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Infants selectively encode the goal object of an actor's reach

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Abstract

Research with young children has shown that, like adults, they focus selectively on the aspects of an actor's behavior that are relevant to his or her underlying intentions. The current studies used the visual habituation paradigm to ask whether infants would similarly attend to those aspects of an action that are related to the actor's goals. Infants saw an actor reach for and grasp one of two toys sitting side by side on a curtained stage. After habituation, the positions of the toys were switched and babies saw test events in which there was a change in either the path of motion taken by the actor's arm or the object that was grasped by the actor. In the first study, 9-month-old infants looked longer when the actor grasped a new toy than when she moved through a new path. Nine-month-olds who saw an inanimate object of approximately the same dimensions as the actor's arm touch the toy did not show this pattern in test. In the second study, 5-month-old infants showed similar, though weaker, patterns. A third study provided evidence that the findings for the events involving a person were not due to perceptual changes in the objects caused by occlusion by the hand. A fourth study replicated the 9 month results for a human grasp at 6 months, and revealed that these effects did not emerge when infants saw an inanimate object with digits that moved to grasp the toy. Taken together, these findings indicate that young infants distinguish in their reasoning about human action and object motion, and that by 6 months infants encode the actions of other people in ways that are consistent with more mature understandings of goal-directed action. © 1998 Elsevier Science B.V. All rights reserved

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1. Introduction

Adults have a rich store of domain specific knowledge that enables them to make sense of the behavior of other people. This folk psychology or theory of mind explains behavior in terms of an actor's probable psychological states (D'Andrade, 1987; Dennett, 1987; Wellman, 1992). If a person stopped walking suddenly with eyes fixed on a spot on the ground and then moved purposefully toward that spot, for example, an observer might hypothesize that the person had seen an object and then intended to retrieve it. Research with preschool children has documented that they share this propensity to reason about the behavior of a person with respect to that person's probable psychological states (e.g., Astington et al., 1988; Stein and Levine, 1989; Lillard and Flavell, 1990; Wellman, 1992). Recent findings suggest that even 1- and 2-year-olds are able to reason about the intentions of another person in some contexts (Baldwin, 1991; Tomasello and Barton, 1994; Meltzoff, 1995). The studies reported here explore the precursors of this ability during the first year of life.

Recent research has revealed much about the structure of cognition during the first year. Young infants have been found to reason about one set of phenomena, the motions of inanimate objects, in accord with basic physical principles. By 3 or 4 months of age, infants expect that two objects will not occupy the same space and that objects will exist and move continuously in time and space (Baillargeon, 1987, 1993; Spelke, 1990; Spelke et al., 1992). At later ages in infancy, these physical conceptions are enriched and differentiated (Oakes and Cohen, 1990; Spelke et al., 1992; Baillargeon, 1993, 1995; Xu and Carey, 1996). Nevertheless, these cognitive structures are of limited value in reasoning about human action. Although infants' understanding of object physics might help them to reason about some aspects of human behavior (e.g., people, like boxes and balls, cannot pass through walls), a useful system for understanding human action would have to diverge from object physics (Gelman and Spelke, 1981; Dennett, 1987; Spelke et al., 1995).

Do young infants reason in specific and appropriate ways about the actions of other people? Two bodies of empirical work suggest that they might. First, infants have been shown to respond to people and inanimate objects differently (Legerstee et al., 1987; Legerstee et al., 1990; Ellsworth et al., 1993) and to be attuned to specific features that would serve to identify people, such as biological patterns of motion (Bertenthal, 1993) and faces (Morton and Johnson, 1991). These findings leave little doubt that even very young infants can distinguish between people and inanimate objects. Second, many researchers have documented the fact that young infants participate in well orchestrated interactions with their caretakers (Trevarthen, 1979; Tronick et al., 1979; Cohn and Elmore, 1988; Cohn and Tronick, 1988). Experiments that tease apart aspects of this interaction such as its timing and contingency and the presence of eye contact (Cohn and Elmore, 1988; Gusella et al., 1988; Ellsworth et al., 1993; Muir and Hains, 1993) suggest that young infants are sensitive to a spectrum of social behaviors. Nevertheless, the existence and nature of this sensitivity has sometimes been questioned (e.g., Rochat, 1996). More generally, observations of naturally occurring social behaviors alone do not tell us how much infants, as opposed to parents, bring to the structure of the interaction, nor do they allow us to draw specific conclusions about babies' ability to reason in this domain (see Moore and Corkum, 1994; Spelke et al., 1995).

The visual habituation paradigm provides a tool for probing infants' reasoning in this domain more precisely. A common logic employed in the use of this method is to habituate infants to an event that can be described along two dimensions. Then infants are shown two test events, each of which preserves one dimension and varies the other. Since infants will look longer at an event that seems new to them following habituation, longer looks to one test event over the other indicate that the infant has encoded the dimension that was changed. Variants of this logic have been used to assess babies' understanding of causal relations (Leslie and Keeble, 1987; Oakes and Cohen, 1990), object permanence (Baillargeon et al., 1985), and gravity (Spelke et al., 1992), among other phenomena. In studies of this sort, researchers often contrast the surface features of an event to its deeper, principle-relevant aspects. This method could be used to explore infants' reasoning about human behavior, therefore, by isolating a dimension of an action that is central to principled understanding in older children and adults, and then assessing whether infants show greater recovery to a change in this dimension than to other, more superficial changes in the action.

By many accounts, the notion of goal-directedness is a central component of folk theories of mind in children and adults (D'Andrade, 1987; Dennett, 1987; Poulin-Dubois and Schultz, 1988; Wellman, 1992). In describing this notion in folk psychology, D'Andrade writes, 'complex human actions are assumed to be voluntary unless something indicates otherwise. A voluntary action is one in which someone did something to accomplish some goal' (1987, p. 120). This has been theorized to be among the first elements present in children's reasoning about human behavior, preceding an understanding of beliefs and other cognitive processes (Poulin-Dubois and Schultz, 1988; Premack, 1990; Wellman, 1992; Leslie, 1993). In fact, three recent studies lend support to the conclusion that 1- and 2-year-olds draw on a notion of the goals of an actor when reasoning about behavior.

Tomasello and Barton (1994) found that 2-year-olds used behavioral cues to an actor's intentions when interpreting a new verb. In their study, an experimenter introduced the child to a novel verb (saying, e.g., 'Let's dax Mickey Mouse.') and then proceeded to perform two novel actions, one apparently accidental, the other apparently purposeful. Regardless of which action came first, 2-year-olds interpreted the verb as the name for the purposeful action rather than the accidental one. Since each of the two actions used was given 'purposefully' for half of the children, this effect could not have been due to any difference in salience between the two actions. Instead, children must have inferred that the speaker intended to refer to the act that was done on purpose rather than the act that was apparently accidental.

Using spontaneous imitation as a measure of children's reasoning, Meltzoff (1995) asked whether 18-month-olds who saw an actor fail to complete an action would infer what the intended action had been, and would imitate the inferred complete action rather than the motions the actor produced in the attempt. Children were introduced to a series of novel toys that could be acted on in specific ways. For example, one of the toys was a box with a hole in it and a peg that could be placed in the hole (the target action). For some of the children, an experimenter demonstrated the target action. For others, the experimenter acted out a failed attempt to complete the action. For example, he picked up the peg and moved it toward the hole, but missed, hitting the box just above the hole. Strikingly, children who saw the failed attempt produced a correct imitation of the target action just as often as children who saw the target action completed. That is, children did not imitate just what they saw the experimenter do (miss the hole), but instead inferred what he intended to do and imitated that action. Control conditions showed that children only inferred an intended outcome when the actor was human, and did not produce the target action when neither the attempt nor the successful action were modeled. Thus, for events involving a human actor, 18-month-olds disregarded the spatiotemporal aspects of an action in service of inferring the intended outcome.

Gergeley et al. (1995) report findings from an habituation study done with 12-month-old babies that support a similar conclusion. Babies saw animated sequences of events involving circles that underwent animate-like motion. Adults who watched the films described the circles as intentional agents who wanted to attain certain goals. Infants were habituated to an event in which a circle moved around a barrier to arrive at a second circle. Then they saw two test events in which the barrier had been removed. In one event, the first circle moved along the same circuitous path to arrive at the second circle; in the other event, the first circle moved in a straight line to arrive at the second circle. Infants looked longer at the former test event, even though the path taken by the circle was the same as in habituation. Because the sequences were structured in a way that made the circle look as if it were acting to attain a goal (getting to the other circle), Gergeley et al. (1995) concluded that babies reasoned that the circle would act in the most direct way to meet the goal once the barrier had been removed.

In each of these studies, children focused selectively on some aspects of the actions they witnessed, namely, those aspects that were relevant to the actor's goals. In the study of Tomasello and Barton (1994), children used behavioral cues to determine which of two acts was intentional, and disregarded actions not relevant to the intentions of the actor. The studies by Meltzoff (1995) and Gergeley et al. (1995) provide evidence that children attend selectively to the intended goal of the action, weighting this information more heavily than other spatiotemporal details of the motion of the actor.

These findings suggest that one place to begin to look at younger infants' reasoning about human action is to see whether infants attend selectively to aspects of an action that are related to the goals of the actor. The present studies approached this question by assessing infants' encoding of a simple goal-directed action: reaching toward and grasping an object. This action is one that young infants can themselves perform: by about 4 months of age, infants are able to reach toward and grasp both stationary and moving objects (Hofsten, 1983; Thelen et al., 1993; Bertenthal and Clifton, 1997). Moreover, this is an action that infants have likely observed frequently in other people. If infants have begun to construct an understanding of action as object-directed, it might first be evident for a familiar action such as grasping.

Research by Leslie (1982, 1984) confirms that infants understand one aspect of grasping events, namely, the fact that hands must be in contact with objects in order to move them. In Leslie's studies, infants were habituated to a filmed event in which an actor, who was hidden except for the arm and hand, grasped and picked up a doll. Then infants saw one of two test events. In one, the same event was shown, but in mirror image, so that if the actor had reached in from the right during habituation, he reached in from the left during test. In the other, the actor reached in from the same side as during habituation, but stopped before his hand touched the doll. The doll and the hand then moved off together, still spatially separated, the doll moving apparently on its own. Infants showed greater dishabituation to the change in contact between hand and doll than to the change in direction of reach, suggesting that they judged contact to be a more important feature of the event than direction of reach. Babies who saw similar events involving a box instead of a person's arm did not show this pattern. Babies who saw events in which a hand grasped the doll but did not lift it also failed to show these effects. Thus, for events in which a person moved an object by picking it up, infants focused selectively on whether the hand and object were in contact, suggesting that they understood that this is a critical component of such 'pick up' events.

Recent work by Baillargeon and her colleagues enriches this picture of infants' knowledge about relations between hands and objects. Infants as young as 3–4 months understand that an object is adequately supported when grasped by a hand, but not when the hand releases it (Needham and Baillargeon, 1993; Baillargeon, 1995). By 5–1/2 months, infants also understand some of the constraints on an actor's ability to retrieve an object; they show surprise when an actor retrieves an object without first removing a barrier that is between the hand and the object (Baillargeon et al., 1990).

While these findings suggest that infants understand some aspects of the mechanics of grasping and lifting, they do not shed light on whether infants would encode the behavior of an actor who grasps a toy in terms of its goal or in terms of its salient spatiotemporal properties. The studies reported here address this question. In the first two studies, infants were habituated to an event in which an actor reached toward and grasped one of two toys which were side by side on a stage (see Fig. 1). In contrast to the events used by Leslie (1982, 1984), the actor did not lift the toy, but instead remained still while grasping it. After habituation, the positions of the toys were switched and infants saw two test events in alternation. In one event, the path of the original reach was preserved, and, because the toys had been switched, the actor grasped a different toy than in habituation. In the other event, the path of the habituation reach was altered, and the actor grasped the same toy as in habituation. Since the actor stood to one side of the toys, the change in path of motion was designed to be perceptually salient. The reach to the nearer toy ended with just the top of her forearm showing, whereas the reach to the far toy ended with her entire arm (clothed in a magenta sleeve) in view of the infant. If infants attend primarily to the spatiotemporal aspects of the reach during habituation, then this

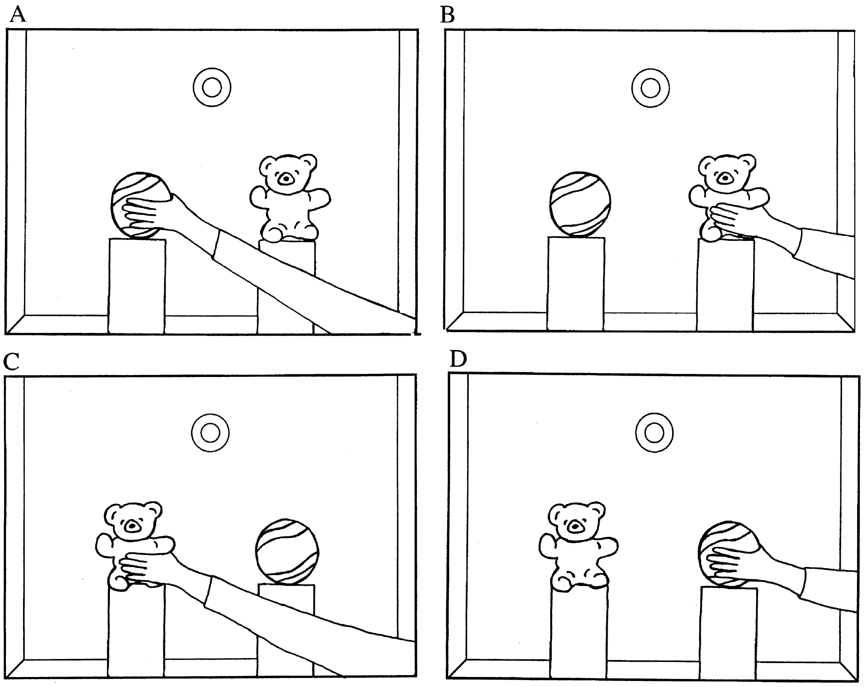

Fig. 1. Events for the hand condition in Studies 1 and 2.

salient change in path of motion might elicit more looking. In contrast, if infants attend selectively to the goal object of the reach during habituation, then the change in target object should elicit more looking.

To test whether infants would attend differently to a similar event involving an inanimate object, another group of infants saw events in which a rod moved toward and touched the toys (see Fig. 2). The rod possessed many of the same superficial features as the actor's arm: it was covered in magenta paper and topped with a nubbly tan sponge that deformed slightly on contact with the toys. This condition provides a control for one possible explanation for positive findings in the person condition: If infants look longer at the event in which the actor grasps a new toy, this could be due to the motion of the arm acting as a salience enhancer, directing the child's attention to one toy in habituation, and then a new toy in this event. If this explanation is correct, the same pattern of findings would be expected when an inanimate object moves toward one of the toys and stops while touching it.

Note that this approach does not directly address the issue of whether infants infer that the actor has a particular intention. Rather, it asks whether infants attend to those spatiotemporal properties that are relevant to the actor's goal (e.g., the relation between the hand and the object) or those that are perceptually salient, but less relevant to the goal (e.g., the path of motion taken by the arm). If infants do attend

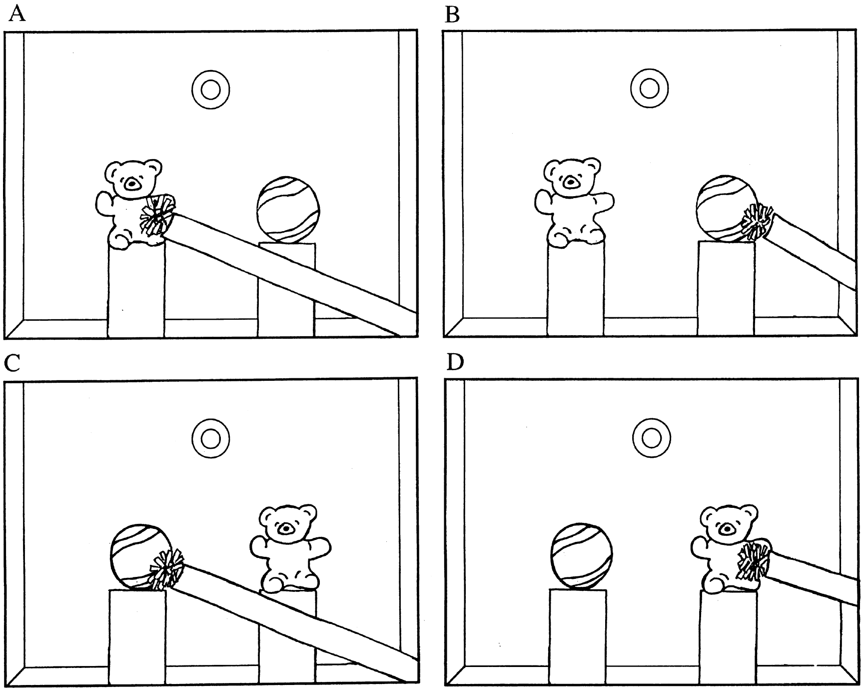

Fig. 2. Events for the rod condition in Studies 1 and 2.

selectively to the goal-related properties of the action, this raises the possibility that infants have knowledge of human action that shares features with mature knowledge. I will return to this question in the final section of the paper.

2. Study 1

2.1. Method

2.1.1. Participants

Thirty-two infants between the ages of 8 months 1 day and 10 months 23 days (mean age = 9 months 11 days) participated in the first study. They were full term infants from the city of Chicago and its suburbs, whose parents had been contacted through mailings and advertisements in local newspapers. Parents were given $10.00 to reimburse their travel expenses. Ten additional infants began the procedure but were not included in the final sample. Three of these infants failed to complete all trials because of fussiness and seven were excluded because of errors in the experimental procedure.

Half of the infants saw events in which an actor reached into a curtained stage area and grasped one of two toys (the hand condition). The other half of the infants saw similar events in which a decorated rod moved in and touched one of the toys (the rod condition). There were 9 boys and 7 girls in the hand condition (mean age = 9 months 12 days) and 7 boys and 9 girls in the rod condition (mean age = 9 months 11 days).

2.1.2. Procedure

Infants sat in a table top seat or on a parent's lap facing a stage 30 inches away. On the stage floor were two toys, a white teddy bear and a multi-colored ball each on pedestals 10.5 inches high and 10 inches apart. The back and sides of the stage were draped in black cloth and the pedestals were covered in black felt. A video camcorder was mounted just above and between the two toys, its lens protruding through a slit in the curtain. A white screen could be raised from below the stage to block the toys from view between trials. If the infant was seated on a parent's lap, the parent was instructed to look down at the baby rather than at the stage. If the infant was in the table top seat, the parent stood behind the table and the infant.

In the hand condition, the actor wore a magenta sweater. The actor's hand was bare, and she wore no rings or other jewelry. The rod was a poster tube covered in magenta paper and topped with a nubbly tan sponge decorated with red dots. The poster tube was approximately the size of the actor's arm, and the sponge deformed slightly on contact with the toy. The rod moved through paths similar to those taken by the actor's arm.

The infant's looking was coded by an observer who watched the infant on a video monitor, pressing a key on a computer keyboard when the infant looked at the area containing the toys and the arm or rod. A computer program calculated looking times and habituation criteria from this input (Pinto, 1994). The camera was placed so that the observer could not see the toys, the actor's arm or the rod. The observer was unaware of the order of test trials assigned to the infant. To assess reliability, a second observer, who was unaware of condition and order of test trials, coded each infant again from the videotaped record (see below).

At the start of each trial the screen was lowered to reveal the two toys. If the infant was not looking at the toys, the actor snapped behind the curtain to draw the infant's attention to the toys. Then, in the hand condition, the actor reached in through a slit in the right side curtain and grasped one of the toys. Only the actor's arm was visible to the infant. The actor remained still after grasping the toy. In the rod condition, the actor slid the rod into the stage area until the sponge on the end of the tube made contact with one of the toys. She then held the rod in place touching the toy for the rest of the trial.

The infant's looking was timed starting when the actor's hand or the rod made contact with the toy and continuing until the infant had looked away from the display for 2 s or until 120 s had elapsed. Thus, looking was timed as the baby saw the static display of the actor holding or rod touching one of the two toys. The observer began coding as soon as the screen was lowered, and a second experimenter, standing behind the infant, began the timing process by clicking the mouse once the actor's hand or the rod had stopped moving on contact with the toy. The time lag between the lowering of the screen and the beginning of timing was approximately 4.5 s for events in which the toy on the left side of the stage was touched or grasped and approximately 4 s for events in which the toy on the right side of the stage was touched or grasped. If the infant looked away before the motion of the arm or rod was complete, the trial was begun again.

For half of the infants, the toy on the right was the target of the grasp or rod touch, for the other half, the toy on the left was the target. Since side placement of the teddy bear and ball was counterbalanced, there were four possible habituation events for each condition (see Figs. 1 and 2). Four babies in each condition were habituated to each of the four events. Girls and boys were distributed approximately evenly across habituation events.

The habituation criterion was computed for each infant based on the first three trials that totaled to 12 s or more. An infant reached criterion after three trials that totaled to less than half of the sum of these trials. Thus, each infant had a minimum of six trials in habituation. If an infant did not set or reach a criterion, habituation was ended after 14 trials and test trials were begun.

At the start of the test phase, the screen was raised to hide the toys, and the positions of the toys were switched. The screen was then lowered and the baby was given one familiarization trial with the toys in their new positions with no hand or rod present. After this trial, each baby then saw two test events on alternating test trials for a total of three trials of each type. In one event (the old goal/new path event) the actor reached in and grasped (or touched with the rod) the same toy as had been grasped/touched during habituation. Since this toy was in a new position, the actor's arm or rod moved through a new path in order to make contact with the toy. In the other event (the new goal/old path event) the actor moved her arm or the rod through the same path as in habituation, thus ending up grasping/touching a new toy. To illustrate, a baby who was habituated to event A in Fig. 1 would see events C (new goal/old path) and D (old goal/new path) in test. Half of the babies in each habituation condition saw the old goal/new path event first, the other half saw the new goal/old path event first.

2.2. *Reliability coding*

Although on-line observers were not informed of the order of trial types, an experienced observer may be able to use cues in the infants' behavior as a basis for guessing, e.g., whether on a given trial the baby sees a reach to the left or right side of the display, and thus be able to make an educated guess about whether a given test trial was an old goal/new path trial or a new goal/old path trial. This possibility for 'infant communicated bias' has been a concern for infancy researchers, who have employed several strategies for minimizing and testing for this source of bias.

In the current studies, one observer coded each infant's looking on-line. To assess the reliability of the on-line observing, a second observer re-coded the video record for each infant. On-line observers were always uninformed about the order of test trial types (new goal versus old goal first), but were not always unaware of condition (hand versus rod). The video observers were unaware of both test trial order and condition. In fact, video observers were unaware of the fact that there had been a rod condition. These observers started to work in the lab after the completion of this study at a time when the studies being run involved only hands. They were not told about specific details of this study until after they had completed the reliability coding.

The on-line and video observers' judgments of trial endings were compared for each trial. Observers were counted as agreeing only if there was no detectable difference between the beep signaling the trial end on the video observer's computer and the beep recorded on the videotape for the on-line observer. On this analysis, the two observers agreed on 82% of trial endings in the hand condition and 88% of trial endings in the rod condition.

Although the amount of discrepancy between the two observers was small, if discrepancies occurred systematically on some trial types and in some directions, then even a small percentage of biased trials could have contributed to artifactual findings. To assess this possibility, the trial ending disagreements in each condition were categorized into two sets: those disagreements for which, if the on-line data were biased, this bias would have contributed to the hypothesized pattern of findings and those disagreements for which potential bias in the on-line observing would have worked against the hypothesized pattern of findings. Disagreements were randomly distributed across these categories for the two conditions, χ^2 (d.f. = 1) = 1.55, $P = 0.21$. Thus, the distribution of disagreements between observers did not suggest that either on-line or video observers were systematically biased in favor of the hypothesized pattern of results.

2.3. Results

Table 1 summarizes infants' looking times for the habituation and test trials in each condition. The patterns of looking during habituation did not differ for babies in the two conditions. Infants in the hand condition averaged 8.3 habituation trials and infants in the rod condition averaged 9.3 ($t < 1$). On the last habituation trial, the two groups had the same level of looking: Babies in the hand condition looked an average of 3.7 s on the final habituation trial and babies in the rod condition looked 3.5 s ($t < 1$). Three infants in each condition completed 14 habituation trials without meeting the habituation criterion[1]. Thus, infants in the two conditions began test trials at comparable levels of attention.

Each infant's looking on the three old goal/new path and three new goal/old path trials was totaled (see Table 1). Planned comparisons revealed that infants in the hand condition looked longer on new goal/old path trials than on old goal/new path trials ($t(15) = 2.56$, $P < 0.05$). That is, they looked longer when the actor moved in the same way as in habituation, grasping a different toy. Infants in the rod condition, in contrast, looked equally on the two kinds of trials ($t(15) = 1.01$, $P = 0.33$). An analysis of variance conducted on the looking times for each trial with condition

[1]In this study, as well as in Studies 2–4, when infants who did not habituate were excluded from the main analyses, the interpretation of the results was not altered.

Table 1
Median total looking time during the last three habituation trials and the three test trials of each type for each study and condition (median absolute deviations are given in parentheses)

	Last 3 habituation trials	Test trials	
		New goal/old path	Old goal/new path
Study 1 (9 months)			
Hand	10.4 (1.7)	16.8 (6.1)**	13.3 (2.7)
Rod	8.6 (3.8)	15.8 (9.2)	18.6 (6.3)
Study 2 (5 months)			
Hand	18.7 (6.5)	19.1 (4.7)*	14.0 (4.4)
Rod	17.4 (7.6)	19.5 (8.8)	27.2 (12.3)
Study 3 (9 and 5 months)			
Flat occluder	14.3 (3.8)	18.0 (7.5)	17.4 (8.2)
Study 4 (6 months)			
Hand	14.0 (5.2)	23.0 (9.2)**	16.5 (9.5)
Claw	16.0 (3.4)	19.0 (12.4)	22.4 (9.6)

**Greater than comparison test event, $P < 0.05$.
*Marginally greater than comparison test event, $P = 0.08$.

(hand versus rod) as the between subjects factor and trial type (old goal/new path versus new goal/old path) and trial pair (first, second or third) as the within subjects factors revealed a significant condition × trial type interaction ($F(1,30) = 7.43$, $P < 0.05$), and a main effect of trial pair ($F(1,30) = 10.27$, $P < 0.0005$), indicating that looking time declined across pairs. There were no other reliable effects.

This pattern of findings was confirmed by non-parametric tests. Wilcoxon signed rank tests performed on the difference between total looking time to new goal/old path test events and old goal/new path test events for each infant confirmed that infants in the hand condition looked longer at the new goal/old path test events ($z = 2.22$, $P < 0.05$), and that infants in the rod condition did not differ in their looking to the two kinds of test events ($z < 1$). A Mann–Whitney test comparing the difference scores for babies in the hand condition to those of the babies in the rod condition confirmed that these conditions differed from one another ($z = 2.15$, $P < 0.05$). This difference is also reflected in the number of infants in each condition who looked for longer overall on new goal/old path versus old goal/new path test trials (see Table 2; χ^2 (d.f. = 1) = 3.24, $P = 0.07$).

In sum, infants in the hand condition looked longer at the new goal/old path test events, whereas infants in the rod condition did not prefer one type of test event to the other. This raises the secondary question of which changes babies in the rod condition noticed. It is possible that infants in the rod condition quickly lost interest in the test events, and thus did not notice either the change in path or the change in the object that was touched. The absence of a reliable main effect of condition in the analysis of variance argues against this conclusion. A second approach to this

Table 2
Number of infants in each study and condition who looked longer on new goal/old path vs. old goal/new path test trials

	New goal/old path trials	Old goal/new path trials
Study 1 (9 months)		
Hand (n = 16)	12	4
Rod (n = 16)	7	9
Study 2 (5 months)		
Hand (n = 16)	11	5
Rod (n = 16)	5	11
Study 3 (9 and 5 months)		
Flat occluder (n = 32)	17	15
Study 4 (6 months)		
Hand (n = 20)	17	3
Claw (n = 20)	8	12

question is to examine infants' recovery from habituation. If babies did not notice the change in path or goal object, then their looking would be expected to stay low relative to the final habituation trials. To test this, the amount of looking on the last three habituation trials was summed for each infant and compared to the total looking time on the three test trials of each type. Infants in the rod condition showed a reliable increase in looking compared to the last three habituation trials for both kinds of test trials ($t(15) = 2.67$, $P < 0.01$ and $t(15) = 2.52$, $P < 0.025$ (both one-tailed), for old goal/new path and new goal/old path trials, respectively). Thus, in this condition, infants noticed changes in both kinds of test events. In contrast, infants in the hand condition showed reliable recovery on new goal/old path trials ($t(15) = 2.14$, $P < 0.025$ (one-tailed)), but not on old goal/new path trials ($t(15) < 1$). In keeping with the main analyses, then, this analysis indicates that babies responded to a change in the object that was grasped by the actor, but not to a change in the path taken by the actor's arm. It is noteworthy that infants did not recover on these trials even though there were two potentially salient dimensions of change: the toys were in new places and the actor reached to a different location than during habituation.

What might this difference in patterns of looking indicate about the infant's understanding of human action? One possibility is that infants have a general attentional bias that leads them to look at hands. Such a bias might derive from the experience of seeing hands associated with many kinds of interesting events such as the motion of objects and the opening and closing of containers, or from hands simply being interesting objects. If this is the case, then the effects seen above could be explained by proposing that in the hand condition, babies mainly stared at the location of the actor's hand, which acted as an attentional 'magnet'. When, in the new goal test events, this magnet was placed on a new object, babies looked longer because something new was being highlighted. Under this explanation, babies in the rod condition did not show this pattern of looking because the end of the rod was less interesting to look at than the hand.

This possible explanation for the findings can be tested with data available from the videotapes. Because every baby was videotaped by a camera located between the two toys, it was possible to go back and code for each test trial the amount of time the baby looked at each of the two toys. If the actor's hand acted as a powerful attention magnet and the rod end did not, then babies in the hand condition would have spent more time looking at the hand's location than babies in the rod condition spent looking at the location of the end of the rod.

Observers who were unaware of the condition of each baby coded the videotapes frame by frame, tallying the total time each infant looked at the toy on the right and the toy on the left for each test trial. Eight babies, four from each condition, were randomly selected to be coded by both observers. The two coders were within 1 s of one another for 90% of observations.

For each trial, the proportion of the total trial spent looking at the toy held by the hand or touched by the rod (the match) and the proportion spent looking at the other toy (the non-match) was calculated. Mean proportions for each condition are given in Fig. 3. Since a baby could look at parts of the display that were not the location of either toy (e.g., the middle section of the rod or arm, or the space between the two toys), the proportions for match and non-match did not always sum to 100%. As an index of the effectiveness of the hand or rod as a spotlight, the difference in percentage of looking to the match and non-match toys was calculated. These scores were reliably higher than 0 for babies in both the hand and rod conditions ($t(15) = 5.09$, $P < 0.0001$ and $t(15) = 12.89$, $P < 0.0001$). The size of this disparity was reliably larger for infants in the rod condition than for infants in the hand condition ($t(30) = 3.30$, $P < 0.005$).

Thus, babies in both the rod and hand conditions showed a strong tendency to look at the location of the toy touched by the rod or hand. In fact, the spotlighting effects were stronger in the rod condition than in the hand condition. Therefore, the principal findings cannot be explained by a general bias to look at hands that exceeds interest in the end of the rod. More generally, this analysis suggests that the main findings result from selective encoding of the events, not selective attention to them. Babies allocated their visual attention in similar ways in the hand and rod conditions. However, babies in the hand condition differed from babies in the rod condition in terms of the features they weighted most heavily in their representation of the event.

2.4. Discussion

When they saw a person reach for and grasp an object, babies attended to the object that was grasped rather than to the path of motion taken by the actor's arm. The fact that this pattern was not obtained in the rod condition provides evidence that the findings in the hand condition were not due to the motion of the arm toward the toy acting as a salience enhancer. Since one quarter of the infants in each condition were habituated to each of the four possible events, these findings cannot

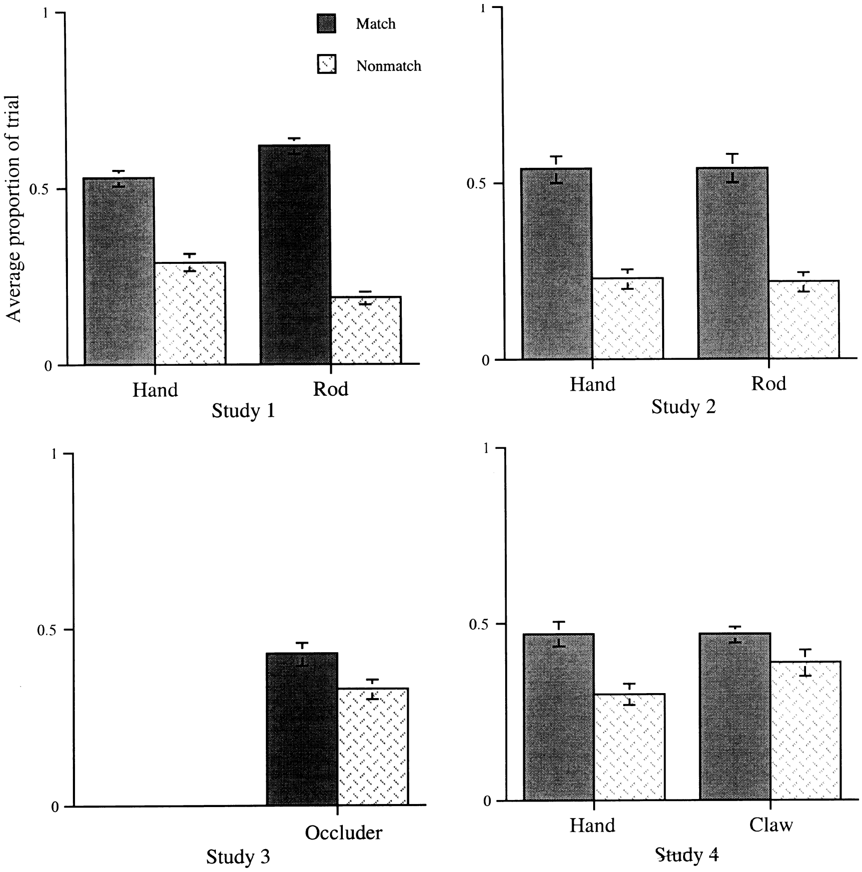

Fig. 3. Average proportion of test trials that infants spent looking at the match and non-match toy for each study and condition (bars show standard errors).

be an artifact of infants preferring, for example, to look at long reaches or to look at hands holding bears. Since the absolute levels of looking at rod and hand events were the same, the differences between conditions are not likely to be due to babies in the rod condition being more bored or less attentive than babies in the hand condition. This conclusion receives further support from infants' patterns of recovery from habituation. Despite the several dimensions of change in the old goal/new path test events, babies in the hand condition showed reliable recovery only on new goal/old path trials. Infants in the rod condition, in contrast, responded to the novelty in both kinds of test events. These effects were not due to attentional spotlighting by the hand. In sum, infants in the hand condition selectively encoded the goal object of the actor's grasp, and babies in the rod condition did not show this pattern.

These findings fit well with other observations of infants at this age: By the time they are 9 months of age, babies' social behaviors strongly suggest that they have a principled understanding of some of the ways other people can act. For example, it is at about this age that babies begin to reliably follow visual line of regard (Butterworth, 1995; Corkum and Moore, 1995), look to parents when confronted with potentially harmful objects (Campos and Stenberg, 1981), and show their first signs of comprehending language (Benedict, 1979) (but see Moore and Corkum, 1994, Baldwin and Moses, 1996 for leaner interpretations of these abilities).

Before about 9 months, these social behaviors are notably lacking. Based on this lack, a number of researchers have reached conclusions like the assertion of Tomasello (1995) that before 9 months of age ‘there is no joint attention or any other indication that infants…understand others as intentional agents’ (p. 108). Similarly, Meltzoff (1995) concludes that before this age, infants seem to lack the ability to reason about relations between people and objects, arguing that ‘younger infants attend to people, or to things, but not to the person-thing relation’ (p. 12). Thus, on these arguments, infants younger than 9 months of age may well lack both the social understanding and the information processing ability required to understand reaching events like the ones in Study 1.

In contrast, it is possible that an ability to encode the goal-directed properties of simple actions precedes abilities to follow line of regard, use others as sources of information about objects and comprehend language. To distinguish between these possibilities, a second study was undertaken: Five-month-old infants were tested in the same procedure as in Study 1.

3. Study 2

3.1. Method

3.1.1. Participants

Thirty-two healthy, full term infants, who were recruited as in Study 1, participated in the second study. These infants ranged in age from 4 months 0 days to 6 months 4 days (mean age = 4 months 28 days). An additional 4 infants came into the laboratory but were not included in the final sample because of failure to complete the procedure due to fussiness (3) and experimental error (1). There were 6 girls and 10 boys in the hand condition (mean age = 4 months 29 days), and 9 girls and 7 boys in the rod condition (mean age = 4 months 27 days).

3.1.2. Procedure

The apparatus, design and procedure were identical to those in Study 1.

3.2. Reliability coding

Reliability of on-line observing was assessed as in Study 1. The video and on-line observers agreed on 80% of trial endings for the hand condition, and 79% of trial endings for the rod condition. The discrepancies between on-line and video observations were randomly distributed with respect to the predicted pattern of findings, χ^2 (d.f. = 1) = 0.42, P = 0.52.

3.3. Results

Table 1 summarizes the main findings. Because the looking times were positively skewed, the data from the habituation and test phases were subjected to a log transformation before parametric analyses were performed. As in Study 1, patterns of habituation did not differ for infants in the two conditions. Infants in the hand condition averaged 9.1 habituation trials and infants in the rod condition averaged 9.6 ($t < 1$). Infants in the hand condition looked for an average of 6.2 s on the final habituation trial and babies in the rod condition looked for an average of 7.7 s ($t < 1$). Three infants in the rod condition and one infant in the hand condition reached 14 trials without meeting the habituation criterion.

As in Study 1, the total amount of looking on new goal/old path and old goal/new path trials was calculated for each infant. Five-month-olds in the hand condition showed a tendency to look longer on the new goal/old path test trials than on old goal/new path test trials ($t(15) = 1.87$, $P = 0.08$). In contrast, 5-month-olds in the rod condition showed the opposite pattern, looking longer on old goal/new path test trials ($t(15) = 2.54$, $P < 0.05$). As was the case in Study 1, a condition (hand versus rod) by test trial type (old goal/new path versus new goal/old path) by test pair (first, second, third) analysis of variance revealed a significant condition $\times$ trial type interaction, ($F(1,30) = 7.66$, $P < 0.01$) and a main effect of trial pair ($F(1,30) = 4.15$, $P < 0.05$), indicating a general decline in looking over the test trials. In this case, the analysis of variance also revealed a reliable main effect of condition ($F(1, 30) = 4.43$, $P < 0.05$) indicating that infants in the rod condition watched both types of test events for longer than babies in the hand condition did.

As for Study 1, non-parametric tests confirmed the main findings. Wilcoxon signed rank tests performed on the untransformed difference scores for each infant confirmed that babies in the hand condition looked marginally longer at the new goal/old path test events ($z = 1.76$, $p = 0.08$), and babies in the rod condition looked longer at old goal/new path test events ($z = 2.28$, $p < 0.025$). A Mann-Whitney test confirmed that the difference scores from the two conditions differed ($z = 3.02$, $p < 0.005$). Table 2 gives the number of infants in each condition who preferred each type of test event. Infants in the two conditions differed reliably in the distribution of their preferences (χ^2 (d.f. = 1) = 4.50, $P < 0.05$).

To compare the findings for 5-month-olds to those for 9-month-olds, an analysis of variance with test trial type (old goal/new path versus new goal/old path) and trial pair (first, second, third) as within subjects factors and condition (hand versus rod) and age group (5 months versus 9 months) as between subjects factors was conducted on the log transformed looking time scores for each infant. This analysis revealed a condition $\times$ trial type interaction ($F(1, 60) = 15.02$, $P < 0.0005$), a main effect of trial pair ($F(1,60) = 12.44$, $P < 0.0005$), and a main effect of age group ($F(1, 60) = 4.02$, $P < 0.05$), reflecting the finding that the younger infants looked longer at test displays overall than the older infants did. Even though the planned comparisons indicated that 5-month-olds, unlike 9-month-olds, looked reliably longer on old goal/new path trials in the rod condition, the age $\times$ condition $\times$ trial type interaction was not reliable ($F < 1$). Thus, infants at the two ages showed essentially the same patterns of looking with respect the hypothesis.

As for Study 1, the next analyses explored infants' recovery from habituation. When the total looking time on the last three habituation trials was compared to looking on the two kinds of test trials, infants in neither condition showed reliable recovery: Infants in the rod condition looked marginally longer on old goal/new path test trials than on the last three habituation trials ($t(15) = 1.23$, $P = 0.12$ (one-tailed), and no other comparisons approached significance. To ask whether infants showed any recovery on test, I next compared the amount of looking on the last habituation trial to the amount of looking on the first new goal/old path and old goal/new path test trial. On this measure, infants in the rod condition recovered on both trial types ($t(15) = 2.39$, $P < 0.025$ and $t(15) = 1.95$, $P < 0.05$ (both one-tailed) for old goal/new path and new goal/old path test trials respectively). Infants in the hand condition showed marginal recovery on new goal/old path trials ($t(15) = 1.57$, $P = 0.07$ (one-tailed)), but no recovery on old goal/new path trials ($t(15) < 1$). Thus, on this more local measure of recovery, 5-month-olds showed similar patterns to the 9-month-olds tested in Study 1.[2]

Next, infants' looks to each toy during test trials were explored. As for Study 1, observers who did not know the condition to which an infant had been assigned coded the videotape of the test trials frame by frame to count the total number of seconds the infant looked at each toy. The coders overlapped for 8 of the 32 infants. Seventy-five percent of their judgments were within 1 s of one another. Fig. 3 gives the average percent of trials that 5-month-olds looked at the toy touched by the hand or rod (the match) versus the other toy (the non-match). As an index of the effectiveness of the hand or rod as a spotlight, the difference in percentage of looking to the match and non-match toys was calculated. These scores were reliably higher than 0 for babies in both the hand and rod conditions ($t(15) = 5.65$, $P < 0.0001$ and $t(15) = 5.09$, $P < 0.0001$, respectively). At 5 months, in contrast to 9 months, babies in the hand and rod conditions did not differ in the size of the disparity in looking to the match or the non-match toys ($t(30) < 1$), indicating that the hand and rod were equally effective as spotlights at this age. Thus, once again, differential spotlighting effects cannot account for infants' performance on test trials.

3.4. Discussion

Although 5-month-olds do not engage in many of the social behaviors that have been taken to indicate an understanding of other people's behavior, Study 2 provides one piece of evidence that infants at this age distinguish between human action and object motion: Like their 9-month-old counterparts, 5-month-olds who saw an inan-

[2]This measure of recovery could be influenced by the fact that there was generally a break in the action after the last habituation trials (to change the positions of the toys). Thus, it is a less clear index of recovery than difference between the last three habituation trials and the test trials. Comparisons of the last habituation trial and first test trial of each type for infants in the other three studies indicate that in all conditions, infants recovered on the first trial of each type.

imate object move toward and touch the toys responded differently from those who saw a human actor grasp the toys. When they saw the rod touch the toys, infants focused on the path taken by the rod, as indicated by their reliable preference for test events in which the path had changed. When they saw a person grasp the toy, in contrast, 5-month-olds showed a tendency to look longer to a change in the toy that was grasped than to a change in the path taken by the actor's arm. As for 9-month-olds, there was evidence that the patterns for 5-month-olds in the test phase did not result from differential spotlighting of the toy by the hand as compared to the rod.

However, unlike the 9-month-olds, 5-month-olds' preference for the new goal/old path event in the hand condition was only marginally reliable, as assessed by both parametric and non-parametric tests. Moreover, 5-month-olds in both conditions showed less robust recovery from habituation during test than did the 9-month-olds in Study 1. These facts point to the need for further evidence to support the conclusion that infants younger than 9 months of age selectively encode the goal object of an actor's reach. Study 4 provides such evidence.

Infants in the younger age group differed from the older infants in another respect: whereas 9-month-olds in the rod condition looked equally at the two test events, 5-month-olds in this condition looked longer at the change in path of motion. It is not clear why this difference between the two age groups occurred. Perhaps younger babies are more captured by salient spatiotemporal features of events. Alternatively, perhaps some of the older infants realized that the rod was being moved by a person even though the actor was hidden behind a side curtain. Given the salience of the change in path for 5-month-olds in the rod condition, it is noteworthy that 5-month-olds in the hand condition tended to show the opposite pattern, looking somewhat longer when the goal object had changed than when the path of motion had changed.

4. Study 3

Why might babies in Studies 1 and 2 have encoded the hand and rod events differently? Maybe grasping, unlike contact by the rod, transformed the object in some way, and infants reacted to a change in the identity of the object that was transformed. One kind of transformation that might account for these findings is a transformation in the appearance of the object. Grasping can sometimes deform objects, but that was not the case for the events in these studies: The actor grasped the toy lightly, and the toys were firm enough that they did not deform when grasped in this way. However, another possibility exists: perhaps grasping transformed the appearance of the toys by hiding parts of them from view in a way that was more noticeable than the rod's occlusion of the toys. If so, then on new goal/old path trials in the hand condition, babies saw a new object noticeably occluded and the previously occluded object fully visible. These differences in occlusion might have led infants to look longer on new goal/old path trials. To test this possibility, a third study assessed infants' encoding of events in which a flat occluder, shaped like the outline of the actor's arm and hand, was placed in front of the toys. If perceptual changes due to the hand's blocking the toy were the cause of the selective encoding findings, such findings would be predicted to emerge for these events as well.

4.1. Method

4.1.1. Participants

Thirty-two infants, recruited as in Studies 1 and 2, participated in Study 3. There were 16 infants in each of two age groups, 9 months (mean age = 8 months 22 days; range = 8 months 1 day to 10 months 0 days), and 5 months (mean age = 5 months 4 days; range = 4 months 0 days to 5 months 29 days). There were 6 girls and 10 boys in the 9 month group, and 9 girls and 7 boys in the 5 month group. Eight infants, 3 at 5 months and 5 at 9 months, visited the laboratory but were not included in the final sample because they did not complete all trials due to fussiness (3), because they moved off camera during a trial (1), or because there was an error in the experimental procedure (4).

4.1.2. Procedure

Infants were seated in the same apparatus as in the first two studies. Instead of the

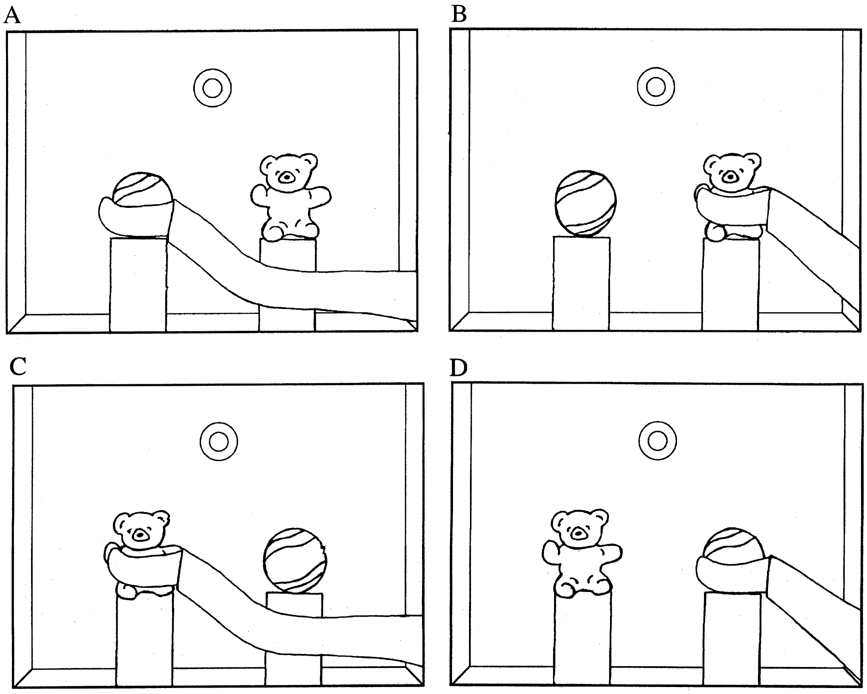

Fig. 4. Events for Study 3.

rod or arm, infants saw a flat occluder, cut to have approximately the same shape as the actor's arm and hand, which moved in from one side to stop in front of one of the two toys while touching it. Fig. 4 shows these events. When the occluder touched the bear, it rested on the bear's lap. When the occluder touched the ball, it was held in place in contact with the front surface of the ball. The occluder was covered in magenta paper, except for the portion that occluded the object, which was covered in tan paper. Like the rod, the occluder was moved from behind the side curtain by an experimenter who remained hidden from view.

As in Studies 1 and 2, each trial began with the screen being lowered to reveal the toys, and then, when the baby was attentive, an experimenter moved the occluder into place in front of one of the toys. Timing of looking was begun once the occluder had stopped moving. Approximately 6.5 s elapsed between the lowering of the screen and the point at which the occluder was in place for the near toy, and approximately 7 s elapsed when the occluder was in place for the far toy. Four infants at each age were habituated to each of the four events in Fig. 4, and then tested on the two events that provided either a change in the object occluded or in the path of motion taken by the occluder. Males and females were distributed approximately evenly across habituation events.

4.2. Reliability coding

The reliability of the on-line observing was assessed as in the first two studies. Video and on-line observers agreed on the trial endings for 81% of trials for 5-month-olds and 89% of trials for 9-month-olds. The discrepancies between observers were randomly distributed across ages and old goal and new goal trials (χ^2 (d.f. = 1) = 0.12, $P = 0.73$).

4.3. Results

Table 1 summarizes the main findings. The two age groups did not differ in terms of the average number of habituation trials taken to reach criterion: Five-month-olds habituated in 9.4 trials on average, and nine-month-olds habituated in 8.8 trials on average ($t < 1$). On the last habituation trial, 5-month-olds looked for slightly longer than did 9-month-olds (7.1 vs. 3.6 s), though this difference was not statistically reliable ($t(30) = 1.61$, $P = 0.12$). Four infants at 5 months and three at 9 months reached 14 trials without meeting the habituation criterion.

For test trials, an analysis of variance with age group (5 versus 9 months) as a between subjects factor and trial type (new goal/old path versus old goal/new path) and trial pair (first, second, third) as within subjects factors was conducted. This analysis yielded a reliable main effect for trial pair ($F(1,60) = 3.37$, $P < 0.05$), and no other effects. Although the analysis of variance did not indicate any differences between the age groups in the amount of looking on the two types of test trials, follow up planned comparisons were carried out on the total looking time for each trial type to verify that there was no preference for the new goal/old path event at either age. At neither 9 months nor 5 months was there a reliable difference in looking during the two types of test trials (at 5 months, mean (new goal/old path) = 25.1 s and mean (old goal/new path) = 27.9 s, and at 9 months, (mean new goal/old path) = 20.9 s and mean (old goal/new path) = 18.8 s, both ts < 1). Wilcoxon signed rank tests at each age provided further confirmation that infants looked equally long during the two types of test trials ($z < 1$ at 5 months, and $z = 1.14$, $P = .25$ at 9 months). In contrast to Study 2, the 5-month-olds in Study 3 did not look longer at the old goal/new path event. There were several differences between the rod and occluder events that might account for this difference. For example, the occluder moved into position more slowly than the rod did, and it was a different shape than the rod. These features may have made the difference between the two paths of motion less salient.

Next, recovery was assessed by comparing the final three habituation trials to each of the sets of test trials. Infants recovered reliably for both new goal/old path and old goal/new path test trials ($t(31) = 2.52$, $P < 0.01$ and $t(31) = 1.80$, $P < 0.05$ (both one-tailed), respectively). Recovery did not vary as a function of age: An analysis of variance conducted on the recovery scores for new goal and old goal trials with age group as the between subjects factor revealed no reliable effects. Thus, as in the rod condition in Study 1, infants seemed to notice both the change in path and the change in the object that was touched.

For the next set of analyses, infants' attention to each of the two toys was coded. As for Studies 1 and 2, the videotape for each infant was coded frame by frame to tally the total number of seconds that the infant looked to each of the toys, and the proportion of time spent looking at the match and non-match toy was calculated (see Fig. 3). The videotape for one 9-month-old infant was too dark to be coded. Two independent coders overlapped for 8 of the 31 infants coded, and they were within 1 s of one another for 78% of observations. As an index of the occluder's effectiveness as a spotlight, the difference between the proportion of looking to the match and non-match locations was calculated for each infant. For the group as a whole, this difference was reliably above 0 ($t(30) = 1.76$, $P < 0.05$ (one-tailed)), and the difference between looking to the match and non-match toys did not differ between age groups ($t < 1$). Thus, as was the case for the hand and rod, the occluder acted as an attentional spotlight.

In the final analysis, the data from Study 3 were compared to the data from the hand condition in Studies 1 and 2. Because of the positive skew in the data from Study 2, all scores were first subjected to a log transformation. An analysis of variance was then conducted with age group (5 versus 9 months) and condition (hand versus flat occluder) as between subjects factors and test trial type (new goal/old path versus old goal/new path) and trial pair (first, second, third) as within subjects factors. This analysis revealed a nearly significant condition × trial type interaction ($F(1, 60) = 3.68$, $P = 0.06$) and a main effect for trial pair ($F(1,60) = 7.58$, $P < 0.001$), as in Studies 1 and 2. In addition, this analysis revealed a main effect of trial type ($F(1,60) = 6.07$, $P < 0.05$), reflecting a general trend to look longer on new goal/old path trials, and a pair × condition × age interaction ($F(1, 60) = 3.46$, $P < 0.05$), indicating that the overall amount of looking did not decline uniformly over pairs in the different ages and conditions. There were no other reliable effects. The age × condition × trial type interaction was not significant ($F < 1$), confirming that 5- and 9-month-olds showed the same patterns of looking with respect to the hypothesis. Moreover, the absence of a main effect of Condition ($F < 1$) suggests that these findings are not due to a general lack of interest on the part of babies in Study 3.

4.4. Discussion

At neither age did babies in Study 3 show the selective encoding effects seen in the hand condition of Studies 1 and 2. Since the occluder hid the same portion of the toys as the hand did, the results of Study 3 argue against the conclusion that the effects in the hand condition of Studies 1 and 2 were due to changes in the appearance of the objects as the result of occlusion by the hand. Moreover, the comparisons with the findings from the hand conditions of Studies 1 and 2 indicated that infants distinguished between the motion of the occluder and the action of the hand, just as they distinguished between the motion of the rod and the action of the hand.

5. Study 4

There is a more subtle difference that might have highlighted the toy in the hand events but not in the rod or flat occluder events: Neither the rod nor the flat occluder gripped the toy. Perhaps the effects seen in the hand conditions of Studies 1 and 2 resulted from the hand’s interaction with the toy making that toy more memorable. That is, we cannot know from the findings of Studies 1–3 whether the differences between the hand and inanimate object conditions were due to infants reasoning differently about people versus objects or due to infants reasoning differently about grasping versus non-grasping relations. To evaluate this possibility, a final study was conducted which assessed infants’ encoding of events in which either a hand or a mechanical tool grasped an object. One group of infants was shown events in which an inanimate claw grasped one of two objects. The claw was manipulated by a hidden researcher. It had two digits that moved together to grasp the toy. A second group of infants saw similar events involving a human hand. As in prior studies, after habituation infants saw test events in which there was a change in either the path of motion taken by the arm /claw or the identity of the object that was grasped. In order to seek further evidence for selective encoding in infants younger than 9 months of age, 6-month-olds were tested.

5.1. Method

5.1.1. Participants

Forty infants, recruited as in the first three studies, participated in Study 4. They ranged in age from 5 months 1 day to 7 months 25 days (mean = 5 months 27 days). Thirteen infants began the procedure, but were excluded from the final sample due to failure to complete all trials (8) or experimenter error (5). Twenty infants saw events in which an actor grasped a toy (the hand condition). The 12 girls and 8 boys in this group had a mean age of 5 months 29 days. Another 20 infants saw similar events in which a mechanical claw grasped a toy (the claw condition). There were 10 girls and 10 boys in this group. They had a mean age of 5 months 25 days.

5.1.2. Procedure

Figs. 5 and 6 depict the events for the hand and claw events. To accommodate the grip of the claw, a slightly smaller ball was used in this study. It was red with black dots. In the hand condition, the actor grasped the toy with her index and middle fingers opposing her thumb. Otherwise, the hand events in Study 4 were identical to those in Studies 1 and 2. In the claw condition, the actor slid a plastic rod topped with a moveable pincer into position and then closed the pincers to grasp the toy. The pincers were closed using a switch at the end of the rod. The actor and the switch were hidden from the infants' view behind a curtain. The rod was covered in the same cloth as the actor's sleeve. The pincer was covered in tan contact paper. The hand and claw events were similar in terms of the amount of the toy that was hidden from view during the grasp.

As in Studies 1–3, each trial began when the screen was lowered to reveal the two

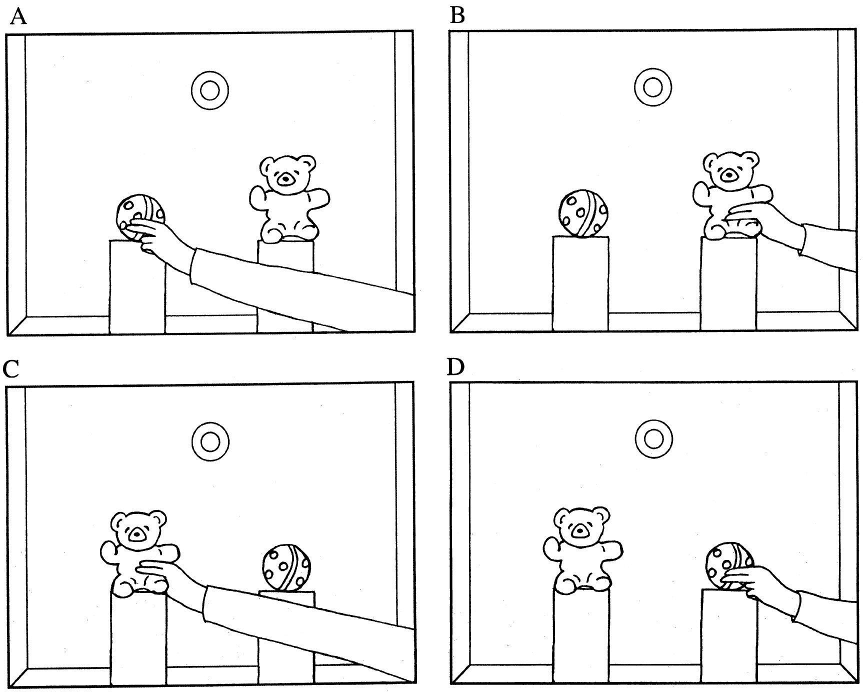

Fig. 5. Events for the hand condition in Study 4.

toys sitting on the pedestals on the stage. When the observer confirmed that the infant was attentive, the actor moved her arm or the claw into position to grasp the toy. Timing of looking was begun once the hand or claw was in place. For the hand condition, the time lag between the lowering of the screen and the beginning of timing was approximately 5.7 s for events in which the actor grasped the toy on the far side of the stage and approximately 5.0 s for events in which she grasped the toy on the near side. For the claw condition, this delay was 6.9 s for events in which the claw grasped the toy on the far side of the stage and 6.1 s for events in which it grasped the toy on the near side.

As in prior studies, following habituation, the positions of the toys were switched and infants were given one familiarization trial on which they saw the toys but not the hand or claw. Then, infants received three new goal/old path and three old goal/new path test trials in alternation. Five infants were habituated to each of the events depicted in Figs. 5 and 6, and then tested with the two events that presented the relevant contrast. The side of the grasp during habituation and the type of test trial given first were counterbalanced within each condition.

5.2. *Reliability coding*

Reliability of on-line observing was assessed as in the prior studies. The video and on-line observers agreed on 78% of trial endings for the hand condition and 77% of

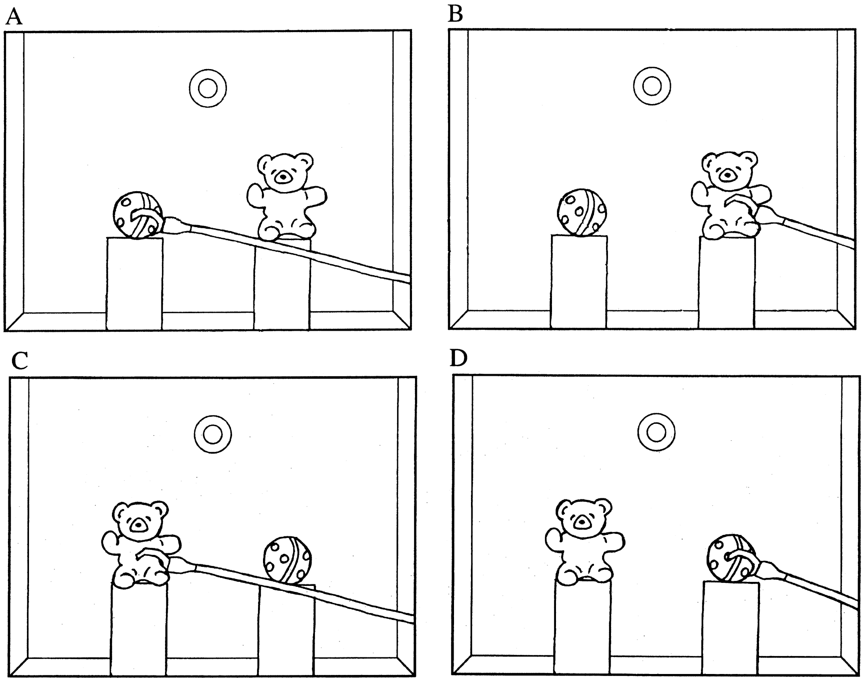

Fig. 6. Events for the claw condition in Study 4.

trial endings for the claw condition. The discrepancies were randomly distributed with respect to the predicted pattern of findings, χ^2(d.f. = 1) = 0.73, P = 0.39.

5.3. Results

Table 1 summarizes the findings for infants in each group. As in Study 2, the looking time data were positively skewed and were subjected to a log transformation before parametric analyses were conducted. The patterns of habituation did not differ for infants in the two conditions. Infants in the hand condition averaged 9.0 habituation trials and infants in the claw condition averaged 9.7 ($t < 1$). On the last habituation trial, infants in the hand condition looked for an average of 5.5 seconds and infants in the claw condition looked for an average of 3.4 seconds; these trial lengths did not differ reliably from one another ($t(38) = 1.49$, $P = 0.15$). Five infants in each condition reached 14 trials without meeting the habituation criterion.

For each infant the amount of looking on new goal/old path and old goal/new path trials was totaled. Infants in the hand condition looked longer on new goal/old path trials than on old goal/new path trials ($t(19) = 4.02$, $p < 0.001$). Infants in the claw condition, in contrast, looked equally on the two kinds of test trials ($t(19) < 1$). An analysis of variance with condition (hand versus claw) as the between subjects factor and trial type (new goal/old path versus old goal/new path) and trial pair (first, second, third) as the within subjects factors revealed a nearly reliable main effect of Pair ($F(2, 76) = 2.80$, $P = 0.07$), indicating a tendency for looking to decline across test trials, and a condition × trial type × trial pair interaction ($F(2, 76) = 3.42$, $P < 0.05$), reflecting the fact that in the hand condition looking times on new goal/old path and old goal/new path trials diverged strongly on later trial pairs, whereas in the claw condition, looking times on new goal/old path and old goal/new path trials were close to one another across pairs.

Non-parametric analyses supported the conclusions that infants in the hand condition looked longer on new goal/old path trials and that infants in the hand and claw conditions differed in their performance on test trials. Wilcoxon signed rank tests indicated that infants in the hand condition looked for longer on new goal/old path test trials than on old goal/new path test trials ($z = 3.02$, $p < 0.005$), but that infants in the claw condition did not differ in their looking on the two kinds of test trials ($z < 1$). A Mann–Whitney test provided evidence that the difference scores of infants in the two conditions differed ($z = 1.87$, $P = 0.06$), a pattern that was confirmed more strongly by an examination of the number of infants in each condition who preferred each test trial type (see Table 2, χ^2 (d.f. = 1) = 8.64, $P < 0.005$).

As in prior studies, infants' recovery on test trials was assessed by comparing the total amount of looking on the last three habituation trials to the total amount of looking on the three test trials of each type. On this measure, infants in the hand condition showed reliable recovery for new goal/old path test trials ($t(19) = 2.59$, $P < 0.01$ (one-tailed)), but not for old goal/new path trials ($t(19) < 1$). Infants in the claw condition showed the opposite pattern: they recovered on old goal/new path trials ($t(19) = 1.71$, $P = 0.05$ (one-tailed)), but did not attain a reliable difference for new goal/old path trials ($t(19) = 1.28$, $P = 0.11$ (one-tailed)). Thus, infants' recovery scores provide further support for the conclusion that infants distinguished between the hand and the claw: Infants in the hand condition showed a strong novelty response for the change in goal object, but not for the change in path. In contrast, infants in the claw condition recovered to the change in path, but did not clearly recover to the change in goal object.

In the next analysis, infants' looks to each toy were coded as in the prior studies. The tapes for two infants, one in the claw condition and one in the hand condition, could not be coded due to problems with the quality of the tape. Two coders overlapped on nine of the 38 infants coded (five in the hand condition and four in the claw condition). These coders were within 1 second of one another for 82% of their judgments. Fig. 3 gives the percentage of each trial that infants in the hand and claw conditions looked at the toy that was grasped versus the other toy. The difference in the amount of looking to the match versus non-match toy was reliably above 0 for infants in the hand condition ($t(18) = 2.54$, $P < 0.01$ (one-tailed)), and marginally above 0 for infants in the claw condition ($t(18) = 1.57$, $P = 0.07$ (one-tailed)). The disparity between looking at the match and non-match toys did not differ between the two conditions ($t(36) < 1$), confirming that the hand and claw did not differ in their effectiveness as spotlights.

The 6-month-olds in the hand condition showed a clearer pattern of effects than did the 5-month-olds in Study 2. Given the similarity in the hand events for Studies 2 and 4, it seems unlikely that this was due to a procedural difference. An analysis of variance conducted on the total test scores from the hand condition with study as the between subjects factor and test trial type as the within subjects factor confirmed this conclusion: There was a reliable effect of test trial type, $F(1, 34) = 17.01$, $P < 0.0005$), reflecting infants' preference for the new goal/old path test trials, but there were no reliable differences between infants in the two studies (all other F's < 1). Although the ages of infants in Studies 2 and 4 overlapped considerably, the infants in Study 4 were 1 month older on average than the infants in Study 2. It is possible, therefore, that 5 to 6 months is a transitional age with respect to selective encoding of grasping events. To explore this possibility, the data from the hand conditions of Studies 2 and 4 were combined, and the correlation between age and effect size (as indexed by the difference in the log transformed total looking scores for new goal/old path and old goal/new path test trials) was calculated. This correlation was moderate and positive ($r = 0.30$, $P = 0.08$): older babies showed somewhat stronger preferences for the new path events. Those infants who were at or above the median age in this combined sample (5 months 17 days) looked reliably longer at the new goal/old path test event ($n = 19$, $t(18) = 5.00$, $P < 0.005$), whereas those babies below the median age did not look reliably longer on these test trials, ($n = 17$, $t(16) = 1.42$, $P = 0.18$)[3]. There were not sufficient data for these effects to be evaluated separately for each study. It is, of course, possible that younger infants would show clearer evidence of selective encoding under more sensitive

[3]A similar analysis was conducted for those infants in the claw condition and those in the rod condition in Study 2. In this case, infants who were below the median age (5 months 12 days) showed a reliable preference for the old/goal new path event over the new goal/old path event, $t(17) = 2.37$, $P < 0.05$, whereas those above the median age did not differentiate between the two test events, $t(17) < 1$.

testing conditions. Further research is required to evaluate this possible developmental difference.

5.4. Discussion

As in Study 1, when the 6-month-olds in Study 4 saw a person grasp a toy they selectively encoded the aspects of the event that were relevant to the actor's goal: that is, they looked longer when the actor grasped a new toy than when she moved her arm through a new path. When 6-month-olds saw an inanimate grasper, in contrast, they looked equally long when the goal changed as when the path taken by the claw changed. This pattern was reinforced by infants' patterns of recovery from habituation. Infants in the hand condition showed reliable recovery only to the new goal/old path events, whereas infants in the claw condition recovered reliably only to the change in path. Thus, once again, there is evidence that infants differentiate between the actions of human beings and the motions of inanimate objects. The fact that infants in the two conditions looked equally long on average during the test phase, and the fact that infants in each condition showed reliable recovery to one of the test events indicates that the response differences seen during test were not due to infants finding the claw events boring. As in prior studies, after the fact coding of the infants' looks to each toy indicated that the hand and the claw were equally effective as spotlights of attention. Therefore, the findings cannot be due to differential spotlighting of the toy by the hand as compared to the claw.

6. General discussion

Like the 1- and 2-year-olds studied by Meltzoff (1995), Tomasello and Barton (1994) and Gergeley et al. (1995), the 6- and 9-month-old infants in the current studies selectively encoded the aspects of a human action that were relevant to the actor's goals over other salient aspects of the event. Moreover, infants at 5, 6 and 9 months distinguished in their encoding of the actor's grasp and similar events in which inanimate objects touched or grasped other objects. Analyses of infants' patterns of looking during test trials indicated that these effects were not a by-product of how babies allocated visual attention: Although the presence of a grasping hand, a rod, a flat occluder that partially covered the toy and a mechanical claw that grasped the toy all drew infants' attention to the object that was contacted, only babies who saw a human actor grasp the toy showed selectively longer looking on test trials in which the object that was grasped had changed. Study 3 provides evidence that these effects were not due to perceptual transformations in the objects as the result of being partially hidden by the hand. The findings of Study 4 indicate that the patterns found for events in which a person grasped an object did not emerge for events in which an inanimate object grasped one of the toys.

Infants showed these effects most clearly at 6 and 9 months. Five-month-olds differentiated between the human grasper and the rod, but their preference for the change in goal object for the former was only marginal. Across the 5- and 6-month-olds, the effects for the hand condition varied as a function of the infant's age, but not as a function of the particular study to which the infant had been assigned. This suggests that infants' understanding of grasping events may be changing at 5 to 6 months of age, a possibility that requires further empirical investigation.

Taken together, these findings indicate that by the time they are 6 months of age, infants have a store of knowledge that leads them to selectively encode the goal-related properties of reaching events, and, moreover, that this knowledge does not extend to similar events involving inanimate objects. The question, then, is what sort of knowledge is it that led infants to encode the two kinds of events in this study differently?

6.1. Action as goal-directed

Is it correct to conclude that the infants in these studies were reasoning about the intentions of the actor? If we take the adult model to define 'intentions', then the answer must be no. As philosophers of mind have described, adults understand intentions as part of a system of mental states including beliefs and desires (Searle, 1983; Dennett, 1987; see also D'Andrade, 1987). The mind is seen as a system that construes or represents reality, rather than directly reflecting it. In research with children, this aspect of understanding the mind has been heavily tested with respect to beliefs (e.g., Astington et al., 1988). Similarly, a mature understanding of intentions also requires understanding how an actor construes the situation. To take an example from Searle (1983),

> …Oedipus intended to marry Jocasta but when he married Jocasta he was marrying his mother…The action was intentional under the description 'marrying Jocasta,' it was not intentional under the description 'marrying his mother' (p. 101).

Given preschoolers' well documented difficulty understanding the representational nature of mind, this component of intentional understanding must emerge later than the infant and toddler years. Yet, as discussed above, researchers have suggested that toddlers can reason about intentions as defined in other terms (Tomasello and Barton, 1994; Gergeley et al., 1995; Meltzoff, 1995). Several theorists have formulated proposals concerning early reasoning about intentional action which lack this aspect of mature theories of mind (Golinkoff, 1981; Flavell, 1988; Poulin-Dubois and Schultz, 1988; Wellman, 1992; Leslie, 1993, 1995; Whiten, 1994). To illustrate, Wellman (1992) has proposed that before the age of three, children understand human behavior as caused by internal states he terms 'simple desires'. Under this account, simple desires differ from desires as understood by adults in that they reflect an attitude toward an actual object or state of affairs rather than toward a represented object or state of affairs. In the young child's understanding,

> …simple desires such as wanting a drink of water or desiring a certain toy are seen as causing the organism to do certain things. For example, simple desires

> cause actors to engage in goal-directed actions, to persist in goal-directed actions…and to have certain emotional reactions (p. 212).

Leslie (1993) proposes a similar model for understanding what he terms ‘actional agency’. Early on, he argues, infants reason about a wide range of phenomena, including human behavior, in accord with a set of mechanical principles. This early mechanics reflects the fact that people, unlike inanimate objects, can move around on their own, but does not include an understanding of goal-directedness. Later in development, babies come to understand the ‘actional’ or goal-directed properties of human behavior,

> …in Actional Agency…the Agent [is] seen as having an internal source of striving or acting (toward a goal). The action or ‘pressure’ to bring about the goal state of affairs arises from within the Agent and ‘flows outward’ from the Agent (p. 138).

As in Wellman’s proposal, Leslie argues that an understanding of actional agency is limited in that it does not include an understanding of mental states as representational. Wellman and Leslie differ in their estimation of when children attain this level of understanding. Wellman proposes that 2-year-olds, but not infants, understand goal-directed action, whereas Leslie suggests that babies understand actional agency beginning at 6 to 8 months.

Perhaps a notion of goal-directed action led the infants in the current studies to give special weight to the goal object of the actor’s reach. Clearly, more evidence is required to conclusively accept this account of infants’ selective encoding. We do not yet have evidence as to whether infants reason about the intentions of others in some of the impressive ways that toddlers do. For one, the current findings do not reveal whether young infants can infer a failed intention from behavioral evidence, as the 18-month-olds in Meltzoff’s (1995) study could, or whether young infants can use behavioral evidence of a goal at one point in time to generate predictions about further actions in pursuit of this goal later on, as the 12-month-olds in Gergeley et al.’s study did (see Spelke et al., 1995 for converging evidence). In addition, the current findings leave open the question of whether infants can distinguish intentional from unintentional acts based on behavioral cues, as the 24-month-olds in Tomasello and Barton’s (1994) study did.

6.2. Hands as movers of objects

An alternative to this proposal is that infants’ encoding of grasping events derives from their understanding of the ways that hands can move objects. As described earlier, a number of studies have provided evidence that infants understand some of the constraints on a hand’s ability to move an object (Baillargeon et al., 1990; Baillargeon, 1995; Leslie, 1982, 1984; Needham and Baillargeon, 1993). The current findings indicate that by 6 months, infants have something in addition to this, in that they selectively attend to the object grasped when a person, but not a mechanical claw, grasps the object. In itself, the fact that infants understand the mechanical constraints on grasping is not sufficient to account for these findings. To start, it is not clear why the identity of the object grasped, as opposed to the distance of the reach, is more central to the mechanics of grasping. It could be argued that the distance of the object from the person who grasps it is more central, since distance determines which objects can be reached. In fact, a study by Yonas and Hartman (1993) indicates that 5-month-old infants take distance into account when deciding whether or not they will be able to grasp an object; their propensity to reach for a toy drops sharply when the toy is placed just beyond the range of their fingertips.

Understanding the mechanics of reaching could be stretched to account for the current findings by making three additional assumptions. First, it could be proposed that infants construe mechanical relations in terms of roles. Leslie (1993, 1995) has argued that this is the case, and provides evidence to support this possibility for 6-month-old infants' reasoning about inanimate causal sequences (Leslie and Keeble, 1987; but see Cohen and Oakes, 1993 for opposing evidence). It is possible, therefore, that infants construe events in which an actor grasps an object primarily in terms of mechanical roles such as 'grasper' and 'thing grasped'. If so, then, the test events in which the actor grasped a new object presented infants with a change in the object that filled the role of 'thing grasped', and this change may have led to longer looking to these test events.

Second, it would have to be argued that infants encode mechanical roles in the absence of any actual motion, since the hand never moved the object. That is, infants would have to identify a hand that grasps an object as a potential mover, and find the relationship between the hand and the thing it might move to be of central importance to the event. This ability has not been explored for inanimate mechanical relations, though Leslie (1993, 1995) has argued that mechanical role analysis occurs only when infants see objects move with respect to one another.

Third, it would have to be argued that this reasoning ability is specific to human action, since it was not invoked in the case of the mechanical claw. Recall that in Study 4, both the actor's hand and the claw grasped the toy, yet only infants in the hand condition selectively encoded the grasped object. There is not strong evidence to indicate that infants have a special set of mechanical expectations that govern their reasoning about human action on objects. Leslie's (1982, 1984) 'pick-up' studies might be evidence for this, since infants distinguished between a grasping hand and a block. However, in other studies, infants have been shown to reason in similar ways about hands and inanimate objects that support other objects (see e.g., Baillargeon, 1995).

In sum, it is possible to devise an account of reasoning at the behavioral level that could explain the current findings. This account rests on three unproved assumptions: that infants construe mechanical relations in terms of roles, that infants do this in absence of any actual mechanical interaction, and that infants do this only for mechanical interactions involving people as potential movers. Further research is required to test these assumptions. If this account turns out to be correct, then infants have a system of knowledge that is specific to human behavior and that includes a notion of 'propensity to act'. These steps bring the infant closer to a notion of action as goal-directed.

7. Conclusions

Either of the accounts outlined here could, in principle, explain infants' selective encoding of the reaching events in the current studies. Of course, these two accounts are not mutually exclusive. The possibility that infants reason about hands as potential movers of objects is not inconsistent with the possibility that they have a nascent understanding of goal-directed action. Both could be true at the same time. In this case, two overlapping systems of knowledge may have contributed to the patterns of encoding seen here.

Alternatively, an early understanding of hands as potential movers might be a step on the path toward developing an understanding of the relationship between intentional agents and the objects they act on. Whiten (1994) has proposed that an understanding of intentional action may develop out of a rich understanding of human behavior. Moreover, if it accounts for the findings of these studies, this knowledge must have the effect of leading babies to encode aspects of the event that are critical to understanding the intentions of the actor, thus providing one source of data relevant to developing theories of mind. In a similar vein, several researchers have proposed that an understanding referential acts such as pointing and labeling develops in part via mechanisms that lead infants to attend to critical aspects of the actor and the situation (Moore and Corkum, 1994; Butterworth, 1995; Baldwin and Moses, 1996).

Under either of these interpretations, the current findings demonstrate that infants as young as 5 to 6 months of age encode human action in a way that is continuous with more mature understandings of intentional action. These findings cast doubt on the conclusion that because infants younger than 9–12 months of age do not reliably follow points or gaze, they lack any understanding of action as directed toward objects. Rather, they suggest that early in life, infants begin to set up a system of knowledge of human action that has features in common with more mature understandings, and that is distinct from their knowledge of inanimate object motion. This system of knowledge likely provides the foundation on which later domain specific knowledge is built.

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