2). For the 12-month-old infants, the tendency to follow the actor's line of regard during familiarization was unrelated to the tendency to look longer at the inconsistent event outcome during the test phase (chi-square (1, $n = 15) = 0$). For the 8-month-old infants, in contrast, the tendency to follow line of regard during familiarization predicted infants' preference on the test trials. Eight-month-old infants who did not follow the actor's line of regard did not show a preference for the inconsistent event outcome; in contrast, most of the infants who did follow her line of regard looked longer at that outcome (chi-square (1, $n = 10) = 4.29$, $p < 0.05$). Because of the small number of subjects included in this analysis, these findings are not conclusive. They suggest that infants who can follow a person's line of regard can also use this information to predict the person's actions.

In summary, two lines of experiments provide evidence that children begin to distinguish in their reasoning between the actions of human beings and the motions of inanimate objects during the first year of life. By 7 months, infants' inferences about a person's actions are not guided by the contact principle, in contrast with their inferences about inanimate object motion and in accord with the notion that human actions are self-propelled. By 12 months, infants' inferences about a person's actions are guided by behavioural indicators of what the person sees or wants. Although these studies do not tell us that infants understand perception or emotion, infants use of these indicators accords with the principle that people act on the things that they perceive and the principle that people approach the things that they desire. Therefore studies of infants' reasoning using preferential looking methods converge with studies of infants' spontaneous social behaviour to suggest that infants differentiate between people and inanimate objects and develop specialized knowledge of human behaviour.

* This analysis could only be conducted for the first experiment because the ability to follow the actor's line of regard could not be assessed in the second study; since the actor continually moved the object at which she looked, infants might have looked at the appropriate object because they detected its motion. In addition, because of lost video records, only 10 of the 8-month-old infants and 15 of the 12-month-old infants could be coded and entered into the analysis.

We do not know what changes take place in infants' understanding of human action during the first year. The findings of our gaze-following study and of studies by other investigators suggest that there may be important developments between 8 and 12 months. At around this age, pointing and following of points first emerge and the ability to follow line of regard improves. This is also the time when intentional attempts to communicate are first evident, when infants begin to communicate using gestures, and when infants first show signs of understanding language (Benedict 1979). Finally, social referencing and interactive games are first noted at about this age. These abilities might reflect an advance in infants' understanding of intentions and, perhaps related to this, the attainment of an understanding of reference.

DOMAIN-SPECIFIC SYSTEMS OF KNOWLEDGE

The findings that we have reviewed are consistent with the view that reasoning depends on domain-specific systems of knowledge. By the end of the first year, infants reason about human action by drawing on information about aspects of human behaviour—direction of gaze, expression of emotion—that do not apply to the behaviour of inanimate objects. Symmetrically, infants reason about inanimate object motion in accord with constraints—action on contact, no action at a distance—that they withhold from their reasoning about human actions. These findings accord with the suggestions arising from naturalistic studies of infant behaviour, from experimental manipulations of naturally occurring social behaviour, and from a number of theoretical accounts of early cognitive development (Mandler 1992; Chapters 5, 6, 7, and 10 of this volume).

Much remains to be learned about the system of knowledge underlying infants' reasoning about persons and about the relation of this system to the system of knowledge underlying infants' reasoning about inanimate objects. Although observations of early developing social behaviour are suggestive, they do not show clearly whether young infants reason about people in accord with conceptions of human actions as directed to goals, guided by perceptions, co-ordinated with the actions of other people, and coloured by emotions. Conclusions about infants' reasoning are difficult to draw from observational studies because of ambiguities that arise in interpreting social behaviour as reflecting expectations on the one hand or responses to social signals on the other. Studies using preferential looking methods could provide a complement to observational studies in this respect. By assessing infants' inferences about a person's hidden or future actions and by focusing on infants' understanding of events in which they are not active participants, these methods may help to reveal infants' understanding of people and of the ways in which people differ from inanimate objects.

Although research with infants implies that infants distinguish people from inanimate objects on some basis, we do not know how infants categorize an entity as a person or an inanimate object or how infants reason about entities such as animals and self-propelled machines that do not fall neatly into the category 'human' or the category 'inanimate' (see Chapters 6 and 7 for suggestions). A suggestion that arises from our studies of shadows, in contrast with some proposals (Gelman 1990; Premack 1990), is that infants do not categorize entities as animate by detecting violations of constraints on inanimate objects. Infants may single out persons by detecting motion patterns that are specific to the class of animate objects (see Chapters 6 and 7).

Studies of the early development of knowledge of persons and objects may provide clues to the nature and organization of this knowledge in its mature state. Adults in Western cultures appear to waver between a conception of persons as physical objects that are deeply subject to all mechanical constraints and a conception of persons as intentional agents who are not subject to the contact principle or perhaps to any physical constraints. Long-standing debates over the existence of free will and the nature of personal identity suggest that these two conceptions are deeply in conflict, but they do not reveal the essence of each conception or the relations between them. Do humans view themselves and others as physical objects who happen to have some mental properties, or as entities of a different kind who happen to have some of the properties of material objects? In either case, what are the physical or mental properties that stand at the centre of the concept 'person'? Studies of the earliest conceptions of people and objects, and of their subsequent development, offer one approach to these questions.

REFERENCES

Baillargeon, R. (1986). Representing the existence and the location of hidden objects: object permanence in 6- and 8-month-old infants. *Cognition* **23**, 21–41.

Baillargeon, R. (1993). The object concept revisited: new directions in the investigation of infants' physical knowledge. In *Visual perception and cognition in infancy, Carnegie-Mellon Symposia on Cognition*, Vol. 23 (ed. C. E. Granrud). Erlbaum, Hillsdale, NJ.

Baillargeon, R. and DeVos, J. (1991). Object permanence in young infants: further evidence. *Child Development* **62**, 1227–46.

Baillargeon, R. and Graber, M. (1987). Where's the rabbit? 5.5-month-old infants' representation of the height of a hidden object. *Cognitive Development* **2**, 375–92.

Baillargeon, R., Graber, M., DeVos, J., and Black, J. C. (1990). Why do young infants fail to search for hidden objects? *Cognition* **36**, 255–84.

Baldwin, D. A. (1991). Infants' contribution to the achievement of joint reference. *Child Development* **62**, 875–90.

Ball, W. A. (1973). The perception of causality in the infant. Presented at the Meeting of the Society for Research in Child Development, Philadelphia, PA.

Bates, E., Benigni, L., Bretherton, I., Camaioni, L. and Volterra, V. (1979). *The emergence of symbols: cognition and communication in infancy*. Academic Press, New York.

Bauer, P. J. and Mandler, J. M. (1989). One thing follows another: effects of temporal structure on 1- to 2-year-olds' recall of events. *Developmental Psychology* **25**, 197–206.

Bauer, P. J. and Shore, C. M. (1987). Making a memorable event: effects of familiarity and organization on young children's recall of action sequences. *Cognitive Development* **2**, 327–38.

Benedict, H. (1979). Early lexical development: comprehension and production. *Journal of Child Language* **6**, 183–200.

Bornstein, M. H. (1985). Habituation of attention as a measure of visual information processing in human infants: summary, systematization, and synthesis. In *Measurement of audition and vision in the first year of life* (ed. G. Gottlieb and N. A. Krasnegor), Ablex, Norwood, NJ.

Borton, R. W. (1979). The perception of causality in infants. Presented at the Meeting of the Society for Research in Child Development, San Francisco, CA, March 1979.

Brazelton, T. B., Koslowski, B., and Main, M. (1974). The origins of reciprocity: the early mother–infant interaction. In *Origins of behavior* (ed. M. Lewis and L. Rosenblum), Wiley, New York.

Bretherton, I., McNew, S., and Beeghly-Smith, M. (1981). Early person knowledge as expressed in gestural and verbal communication: when do infants acquire a 'theory of mind'? In *Infant social cognition* (ed. M. Lamb and L. R. Sherrod). Erlbaum, Hillsdale, NJ.

Bruner, J. S. (1975). From communication to language: a psychological perspective. *Cognition* **3**, 255–87.

Butterworth, G. and Grover, L. (1988). The origins of referential communication in human infancy. In *Thought without language* (ed. L. Weiskrantz). Clarendon Press, Oxford.

Campos, J. J. and Stenberg, C. R. (1981). Perception, appraisal, and emotion: the onset of social referencing. In *Infant social cognition* (ed. M. E. Lamb and L. R. Sherrod). Erlbaum, Hillsdale, NJ.

Carey, S., Klatt, L. and Schlaffer, M. (1992). Infants' representations of objects and nonsolid substances. Unpublished manuscript, Massachusetts Institute of Technology.

Caron, A. J., Caron, R. F., and MacLean, D. J. (1988). Infant discrimination of naturalistic emotional expressions: the role of face and voice. *Child Development* **59**, 604–16.

Cohn, J.F. and Elmore, M. (1988). Effect of contingent changes in mothers' affective expression on the organization of behavior in 3-month-old infants. *Infant Behavior and Development* **11**, 493–505.

Cohn, J. F. and Tronick, E. Z. (1988). Mother–infant face-to-face interaction: influence is bidirectional and unrelated to periodic cycles in either partner's behavior. *Developmental Psychology* **24**, 386–92.

DeVries, R. (1987). Children's conceptions of shadow phenomena. *Genetic Psychology Monographs* **112**, 479–530.

Ehrlich, S. (1993). Infant perception of gaze direction. Presented to the Meeting of the Society for Research in Child Development, New Orleans, LA.

Ellsworth, C. P., Muir, D. W., and Hains, S.M.J. (1993). Social competence and person–object differentiation: an analysis of the still-face effect. *Developmental Psychology* **29**, 63–73.

Feinman, S. and Lewis, M. (1983). Social referencing at 10 months: a second order effect on infants' responses to strangers. *Child Development* **54**, 878–87.

Fernald, A. (1993). Approval and disapproval: infant responsiveness to vocal affect in familiar and unfamiliar languages. *Child Development* **64**, 657–74.

Field, T. (1977). Effects of early separation, interactive deficits, and experimental manipulation on infant-mother face-to-face interaction. *Child Development* **48**, 763–71.

Field, T. (1982). Infant arousal, attention, and affect during early interactions. In *Advances in infancy research*, Vol. 1, (ed. L. Lipsitt). Ablex, Norwood, NJ.

Field, T. and Walden, T. (1981). Production and perception of facial expressions in infancy and early childhood. In *Advances in child development and behavior* (ed. H. W. Reese and L. P. Lipsitt). Academic Press, New York.

Field, T. M., Woodson, R., Greenberg, R., and Cohen, D. (1982). Discrimination and imitation of facial expressions by neonates. *Science* **218**, 179–81.

Field, T., Goldstein, S., Vega-Lahr, N., and Porter, K. (1986*a*). Changes in imitative behavior during early infancy. *Infant Behavior and Development* **9**, 415–21.

Field, T., Vega-Lahar, N., Scafidi, F., and Goldstein, S. (1986*b*). Effects of maternal unavailability on motion–infant interactions. *Infant Behavior and Development* **9**, 473–8.

Gelman, R. (1990). First principles organize attention to and learning about relevant data: number and the animate–inanimate distinction as examples. *Cognitive Science* **14**, 79–106.

Golinkoff, R. M. (1983). Infant social cognition: self, people and objects. In *Piaget and the foundations of knowledge* (ed. L. S. Liben). Erlbaum, Hillsdale, NJ.

Golinkoff, R. M., Harding, C. G., Carlson, V., and Sexton, M. E. (1984). The infant's perception of causal events: the distinction between animate and inanimate objects. In *Advances in infancy research* (ed. L. P. Lipsitt and C. Rovee-Collier). Ablex, Norwood, NJ.

Gusella, J. L., Muir, D. W., and Tronick, E. Z. (1988). The effect of manipulating maternal behavior during an interaction on 3- and 6-month-olds' affect and attention. *Child Development* **59**, 1111–24.

Hains, S. M. J., Rehkopf, B., and Case, A. (1992). Facial orientation of parents and elicited smiling by infants. *Infant Behavior and Development* **15**, 444.

Haviland, J. M. and Lelwica, M. (1987). The induced affect response: 10-week-old infants' responses to three emotional expressions. *Developmental Psychology* **23**, 97–104.

Hornick, R., Risenhoover, N., and Gunnar, M. (1987). The effects of maternal positive, neutral, and negative affective communications on infant responses to new toys. *Child Development* **58**, 937–44.

Huttenlocher, J. and Smiley, P. (1990). Emerging notions of persons. In *Psychological and biological approaches to emotion* (ed. N. Stein, B. Leventhal, and T. Trabasso). Erlbaum, Hillsdale, NJ.

Jones, S. S., Collins, K., and Hong, H. (1991). An audience effect on smile production in ten-month-old infants. *Psychological Science* **2**, 45–9.

Kestenbaum, R., Ternine, N., and Spelke, E. S. (1987). Perception of objects and object boundaries by three-month-old infants. *British Journal of Developmental Psychology* **5**, 367–83.

Legerstee, M. (1991). The role of person and object in eliciting early imitation. *Journal of Experimental Child Psychology* **51**, 423–33.

Legerstee, M. (1992). A review of the animate–inanimate distinction in infancy: implications for models of social and cognitive knowing. *Early Development and Parenting* **1**, 59–67.

Legerstee, M. (1994). Patterns of 4-month-old infant responses to hidden silent and sounding people and objects. *Early Development and Parenting* **3(2)**, 71–80.

Legerstee, M., Pomerleau, A., Malcuit, G., and Feider, H. (1987). The development of infants' responses to people and a doll: implications for research in communication. *Infant Behavior and Development* **10**, 81–95.

Legerstee, M., Corter, C., and Kienapple, K. (1990). Hand, arm and facial actions of young infants to a social and non-social stimulus. *Child Development* **61**, 774–84.

Leslie, A. M. (1982). The perception of causality in infants. *Perception* **11**, 173–86.

Leslie, A. M. (1984). Spatiotemporal continuity and the perception of causality in infants. *Perception* **13**, 287–305.

Leslie, A. M. (1988). The necessity of illusion: perception and thought in infancy. In *Thought without language* (ed. L. Weiskrantz). Clarendon Press, Oxford.

Leslie, A. M. (1991). Infants' understanding of invisible displacement. Presented at the Meeting of the Society for Research in Child Development, Seattle, WA.

Leslie, A. M. and Keeble, S. (1987). Do six-month-old infants perceive causality? *Cognition* **25**, 265–88.

Liwag, M. D. and Stein, N. L. (1993). The effects of retrieval instructions on children's memory for emotion episodes. Presented at the Meeting of the Society for Research in Child Development, New Orleans, LA.

Mandler, J. M. (1992). How to build a baby II: conceptual primitives. *Psychological Review* **99**, 587–604.

Meltzoff, A. N. and Moore, M. K. (1977). Imitation of facial and manual gestures by human neonates. *Science* **198**, 75–78.

Meltzoff, A. N. and Moore, M. K. (1983). Newborn infants imitate adult facial gestures. *Child Development* **54**, 702–9.

Meltzoff, A. N. and Moore, M. K. (1992). Early imitation within a functional framework: the importance of person identity, movement, and development. *Infant Behavior and Development* **15**, 479–505.

Michotte, A. (1963). *The perception of causality* Basic Books, New York.

Muir, D. W. and Hains, S. M. J. (1993). Infant sensitivity to perturbations in adult facial, vocal, tactile, and contingent stimulation during face to face interactions. In *Developmental neurocognition: speech and face processing in the first year* (ed. B. de Boysson-Bardies, S. de Schonen, P. Jusczyk, P. McNeilage, and J. Morton). Kluwer, Dordrecht.

Murphy, C. M. and Messer, D. J. (1977). Mothers, infants and pointing: a study of a gesture. In *Studies in mother–infant interaction* (ed. H. R. Schaffer). Academic Press, London.

Oakes, L. M. (1993). The perception of causality by 7- and 10-month-old infants. Presented at the Meeting of the Society for Research in Child Development, New Orleans, LA.

Oakes, L. M. and Cohen, L. B. (1990). Infant perception of a causal event. *Cognitive Development* **5**, 193–207.

O'Neill, D. (1993). Two-year-olds' ability to provide their mothers with knowledge. Presented at the Meeting of the Society for Research in Child Development, New Orleans, LA.

Oster, H. (1981). 'Recognition of emotional expressions in infancy? In *Infant social cognition: empirical and theoretical considerations* (ed. M. E. Lamb and L. R. Sherrod), pp. 85–125. Erlbaum, Hillsdale, NJ.

Pelaez-Nogueras, M. (1993). Infant learning to reference maternal emotional cues. Unpublished doctoral dissertation, Florida International University.

Pelaez-Nogueras, M. and Gewirtz, J. L. (1993). Mothers' contingent imitation increases infant vocalizations. Presented at the Meeting of the Society for Research in Child Development, New Orleans, LA.

Poulin-Dubois, D. and Schultz, T. R. (1988). The development of the understanding of human behavior: from agency to intentionality. In *Developing theories of mind* (ed. J. W. Astington, P. L. Harris, and D. R. Olson), pp. 109–25. Cambridge University Press.

Premack, D. (1990). The infant's theory of self-propelled objects. *Cognition* **36**, 1–16.

Rach-Longman, K. and Muir, D. W. (1990). Three-month-olds' responses to televised upright and inverted faces of their mothers and a stranger during face-to-face interactions. *Infant Behavior and Development* **3**, 576.

Reissland, N. (1988). Neonatal imitation in the first hour of life: observations in rural Nepal. *Developmental Psychology* **24**, 464–9.

Rosen, W. D., Adamson, L. B. and Bakeman, R. (1992). An experimental investigation of infant social referencing: mothers' messages and gender differences. *Developmental Psychology* **28**, 1172–8.

Ross, H. S. and Lollis, S. P. (1987). Communication within infant social games. *Developmental Psychology* **23**, 241–8.

Rovee-Collier, C. K., Earley, L. and Stafford, S. (1989). Ontogeny of early event

memory: III. Attentional determinants of retrieval at 2 and 3 months. *Infant Behavior and Development* **12**, 147–61.

Scaife, M. and Bruner, J. S. (1975). The capacity for joint visual attention in the infant. *Nature, London* **253**, 265.

Scollon, R. (1976). *Conversations with a one-year-old*. University of Hawaii Press, Honolulu, HI.

Shatz, M. (1983). Communication. In *Handbook of child psychology*, Vol. 3, *Cognitive development* (ed. J. H. Flavell and E. M. Markman), pp. 841–89. Wiley, New York.

Shatz, M., Wellman, H. M. and Silber, S. (1983). The acquisition of mental verbs: a systematic investigation of the first reference to mental states. *Cognition* **14**, 301–21.

Sitskoorn, H. M. and Smitsmon, A. W. (submitted). *Infants' perception of object relations: passing through a support*?

Sorce, J., Emde, R., Campos, J. and Klinnert, M. (1985). Maternal emotional signaling: its effect on the visual cliff behavior of 1-year-olds. *Developmental Psychology* **21**, 195–200.

Spelke, E. S. (1985). Preferential looking methods as tools for the study of cognition in infancy. In *Measurement of audition and vision in the first year of postnatal life* (ed. G. Gottlieb and N. Krasnegor). Ablex, Norwood, NJ.

Spelke, E. S. (1988). Where perceiving ends and thinking begins: the apprehension of objects in infancy. In *Perceptual development in infancy. Minnesota Symposium on Child Psychology*, Vol. 20 (ed. A. Yonas). Erlbaum, Hillsdale, NJ.

Spelke, E. S. and Van de Walle, G. (1993). Perceiving and reasoning about objects: insights from infants. In *Spatial representation* (ed. N. Eilan, W. Brewer, and R. McCarthy). Blackwell, New York.

Spelke, E. S., von Hofsten, C. and Kestenbaum, R. (1989). Object perception and object-directed reaching in infancy: interaction of spatial and kinetic information for object boundaries. *Developmental Psychology* **25**, 185–96.

Spelke, E. S., Breinlinger, K., Macomber, J. and Jacobson, K. (1992). Origins of knowledge. *Psychological Review* **99**, 605–32.

Spelke, E. S., Katz, G., Purcell, S. E., Ehrlich, S. M. and Breinlinger, K. (1994). Early knowledge of object motion: continuity and inertia. *Cognition* **51(2)**, 131–76.

Spelke, E. S., Breinlinger, K., Jacobson, K. and Phillips, A. Gestalt relations and object perception in infancy: a developmental study. *Perception* **22**, 1483–501.

Stern, D. N. (1974). Mother and infant at play. In *The effect of the infant on its caregiver* (ed. M. Lewis and L. Rosenblum). Wiley, New York.

Stevenson, M. B., Hoeve, J. N. V., Roach, M. A. and Leavitt, L. A. (1986). The beginning of conversation: early patterns of mother–infant vocal responsiveness. *Infant Behavior and Development* **9**, 423–40.

Stewart, J. (1984). Object motion and the perception of animacy. Presented at the Meeting of the Psychonomic Society, San Antonio, TX.

Tomasello, M. (1993). Acquiring words in non-ostensive context. Paper presented at the Meeting of the Society for Research in Child Development, New Orleans, LA.

Travis, L. L. (1993). Goal-based orizanization of event memory in toddlers. Presented at the Meeting of the Society for Research in Child Development, New Orleans, LA.

Trevarthen, C. (1977). Descriptive analyses of infant communicative behavior. In

Studies in mother–infant interaction (ed. H. R. Schaffer). Academic Press, London.
Trevarthen, C. (1979). Communication and cooperation in early infancy: A description of primary intersubjectivity. In *Before speech: the beginning of interpersonal communication* (ed. M. Bullowa), pp. 321–47. Cambridge University Press.
Tronick, E. (1981). Infant communicative intent: the infant's reference to social interaction. In *Language behavior in infancy and early childhood* (ed. R. E. Stark). Elsevier, New York.
Tronick, E., Als, H., Adamson, L., Wise, S. and Brazelton, T. B. (1978). The infant's response to entrapment between contradictory messages in face-to-face interaction. *Journal of the American Academy of Child Psychiatry* **17**, 1–13.
Tronick, E. Z., Cohn, J. and Shea, E. (1986). The transfer of affect between mothers and infants. In *Affective development in infancy* (ed. T. B. Brazelton and M. W. Yogman, pp. 11–25. Ablex, Norwood, NJ.
Van de Walle, G. and Spelke, E. S. (1993). Integrating information over time: infant perception of partly occluded objects. Presented at the Meeting of the Society for Research in Child Development, New Orleans, LA.
Vinter, A. (1986). The role of movement in eliciting early imitations. *Child Development* **57**, 66–71.
Van de Walle, G., Woodward, A. L. and Phillips, A. (1994). Infants' inferences about contact relations in a causal event. Presented at the IXth Biennial Meeting of the International Society for Infant Studies, Paris.
van Hofsten, C. and Spelke, E. S. (1985). Object perception and object-directed reaching in infancy. *Journal of Experimental Psychology: General* **114**, 198–212.
Walden, T. A. and Baxter, A. (1989). The effect of context and age on social referencing. *Child Development* **60**, 1511–18.
Walden, T. A. and Ogan, T. A. (1988). The development of social referencing. *Child Development* **59**, 1230–40.
Walker, A. S. (1982). Intermodal perception of expressive behaviors by human infants. *Journal of Experimental Child Psychology* **33**, 514–35.
Walker-Andrews, A. S. and Grolnick, W. (1983). Infants' discrimination of vocal expressions. *Infant Behavior and Development* **6**, 491–8.
Walker-Andrews, A. S. and Lennon, E. (1991). Infants' discrimination of vocal expressions: Contributions of auditory and visual information. *Infant Behavior and Development* **14**, 131–42.
Watson, J. S. (1972). Smiling, cooing, and 'the game'. *Merrill-Palmer Quarterly* **118**, 323–40.
Wellman, H. M. and Wooley, J. D. (1990). From simple desires to ordinary beliefs: the early development of everyday psychology. *Cognition* **35**, 245–75.
Wilcox, T., Rosser, R., and Nadel, L. (submitted). *Location memory in young infants.*
Woodward, A. L., Phillips, A. and Spelke, E. S. (1993). Infants' expectations about the motion of animate versus inanimate objects. Proceedings of the Fifteenth Annual Meeting of the Cognitive Science Society, Boulder, CO, pp. 1087–91. Erlbaum, Hillside, NJ.
Wynn, K. (1992). Addition and subtraction by human infants. *Nature* **358**, 749–50.
Xu, F. and Carey, S. (1992). Infants' concept of numerical identity. Presented at the Boston University Language Acquisition Conference.

4

The acquisition of physical knowledge in infancy

RENEE BAILLARGEON, LAURA KOTOVSKY, AND AMY NEEDHAM

INTRODUCTION

What role does causality play in the development of infants' physical reasoning? The answer to this question naturally depends on *how* we define causality. On the one hand, we might characterize causal reasoning at a very general level in terms of the construction of conceptual descriptions that capture regularities in the displacements of objects and their interactions with other objects. On the other hand, we might take causality to mean something far more specific associated with the formation of sequences in which one event is understood to bring about another event through the transmission of force or some other generative process.

In this chapter we focus primarily on the first of the two definitions listed above. There is now considerable evidence that, in learning about physical events, infants construct increasingly elaborate descriptions that enable them to arrive at increasingly accurate predictions about the events. How does this construction process take place? Over the past few years, we have begun to build a model of the development of infants' physical reasoning. This model is based on the assumption that infants are born, not with substantive beliefs about objects, as Leslie (1988; Chapter 5 of this volume) and Spelke and her colleagues (Spelke 1991; Spelke *et al.* 1992; Chapter 3 of this volume) have proposed, but with a highly constrained mechanism that guides infants' acquisition of knowledge about objects. The model is derived from findings concerning the development of infants' intuitions about different phenomena (for example support, collision, unveiling, arrested-motion, occlusion, and containment phenomena). Comparison of these findings points to a developmental pattern that recurs across ages and phenomena. We assume that this pattern reflects, at least indirectly, the nature and properties of infants' innate learning mechanism.

In what follows, we describe the developmental pattern identified in