PAPER

Infants' developing understanding of the link between looker and object

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Abstract

Three studies investigated infants' understanding that gaze involves a relation between a person and the object of his or her gaze. Infants were habituated to an event in which an actor turned and looked at one of two toys. Then, infants saw test events in which (1) the actor turned to the same side as during habituation to look at a different toy, or (2) the actor turned to the other side to look at the same toy as during habituation. The first of these involved a change in the relation between actor and object. The second involved a new physical motion on the part of the actor but no change in the relation between actor and object. Seven- and 9-month-old infants did not respond to the change in relation between actor and object, although infants at both ages followed the actor's gaze to the toys. In contrast, 12-month-old infants responded to the change in the actor–object relation. Control conditions verified that the paradigm was a sensitive index of the younger infants' representations of action: 7- and 9-month-olds responded to a change in the actor–object relation when the actor's gaze was accompanied by a grasp. Taken together, these findings indicate that gaze-following does not initially go hand in hand with understanding the relation between a person who looks and the object of his or her gaze, and that infants begin to understand this relation between 9 and 12 months.

Introduction

Gaze is central to our understanding of human behavior. Adults spontaneously monitor a person's eyes and use gaze direction to support inferences about his or her intentions, emotions, attention, knowledge states and likely future actions. When we can't see a person's eyes, we feel cut off, deprived of a link to his or her mind. The belief that eyes give us contact with the mind is not limited to everyday reasoning. Experimental psychologists have long used eye movements as evidence about underlying mental processes. Thus, for adults, the eyes provide important evidence about a person's mental states and their predispositions toward objects in the world. Preschoolers also understand some of these aspects of gaze, for example, the relation between seeing and knowing (e.g. Pratt & Bryant, 1990; Flavell, 1988). Even so, a mature understanding of gaze is the product of a long process of development. Children's knowledge about seeing is enriched and refined throughout the preschool and elementary school years (Winer, 1991).

The special significance of gaze has roots very early in life. Infants as young as 2 to 6 months show preferential attention to eyes over other aspects of the face (Caron, Caron, Caldwell & Weiss, 1973; Haith, Bergman & Moore, 1977; Maurer & Salapatek, 1976), respond to shifts in gaze direction (Hains & Muir, 1996; Symons, Hains & Muir, 1998; Vecera & Johnson, 1995) and sometimes direct their own attention based on another person's gaze (Butterworth & Jarrett, 1991; D'Entremont, Hains & Muir, 1997; Hood, Willen & Driver, 1998; Scaife & Bruner, 1975). This final ability, gaze-following, varies as a function of the context, and becomes more robust between 6 and 18 months of age (Butterworth & Jarrett, 1991; Carpenter, Nagell & Tomasello, 1998; Corkum & Moore, 1998; Scaife & Bruner, 1975). During this time, infants become both more likely to follow shifts in another person's gaze and more accurate in doing so. For example, Butterworth and Jarrett (1991) found that 6-month-olds responded to an adult's shift in head and eye direction by turning in the same direction, though they would stop and stare at whichever object they encountered first on that side. By 12 months, infants were able to locate the correct target when there was more than one object present. Finally, 18-month-olds, unlike younger babies, could follow gaze to items behind them.

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It is tempting to conclude that infants begin to follow gaze because they understand something about visual attention or perception. However, a number of theorists have argued that understanding what gaze is and the propensity to follow gaze are logically and developmentally distinct (Butterworth, 1998; Butterworth & Jarrett, 1991; Moore & Corkum, 1994; Povinelli & Eddy, 1996). To illustrate, Moore and Corkum (1994) argued against the commonsense view that gaze-following is evidence for infants' understanding the other person as 'looking at', 'seeing' or 'attending to' the object. Instead, they suggested that the propensity to follow gaze originates from infants' history of behavioral reinforcement (turning in the same direction as an adult is consistently rewarded with interesting sights), or from an innate orienting response to gaze. Under neither of these scenarios, they concluded, 'is it necessary to postulate that the infant represents the adult as looking at something' (1994, p. 355). Infants may respond to gaze direction, therefore, without yet understanding that this behavior indicates a particular kind of relation, or indeed any kind of relation, between looker and object.

The possibility that gaze-following could exist independent of a deeper analysis of gaze is supported by recent evidence that these two levels of response can be separated in adults. Researchers have found that adults shift their attention reflexively in response to gaze direction portrayed in a photograph or schematic line drawing, and that they do this even when the direction of gaze is explicitly unrelated to or counter to the location of a target in a vigilance task (Driver, Davis, Ricciardelli, Kidd, Maxwell & Baron-Cohen, 1999; Kingstone, Friesen & Gazzaniga, 2000; Langton & Bruce, 1999). Although it seems unlikely that adult subjects believe the schematic line drawing or photograph to be looking at something, nevertheless, they respond to gaze in these situations by directing their attention in the same direction as the observed gaze.

Adults' deeper understanding of gaze is embedded in knowledge about psychological life and action. For one, we understand the likely phenomenological experience of a person who looks at something. In many situations, we can imagine what he or she is seeing. In addition, we can predict the effects that this experience will have on his or her epistemic states, emotional reactions and other mental processes. To illustrate, we know that having seen an item, a person is now aware of its existence, and we know that seeing some items is likely to elicit pleasure while seeing others is likely to elicit disgust or fear. Finally, we also understand the likely implications of the act of looking for a person's subsequent behavior. For example, people tend to move in the direction that they are looking, and act on items that have been the targets of their gaze. Underlying all of this knowledge is the very basic understanding that there is a connection between the person who looks and the object of her gaze. Without this understanding, it would be impossible to interpret gaze as anything more than a series of motions, like sneezing or jumping, or as a signal to orient in a particular direction.

The current studies investigated infants' understanding of this most basic fact about gaze, drawing on a logic developed in prior work to assess infants' understanding of the relation between actors and objects for manual actions (Guajardo & Woodward, under review; Woodward, 1998, 1999; Woodward & Guajardo, 2002; Woodward & Sommerville, 2000; Woodward, Sommerville & Guajardo, 2001). For any event in which a person acts, there are multiple dimensions that an observer could encode in memory. To illustrate, take the event depicted at the top of Figure 1. Adults would likely describe this event in terms of the relation between the actor and the object of her gaze (e.g. 'She looked at the bear'). However, it is also possible to describe this event only in terms of the actor's motions, without referring to this relation at all (e.g. 'She turned her head to the left, with her face pointed downward'). The current studies tested which of these descriptions is closest to infants' representation of the event.

The visual habituation/dishabituation paradigm provides a way to tap infants' representations of this event. Having been habituated to one event, infants will look longer at another event that is different from the original. This novelty response can serve as an index of the features infants focused on during habituation. In the first study, infants were habituated to one event (e.g. the top event in Figure 1). Then, the positions of the toys were reversed and infants saw two kinds of test trials. On *new toy trials*, the actor turned her head to the same side as during habituation, this time looking at the other toy. On *old toy trials*, the actor turned her head to the other side, this time looking at the same toy as during habituation. If infants attend to the relation between the person who looks and the object of her gaze, they would be predicted to look longer on new toy trials than on old toy trials. If, however, infants construed these events only in terms of the motion of the actor, they might show the reverse pattern. Brooks, Caron and Butler (1998) reported the results of a preliminary study using this logic with 15- and 18-month-old infants. They found that at both ages, infants looked longer on new toy trials than on old toy trials, suggesting that by 15 months, infants attend to the relation between looker and object.

The current studies tested younger infants, 7-, 9- and 12-month-olds. Prior work using the habituation paradigm indicates that infants as young as 6 months have a
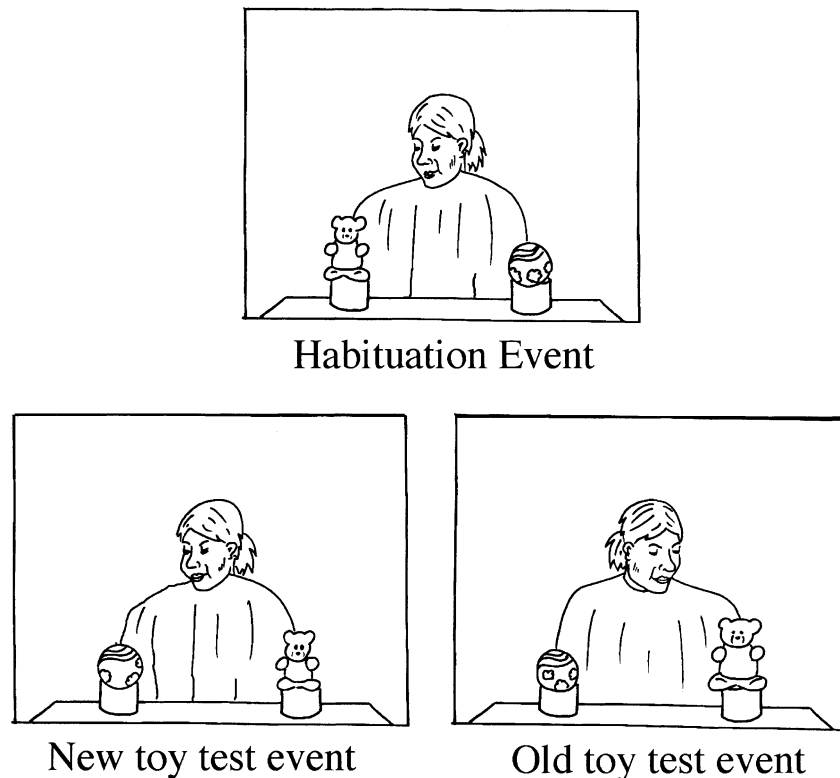
Figure 1 *Sample habituation and test events for Studies 1 and 3.*

related ability, in that they understand another action, grasping, in terms of the relation between actor and object (Woodward, 1998, 1999; see also Wellman & Phillips, 2001). In these experiments, the events did not involve gaze; infants only saw the actor's arm. After they were habituated to one grasping event, infants showed a stronger novelty response to a change in the object that was grasped than to a change in the path of reach. Infants did not show this pattern for inanimate 'actors' such as a mechanical claw (Woodward, 1998), or for events in which an actor touched the toy with her hand but did not grasp it (Woodward, 1999; see also Woodward & Guajardo, 2002). Thus, infants' initial understanding of actor–object relations appears to be specific to particular familiar actions. Gaze, like grasping, is highly familiar to infants, and, as discussed above, quite salient to them. For these reasons, infants may also appreciate that this action involves a relation between actor and object.

On the other hand, there are several reasons why the relation between a person and the object of her gaze may be harder for infants to discover than the relation between a person and the object she grasps. For one, the lack of a physical connection between the actor and the object, and the demands posed by relating entities separated in space may make it difficult for infants to learn

about this aspect of gaze. The connection between actor and object is less concrete for gaze than for grasping in a second sense as well: in everyday life, grasping often involves physical consequences for the object (e.g. it might be moved closer to the actor), which could help infants to understand the actor's goals (e.g. obtaining the object). In contrast, the consequences of gaze for the actor are not as readily observed, and gaze has no effect on the object. Finally, unlike grasping, infants cannot observe their own gaze. To the extent that infants understand the actions of others on analogy with their own actions, therefore, they may do this more readily for grasping than for gaze.

A second question investigated in the current studies is whether infants followed the actor's gaze during the experiment. This was important for several reasons. First, gaze-following is a prerequisite for encoding the relation between the actor and the object. If infants were unable to do the former in the context of this experiment, their failure to do the latter would be uninformative. Second, assessing gaze-following in this context provides a point of contact with prior studies. Prior research indicates that when the object is in the infant's visual field and there is only one object on a side, infants 6 months of age and younger follow gaze (Butterworth & Jarrett, 1991; D'Entremont *et al.*, 1997; Scaife &

Bruner, 1975). Therefore, given the events depicted in Figure 1, 7-, 9- and 12-month-olds would be predicted to follow gaze in the current experiments. Finally, measuring gaze-following makes it possible to directly investigate the relation between infants' orienting response to gaze and their understanding of the link between looker and object. This relation has not been investigated in earlier studies of infants' understanding of gaze. Our prior findings indicated that infants' propensity to orient in response to an action could be distinguished from their representation of the relational structure of the action (Woodward, 1998, 1999; see also Woodward & Guajardo, 2002). Motion toward and contact with a toy drew infants' attention to the toy whether the event involved a grasping hand, mechanical claw or non-grasping hand. However, infants only selectively represented the relation between actor and object for grasping hands. Thus, the attention-directing status of an action does not guarantee that infants will construe this action in terms of the relation between actor and object.

With these issues in mind, two measures were obtained for each infant. The first assessed infants' sensitivity to the relation between the person and the target of her gaze, as indexed by their overall levels of attention to the two test events, as described above. The second assessed infants' propensity to follow the actor's gaze to the toy at which she looked during those same test trials. This propensity was indexed by the length of time infants looked at the toy that was the target of the actor's gaze as compared to the other. This measure of gaze-following is different from, and perhaps more sensitive than the measure used in earlier studies. Most studies of gaze-following have assessed the first direction to which the infant turns after the experimenter turns, within a brief response interval (but see Hood *et al.*, 1998 for an exception). For young infants, this may not be the most reliable indicator of the ability to follow gaze to an object. Young infants may be less organized in the way that they scan an event, yet still respond to a person's gaze by spending more time attending to the object at which she looks. This concern suggests that infant-timed procedures like the one used in the current studies, in which infants are free to scan the items in an event in any order for as long as they remain attentive, might provide a more sensitive measure of infants' propensity to follow gaze.

Study 1

In the first study, 7- and 9-month-old infants were tested. As summarized above, prior findings indicate that infants at these ages have two abilities relevant to

understanding the relation between a person who looks and the object of her gaze – they follow gaze in supportive contexts, and encode another action, grasping, in terms of the relation between actor and object. Infants at these two ages were also tested because, given reported developments in gaze-following, it seemed possible that there would be differences in 7- and 9-month-olds' response to and, perhaps, understanding of gaze. For example, Scaife and Bruner (1975) reported that 67% of the 9-month-olds they tested followed an experimenter's gaze, whereas only 39% of the 6-month-olds they tested did so (see also Butterworth & Jarrett, 1991; Corkum & Moore, 1998).

Method

Participants

Forty full-term infants from the Chicago area participated in the first study. The infants' parents had been contacted by advertisements or mailings, and were offered $10 to reimburse their travel expenses. There were 20 infants in each of two age groups: the 7-month-olds had a mean age of 6 months 24 days (range: 6 months 0 days to 7 months 29 days); the 9-month-olds had a mean age of 8 months 23 days (range: 8 months 0 days to 9 months 27 days). There were 8 females and 12 males in the 7-month group, and 11 females and 9 males in the 9-month group. Ten additional infants began the procedure but were excluded from the final sample because they did not complete all trials due to distress (three 7-month-olds and two 9-month-olds) or because of an error in the experimental procedure (two 7-month-olds and three 9-month-olds).

Apparatus

Infants sat in a table top seat or on a parent's lap while watching the experimental events. If the infant was seated on the parent's lap, the parent was instructed to look down at the infant rather than at the experimental events. If the infant sat in the table top seat, the parent stood just behind the table and the infant. The infant faced a small stage, approximately 75 cm away, on which there were two toys, a white teddy bear and a multi-colored ball. Each toy was mounted on a 9 cm high black pedestal. The pedestals were 28 cm apart from one another. An actor sat between the back of the stage and the back curtain. Her upper body and face were in view of the infant (see Figure 1). Her lower arms and hands were hidden from view under the stage. She wore a magenta long-sleeved garment that hid her other clothing from view. Just above the actor's head, a video camera

was mounted so that its lens protruded through the back curtain. The curtains surrounding the stage and the stage floor were black. A white screen was raised from below the stage to hide the toys and the actor from view between trials.

An observer watched the infant over video and coded looking times on-line using a custom software package (Pinto, 1994). The observer could not see the stage area, the toys or the actor. Observers had been trained to be able to judge, based on the direction of the infant's gaze, whether the infant was looking at the area containing the toys and the actor.[1] The observer was not informed of the condition to which the infant had been assigned. After the session, the reliability of the on-line observing was assessed by having a second observer code the videotape for each infant (see below for details).

Procedure

Each trial began when the screen was lowered to reveal the two toys and the actor. The actor made eye contact with the infant and waited silently until the observer confirmed that the camera was in focus. At this point, she said 'Hi' and then 'Look' as she turned to look at one of the two toys. She remained still in this position for the remainder of the trial.[2] If the infant was inattentive at the start of the trial, the actor repeated the greeting 'Hi' until the infant made eye contact with her. She then said 'Look' as she turned to look at the toy. The infant's looking was coded beginning when the actor had stopped moving and was in her final position looking at the toy. This was achieved by having a third experimenter

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[1] Observers trained by coding videotapes of pilot subjects until they agreed with the on-line coder on the trial ending for at least four of the six test trials for five infants in a row.

[2] Live, rather than videotaped, events were used in an effort to maximize infants' attentiveness. This choice necessitated procedure checks to evaluate the consistency of the actor's behavior, and this was completed in two steps. First, an experimenter monitored the events for procedure errors on-line, checking that the actor produced the correct action and that she remained still, in the correct pose, once she had turned to look at the toy. Second, the actor's behavior was filmed by a camera behind and slightly above the infant, and this tape was coded after the fact to evaluate whether there were subtle cues that could have led infants to look longer on new object as compared to new side trials. A coder who was unaware of the hypothesis watched only the test trials for each infant. The alternation pattern yielded three pairs of test trials of each type (new toy and old toy). For each pair, the coder was asked to assume that the actor wanted the infant to look longer on one of the trials, and then to determine which trial this was, using any aspect of the actor's behavior to make this determination. Due to lost videotapes this coding was completed for 29 infants in Study 1, 39 in Study 2 and 18 in Study 3. In no case did the coder select new toy trials at rates greater than chance. Of three trial pairs, new toy trials were selected for 1.65 (SD = 1.05) pairs in Study 1, 1.54 (SD = .88) in Study 2 and 1.56 (SD = .78) in Study 3, all $ts < 1$.

click the computer mouse to begin the timing process once the actor had reached this position. The trial ended when the infant had looked away for 2 consecutive seconds or when 120 seconds had elapsed.

During the habituation phase, the actor always looked at the same toy. For half of the infants at each age she turned to the left, and for the other half she turned to the right. For each direction, half of the infants saw the actor looking at the bear and half saw her looking at the ball. The habituation criterion was set based on the first three trials, so long as the infant's looking times on these trials combined totaled to 12 seconds or more.[3] The criterion for habituation was met when the infant had three consecutive trials that totaled less than half of the sum of the first three trials. Thus, each infant had a minimum of six trials in habituation. If an infant did not meet this criterion after 14 trials, the habituation phase was ended and test trials were begun.

After the last habituation trial, the positions of the toys were reversed while the screen hid the stage from view. Then, each infant was given two kinds of test trials in alternation for a total of three trials of each type. As during habituation, the actor made eye contact with the infant, said 'Hi. Look' and turned to look at one of the toys. As was the case during the habituation phase, test trials began when the actor had stopped moving and ended when the infant looked away for 2 consecutive seconds. In one test event, the actor turned to the same side as during habituation, thus looking at a different toy than the one she had looked at during habituation (the *new toy test event*). In the other, she turned to the other side of the stage, this time looking at the same toy as during habituation (*the old toy test event*). Half the infants at each age began testing with a new toy trial and half began with an old toy trial.

Video coding

Reliability coding

To assess the reliability of the on-line coding, a second observer coded the test trials of each videotaped session. Coders were counted as agreeing if the beep signaling the end of the trial on the videotape was indistinguishable from the beep signaling the end of the trial for the reliability coder. On this measure, the two coders agreed on the trial endings for 78% of trials at 7 months and 97% of trials at 9 months. Next, the trial ending disagreements were categorized based on direction for each trial type,

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[3] If the infant did not look for a total of at least 12 seconds on the first three habituation trials, the criterion was set based on the first three consecutive trials that totaled 12 seconds.

to determine whether there was systematic bias on the part of the on-line observer which favored the hypothesized pattern (longer looking on new toy test trials and shorter looking on old toy test trials as opposed to shorter looking on new toy test trials and longer looking on old toy test trials). The disagreements were randomly distributed among these categories at both ages, Fisher's exact $p = .99$, and $p = .40$ at 9 and 7 months, respectively.

Direction of gaze

To assess whether infants followed the actor's gaze, in a second pass of the tapes, infants' looks to each of the two toys during the test trials were coded. Observers watched the tape in slow motion (6 frames/s), using a computer-driven timing program to calculate the amount of time that babies spent looking at each of the two toys. They were not informed of the condition to which an infant had been assigned, and they could see neither the toys nor the actor. Two independent coders overlapped for 12 infants, 6 at each age. Their judgments of the lengths of infants' looks to each of the two toys were strongly correlated, $r = .91$ at both ages.

Results

Response to the change in relation between actor and object

On average, 7-month-olds met the habituation criterion in seven trials and 9-month-olds did so in eight. One infant at each age reached 14 habituation trials without meeting the criterion. When these infants were excluded from the analyses, the interpretation of the results was unchanged. Therefore, the analyses reported below include all 40 infants. Infants at the two ages did not differ reliably in their levels of attention at the end of habituation, $t(38) = 1.12$, $p > .3$ (see Table 1).

The main analyses tested whether infants responded to the change in the relation between the actor and the object. For each infant, the average looking times on the three new toy trials and the three old toy trials were computed. These scores are summarized in Table 1. To reduce positive skew, the data were subjected to a log transformation before parametric analyses were conducted. Because preliminary analyses revealed no effects of the side to which the experimenter looked during habituation, the object at which she looked or the type of test trial given first, subsequent analyses collapsed across these dimensions. An analysis of variance with age group (7 versus 9 months) as the between-subjects factor and test trial type (new toy versus old toy) as the within-subjects factor revealed a marginal main effect of

Table 1 *Mean (SE) average per trial looking time during the last two habituation trials and the old toy and new toy test trials for each study*

|	Last 2 habituation trials	Test trials	
		Old toy trials	New toy trials
Study 1: Gaze Only			
7 months	9.4 (1.4)	12.0 (3.0)	9.6 (1.4)
9 months	6.9 (1.2)	6.5 (0.9)	6.5 (1.0)
Study 2: Gaze + Grasp			
7 months	7.8 (1.6)	8.7 (1.5)	11.5 (1.5)[a,b]
9 months	8.0 (1.5)	8.5 (1.4)	11.2 (1.6)[a,b]
Study 3: Gaze Only			
12 months	5.5 (1.1)	5.9 (0.7)	8.5 (1.5)[a,b]

[a] greater than old toy test event, $p < .05$
[b] greater than final habituation trials, $p < .05$

age group, indicating a nonsignificant tendency for 7-month-olds to look for longer than 9-month-olds, $F(1, 38) = 3.33$, $p < .08$, and no other reliable effects (all other $Fs < 1$). Separate planned contrasts revealed reliable differences in infants' looking on the two kinds of test trials at neither age, both $ts < 1$. At an individual level, at 7 months 10 of 20 infants had longer overall looking times on new toy trials than on old toy trials, and at 9 months this was the case for 8 of 20 infants. Thus, there was no evidence that infants looked longer on new toy trials than on old toy trials, or that the two age groups differed from one another in their response to new toy trials versus old toy trials.

The primary analyses indicated that infants did not differentiate in their levels of attention to the two test events. This raises the question of whether infants responded to the novelty present in either kind of test event. New toy and old toy trials each presented infants with several changes from the habituation event. For one, on both kinds of trials, the toys were in new positions. In addition, on new toy trials, the actor looked at a new toy, and on old toy trials, the actor turned her head to the side opposite to the side she turned to in habituation. To assess whether infants responded to these changes, the next analyses compared infants' average looking times on each kind of test trial to their average looking time on the last two habituation trials. At neither age were there any reliable differences (all $ts < 1$). Thus, infants' overall looking times did not indicate a strong novelty response either to a change in the relation between the actor and the object of her gaze or to a change in the actor's motions.

Gaze-following

The next analyses tested whether infants at either age
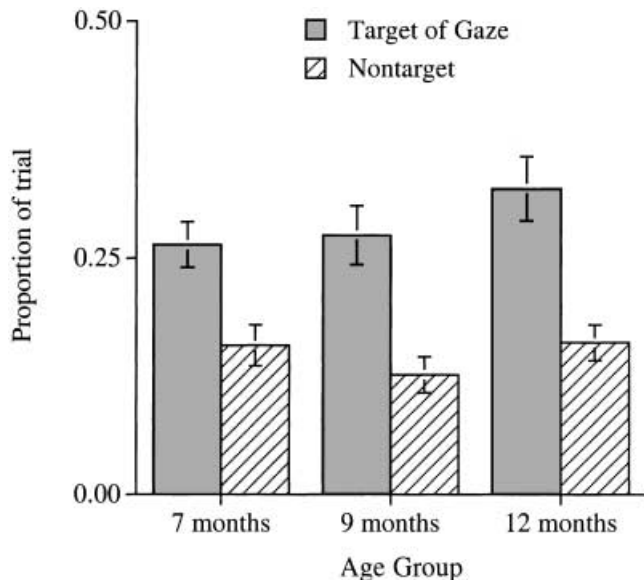
Figure 2 *Mean (SE) proportion of each test trial that infants spent looking at the toy looked at by the actor versus the other toy for Study 1 (7- and 9-month-olds) and Study 3 (12-month-olds).*

followed the actor's gaze. These analyses compared the amount of time infants spent looking at the toy that was the object of the actor's gaze versus the other toy during the test trials. Four 7-month-olds and two 9-month-olds could not be coded due to problems with the quality of the videotape. For the remaining infants, the average proportion of each test trial that the infant spent looking at the same toy as the actor versus at the other toy was calculated (see Figure 2). Because infants could look at portions of the event other than the two toys (e.g. the actor's face or the area between the two toys), these proportions did not always sum to 100. As an index of whether the actor's gaze directed infants' attention to the toy, the difference between the proportion of the trial spent looking at the object of the actor's gaze and the proportion of the trial spent looking at the other toy was calculated for each infant. This difference was reliably above 0, $t(33) = 6.40$, $p < .0001$. Infants' propensity to follow the actor's gaze did not vary as a function of age group or test trial type: an analysis of variance conducted on the difference scores with age group (7 versus 9 months) as the between-subjects factor and test trial type (new toy versus old toy) as the within-subjects factor yielded no reliable effects. Thirteen of the 16 codeable 7-month-olds, and 17 of the 18 codeable 9-month-olds looked longer at the object of the actor's gaze than at the other toy, $p < .05$ and $p < .005$ by sign test. In summary, infants at both ages followed the actor's gaze robustly.

These findings raise the question of whether gaze-following was related to infants' ability to note the relation between actor and object. Did those infants who followed gaze most robustly show increased attention to the relation between actor and object? To address this question, the next analyses assessed the correlation between the infants' gaze-following difference scores and the strength of their preferences for the new toy event. As an index of the latter, for each pair of test trials the amount of looking on the new toy trial as a proportion of the amount of looking on both the new toy and old toy trials was calculated and these scores were then averaged. This average score reflects the relative size of the preference across infant to infant variations in the overall length of trials and also reflects the stability of the infants' preference across pairs of test trials. Because 7- and 9-month-olds differed neither in their levels of attention to the two test trials nor in gaze-following, the two age groups were analyzed together. A Spearman rank order correlation revealed a nonsignificant negative relation between the two measures, rho $= -.25$, $z = 1.46$, $p < .15$. Thus, infants who followed gaze more strongly did not show increased attention to the relation between actor and object.

Discussion

This study did not reveal any differences between 7- and 9-month-olds in either their orienting response to gaze or in their understanding of the relation between looker and object. Both 7- and 9-month-old infants responded systematically to the actor's gaze, in that they followed the actor's eyes to the toy that was the object of her gaze. During the test trials, infants spent close to twice as much time on average looking at the object that was the target of the actor's gaze than at the other toy. Nearly every infant tested looked for longer at the target of the actor's gaze than at the other toy. In keeping with a number of prior findings, therefore (e.g. Butterworth & Jarrett, 1991; D'Entremont *et al.*, 1997; Hood *et al.*, 1998; Scaife & Bruner, 1975), the current findings indicate that gaze is a powerful attentional signal for infants.

Despite the fact that they responded systematically to the actor's shift in gaze, 7- and 9-month-old infants did not organize their representations of the event around the relation between the actor and the toy. Having been habituated to the actor repeatedly looking at one of the toys, infants did not respond to a change in the toy at which the actor looked. In fact, infants did not show reliable recovery from habituation on either kind of test trial, even though the toys were in new positions on these trials and even though the actor's head turned to a different side on old toy trials. It is as if infants identified

the visible objects (the bear, the ball and the actor) as being the same as during habituation, without considering the relations between them. Infants' lack of a novelty response during test trials is noteworthy given their strong propensity to orient in accord with the actor's gaze on those same test trials. At one level, infants were robustly attentive and responsive to the actor's gaze. Nevertheless, they did not seem to be sensitive to the relation between the actor and the object of her gaze.

These findings suggest that gaze-following is not initially linked to an understanding of the relation between a person and the object at which he or she gazes. However, before taking these findings as support for this conclusion, an alternative possibility must be explored. The experimental events may not have provided a sensitive index of infants' representational abilities. Although infants as young as 6 months of age responded to a change in the relation between an actor and the object she grasped in studies of similar design to the current study (Woodward, 1998, 1999), there were differences in how the experimental events were configured. In prior work, infants saw only the actor's arm. In Study 1, the actor's upper body and face were in full view of the infant. The presence of the actor's face, and the fact that she greeted infants at the start of each trial may have detracted from infants' attention to the relation between the actor and the toys. Infants may have been more interested in interacting with the experimenter than in considering her actions.

To test this possibility, in Study 2, 7- and 9-month-old infants were shown grasping events that occurred in the same context as in Study 1. The actor sat between the toys, visible from the chest up, and greeted the infant at the start of each trial. As in Study 1, she then turned to gaze at one of the toys. In this study, however, she also reached up from between the two toys to grasp the toy at which she gazed. Thus, in Study 2 infants saw an action that prior research suggests they encode in terms of the relation between actor and object. If the current paradigm is sensitive to infants' ability to attend to actor–object relations, then the effect seen in prior studies should be evident in Study 2.

Study 2

Method

Participants

Forty full-term infants, recruited as in Study 1, participated in the second study. There were 20 infants in the 7-month age group (mean age: 7 months 6 days; range: 6 months 15 days to 7 months 26 days) and 20 infants in the 9-month age group (mean age: 8 months 28 days; range: 8 months 0 days to 10 months 2 days). There were 9 females and 11 males at each age. An additional 9 infants began the procedure but were excluded from the final sample because of failure to complete all trials due to distress (one 7-month-old and four 9-month-olds) or because of an error in the experimental procedure (two 7-month-olds and two 9-month-olds).

Procedure

The procedure was identical to that in the first study with one exception: in addition to looking at the toy, the actor moved one of her hands up from between the toys to grasp it as she looked at it (see Figure 3). She used her left hand to grasp the toy on her right and her right hand to grasp the toy on her left. The actor's hands were bare and she wore no jewelry. As in Study 1, the actor began each trial by making eye contact with the infant and then saying 'Hi'. Then she said 'Look' as she turned to look at and grasp one of the toys. She remained still in this position for the duration of the trial. For the habituation phase, half of the infants at each age saw the actor reach to the object on the left and half saw her reach for the object on the right. On each side, half the infants saw the actor grasp the bear and half saw her grasp the ball. Following habituation, the positions of the toys were reversed and infants were given three new toy and three old toy test trials in alternation. Half of the infants at each age began with an old toy trial and half began with a new toy trial.

Video coding

As for Study 1, the videotapes of each infant were coded in two passes to assess the reliability of on-line observing and to code the amount of time that infants attended to the toy looked at and grasped by the actor versus the other toy during test trials. As in Study 1, for the first of these, the on-line coding was compared to after-the-fact coding from videotape for each infant. The video and on-line coders agreed on 91% of the trial endings at 7 months, and 87% at 9 months. At neither age was there a reliable tendency for the direction of their disagreements to be distributed systematically with respect to the hypothesized pattern of results, Fisher's exact $p = .58$ at 9 months and $p = .09$ at 7 months. For the coding of looks to each side, two independent coders overlapped for six infants at each age. Their judgments of the length of looks to each side were highly correlated, $r = .97$ at 7 months and $r = .92$ at 9 months.
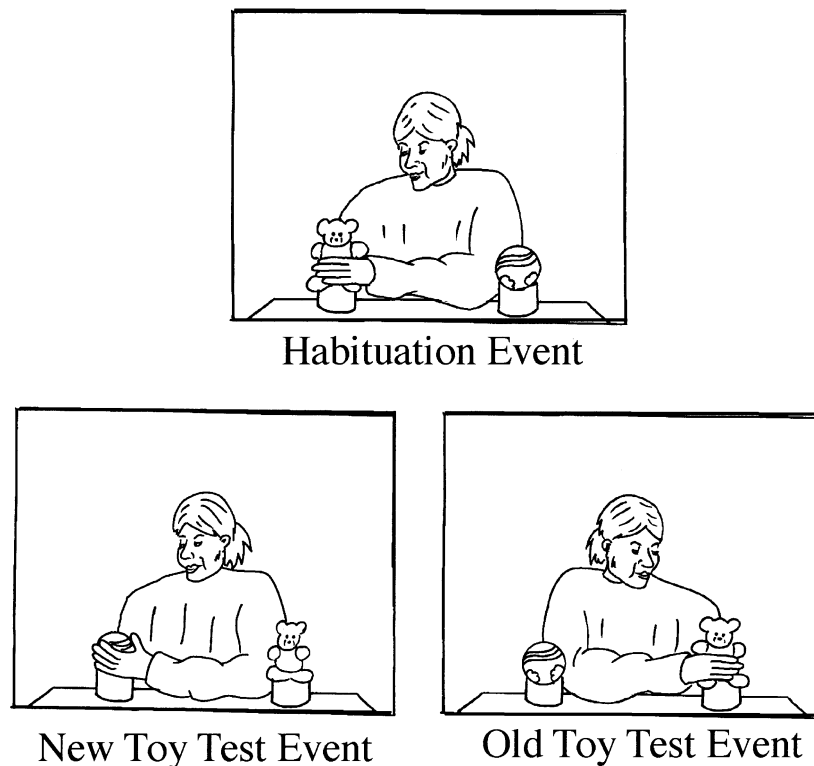
Figure 3   *Sample habituation and test events for Study 2.*

Results

Response to the change in relation between actor and object

On average, 7-month-olds reached the habituation criterion in nine trials and 9-month-olds did so in seven. One 7-month-old reached 14 trials without meeting the habituation criterion. When this infant was excluded from the sample, the interpretation of the results was unchanged. Therefore, this infant was included in the analyses reported below. Infants at the two ages did not differ in their level of attention at the end of habituation, $t(38) < 1$ (see Table 1).

As in Study 1, infants' looking times on the three test trials of each type were averaged, and, to reduce positive skew, these scores were then subjected to a log transformation. Table 1 summarizes the untransformed scores. Preliminary analyses revealed no reliable effects of the side to which the experimenter looked during habituation, the object that she grasped and the type of test trial given first. Therefore, subsequent analyses collapsed across these dimensions. To assess whether infants at either age responded more strongly to the change in relation between the actor and the object than to a change in the

actor's patterns of motion, an analysis of variance with age group (7 versus 9 months) as the between-subjects factor and test trial type (new toy versus old toy) as the within-subjects factor was conducted. This analysis revealed a main effect of test trial type, $F(1, 38) = 12.66$, $p < .005$, and no other reliable effects (all other $Fs < 1$). As can be seen in Table 1, the main effect reflected the fact that infants looked longer on new toy trials than on old toy trials. Planned comparisons confirmed that this was the case for each age group, $t(19) = 2.52$, $p < .05$ and $t(19) = 2.53$, $p < .05$ for 7- and 9-month-olds, respectively. At an individual level, 14 of 20 7-month-olds and 15 of 20 9-month-olds had longer overall looking times on new toy trials than on old toy trials.

Next, performance of the infants in Study 2 was compared to the performance of infants in Study 1. These two studies presented infants with very similar events, and they were conducted by the same set of researchers, partially overlapping in time. Therefore, it seemed reasonable to compare performance in the two studies within a single analysis. Each infant's total looking time for each kind of test trial was entered into an analysis of variance with Study (1 versus 2) and age group (7 versus 9 months) as the between-subjects factors and test trial type (new toy versus old toy) as the within-subjects

factor. This analysis revealed a reliable Study × Trial Type interaction, $F(1, 76) = 5.61$, $p < .05$, and no other reliable effects. This analysis confirms that infants in the two studies differed in their responses on test trials.

Infants looked longer on new toy trials than on old toy trials. However, old toy trials also presented infants with several changes from the habituation event. To ask whether infants responded to these changes, the next analyses compared their average looking times on the last two habituation trials to their average looking times on the two kinds of test trials. Neither age group showed a reliable increase in looking in response to old toy trials, $t(19) = 1.59$, $p > .12$ for 7-month-olds and $t(19) < 1$ for 9-month-olds. In contrast, infants at both ages showed reliable recovery on new toy trials, $t(19) = 3.98$, $p < .001$ and $t(19) = 2.31$, $p < .05$ for 7- and 9-month-olds, respectively. This pattern of results is in keeping with prior findings (Woodward, 1998, 1999). Despite the several changes in the old toy events, infants seemed to treat them as similar to the habituation event. In contrast, infants responded strongly to the change in the relation between the actor and the object on new toy trials.

Gaze- (and grasp-) following

As in the first study, infants' looking to each of the two toys during the test trials was coded, and the average proportion of each test trial that the infant spent looking at the same toy as the actor versus at the other toy was calculated. There were problems with the quality of the videotape for one 7-month-old and one 9-month-old, and therefore those infants could not be coded. The scores for the remaining infants are summarized in Figure 4. As an index of whether the actor's gaze and grasp directed infants' attention to the toy, the difference between the proportion of the trial spent looking at the object of the actor's gaze and grasp and the proportion of the trial spent looking at the other toy was calculated for each infant. This score was reliably greater than 0, indicating that infants looked longer at the toy grasped and looked at by the actor than at the other toy, $t(37) = 9.49$, $p < .0001$. An analysis of variance conducted on the difference scores with age group (7 versus 9 months) as the between-subjects factor and test trial type (new toy versus old toy) as the within-subjects factor yielded a marginal effect of trial type, $F(1, 36) = 3.01$, $p < .10$, reflecting a tendency for infants to have larger difference scores on old toy trials than on new toy trials. There was no effect of age group and no age group by trial type interaction, both $Fs < 1$. Of the 19 codeable infants at each age, 18 7-month-olds and 17 9-month-olds looked longer at the toy looked at and grasped by the actor than at the other toy, $p < .0001$ and $p < .001$ by
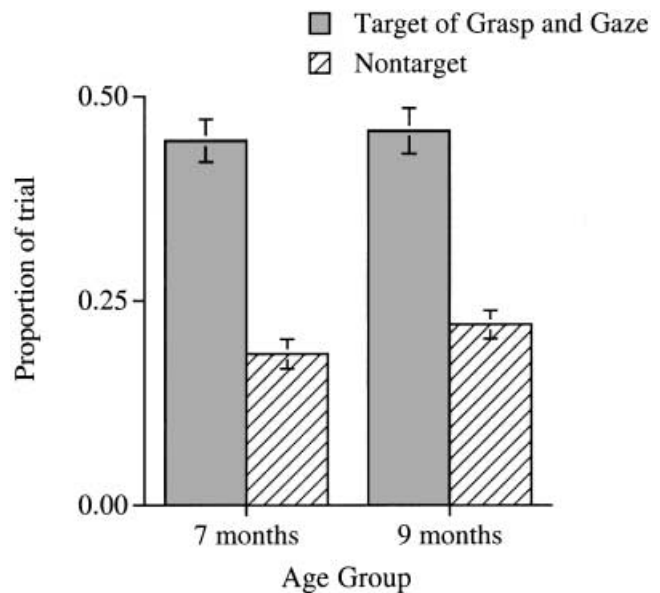
Figure 4 *Mean (SE) proportion of each test trial that infants spent looking at the toy looked at and grasped by the actor versus the other toy for Study 2.*

sign test. Infants' attention to the object of the actor's gaze and grasp seemed to be unrelated to their response to the change in the relation between actor and object: a Spearman rank order correlation conducted as in Study 1 did not reveal a reliable correlation, rho = .15, $z < 1$.

Discussion

As was the case for gaze alone, gaze accompanied by grasping led infants at both ages to attend to the object that was the target of the actor's behaviors. In this study, in contrast to Study 1, both 7- and 9-month-olds also attended to the relation between the actor and the object, responding to a change in this relation on test trials. These findings replicate prior findings with somewhat different experimental events, and lend support to the conclusion that infants understand grasping in terms of the relation between actor and object (Woodward, 1998, 1999). Critically for the present purposes, these findings suggest that the type of event used in these studies is sensitive to infants' representations of action. Seven- and 9-month-old infants were not distracted by the actor's face or her utterances during the procedure. They readily construed grasping in terms of the relation between actor and object in this situation, but, in Study 1, infants of the same ages did not do so for gaze alone.

Study 3

The final question was whether older infants would encode the relation between actor and object for gaze alone. To address this question, 12-month-old infants were tested in Study 3.

Method

Participants

Twenty full-term 12-month-old infants, recruited as in the prior studies, participated in Study 3. The 15 males and five females had a mean age of 11 months 27 days (range = 10 months 27 days to 12 months 24 days). Seven additional infants began the procedure but were excluded from the sample. Two of these infants failed to complete all trials due to distress, four had procedures with an experimental error, and one infant was replaced because his total looking time during test trials was more than 3 standard deviations above the mean.

Procedure

The apparatus and procedure were the same as in Study 1. Infants sat in an infant seat or on a parent's lap. At the start of each trial, the actor made eye contact with the infant and said 'Hi', and then said 'Look' as she turned to look at one of the toys. She remained still, looking at the toy for the duration of the trial. Eleven infants saw the actor turn to the right during habituation and nine saw her turn to the left. At each side, approximately half the infants saw the actor look at the ball and half saw her look at the bear. Following the habituation phase, the toys' positions were reversed and infants were given three new toy and three old toy test trials in alternation. Ten infants began with an old toy trial and ten began with a new toy trial.

Video coding

As in the first two studies, a second coder scored the test trials for each infant after the fact to assess the reliability of the on-line observing. The two coders agreed on 92% of trial endings, and their disagreements were randomly distributed in terms of direction and trial type, Fisher's exact $p = .44$. In a second pass of the tapes, each infant's looks to each of the two toys were coded. Two independent coders overlapped for six infants. Their judgments of the amount of looking to each toy were strongly correlated, $r = .92$.

Results

Response to the change in relation between actor and object

Infants reached the habituation criterion in eight trials on average. Three infants reached 14 trials without meeting the habituation criterion. Because these three infants showed the same overall patterns as the rest of the group, their data were included in the analyses reported below.

As in prior studies, infants' looking times on the three test trials of each type were averaged (see Table 1). Preliminary analyses revealed no effects of the kind of test trial given first, the side to which the experimenter looked during habituation or the object that was the target of her gaze. Therefore, subsequent analyses collapsed across these dimensions. A planned paired comparison revealed that the 12-month-olds looked longer on new toy trials than on old toy trials, $t(19) = 2.23$, $p < .05$. Overall, 12 of 20 infants looked longer on new toy trials than on old toy trials. In contrast to younger infants, then, 12-month-olds responded more strongly to a change in the relation between looker and object than to a change in the actor's motion.

Next, infants' average looking times on each kind of test trial were compared to their average looking time on the last two habituation trials. Infants' looking increased from habituation on new toy trials, $t(19) = 2.61$, $p < .02$, but not on old toy trials, $t(19) < 1$. Thus, as was the case for younger babies' responses to the looking and grasping events in Study 2, 12-month-olds responded to the old toy event as similar to the habituation event, but increased attention in response to the change in the relation between actor and toy in the new toy event.

Gaze-following

As in the first two studies, infants' looking to each of the two toys during the test trials was coded, and the average proportion of each test trial that the infant spent looking at the same toy as the actor versus at the other toy was calculated. One infant could not be included in this analysis due to problems with the quality of the videotape. The scores for the remaining 19 infants are summarized in Figure 2. As was the case for 7- and 9-month-olds, the 12-month-olds followed the actor's gaze. They looked longer overall at the toy at which the actor looked than at the other toy; the difference between the proportion of looking to the target toy and the proportion of looking to other toy was reliably above 0, $t(18) = 5.02$, $p < .0001$. Sixteen of 19 infants looked longer at the target of the actor's gaze than the other toy, $p < .005$ by sign test. A paired comparison conducted on

the difference scores for new toy and old toy trials revealed that infants' propensity to follow gaze did not vary reliably as a function of trial type, $t(18) < 1$.

To assess whether infants' propensity to follow gaze in this paradigm varied as a function of age from 7 to 12 months, the scores from 12-month-olds were next compared to those of the 9- and 7-month-olds from Study 1. An analysis of variance conducted on the difference scores (proportion of looking to the target object – proportion of looking to the other object) with age group (7 months, 9 months, 12 months) as the between-subjects factor did not reveal a reliable age difference, $F(2, 88) < 1$.

Finally, a Spearman rank correlation was computed to determine whether there was a relation between gaze-following and response to the test events (as indexed by the average proportion of preference for the new toy event) at 12 months. There was not a reliable relation between these measures, although, in contrast to the 7- and 9-month-olds in Study 1, the trend was in the direction of a positive relation rather than a negative one, rho = .25, $z = 1.06$, $p < .30$.

Discussion

As was the case for younger infants, gaze was a powerful attentional signal for 12-month-olds. Infants at this age spent twice as long looking at the target of the actor's gaze than at the other toy. In contrast to younger infants, 12-month-olds also showed systematic attention to the relation between the actor and the object of her gaze. They looked longer at test trials in which the relation between actor and object had changed than at test trials in which the motion of the actor had changed. In fact, they showed reliable recovery from habituation only when there was a change in the relation between the actor and the toy. This pattern of findings is similar to that seen in younger infants who view events in which a person grasps a toy. Taken together with the findings from Studies 1 and 2, these findings indicate that infants begin to understand gaze in terms of the link between actor and object between 9 and 12 months of age.

General discussion

The current findings lend support to the conclusion that infants' gaze-following is not initially accompanied by an understanding of gaze as an action that relates a person to some object (Butterworth, 1998; Butterworth & Jarrett, 1991; Moore & Corkum, 1994; cf. Povinelli & Eddy, 1996). The 7- and 9-month-olds tested in the current studies responded systematically to the experi-

mental events in several respects. When they saw an actor look at a toy, they followed the actor's gaze, directing their own attention to match that of the actor. Moreover, when they saw the actor look at and grasp a toy, they not only looked at that toy, but also selectively attended to the relation between actor and toy over other aspects of the event. However, when they saw the actor look at the toy but not touch it, 7- and 9-month-olds seemed not to encode the actor–object relation. They did not show a greater novelty response when the relation between actor and object changed than when the motions of the actor changed, and, indeed, did not even show reliable recovery from habituation.

While it is often difficult to interpret findings in which infants do not show a systematic pattern of behavior, the current studies provide evidence to inform the interpretation of these findings. This evidence weighs against some explanations for 7- and 9-month-olds' failure to respond to the change in relation between looker and object. For one, when infants fail to respond to novelty during test trials, it is possible that this reflects inattention, boredom or lack of interest, rather than a legitimate failure to encode the dimension of change. In the current studies, on the very same test trials during which they failed to respond to the change in looker–object relation, 7- and 9-month-old infants responded robustly to the actor's gaze by following her eyes to the target toy. These patterns of response indicate that infants were attentive during the test trials, they noticed the actor's gaze and they were motivated to respond to it. A second potential concern in the face of unsystematic performance is that the methods used may have been insensitive to the information infants had encoded in memory. Study 2 explored this concern by presenting infants with events that were identical to the looking events except that the actor grasped the toy as well as looking at it. In this context, infants at 7 and 9 months responded to the change in relation between actor and object. These findings support the conclusion that the current methods were sensitive to infants' representations of events.

Taken together, these findings indicate that between 7 and 9 months, infants' propensity to follow an actor's gaze does not seem to be informed by an understanding of the relation between looker and object. It is possible, of course, that infants at these ages are able to note the relation between looker and object under more supportive situations. Ongoing work investigates this possibility. However, the current findings demonstrate that 7- and 9-month-old infants strongly follow gaze in a situation in which they are not sensitive to the relation between looker and object.

By 12 months, the picture is different. The 12-month-olds, like younger infants, responded to gaze as an atten-

tional signal, but, unlike younger infants, they also noted the relation between looker and object. They showed a novelty response to a change in this relation, but no such response to a physically different pattern of movement that resulted in the actor looking at the same toy. Therefore, between 9 and 12 months, infants begin to represent gaze primarily in terms of the relation between the person and the object of her gaze.

The findings from the analyses of gaze-following concur with a number of reports indicating that gaze is a powerful attentional signal from early in infancy (Butterworth & Jarrett, 1991; D'Entremont et al., 1997; Hood et al., 1998; Scaife & Bruner, 1975). Infants at 7, 9 and 12 months showed similar levels of increased attention to the toy that was the target of the actor's gaze, looking for roughly twice as long at the target toy than at the other toy. At all three ages, nearly every baby looked longer overall at the target toy than at the other toy. This measure of gaze-following did not reveal differences in performance at the three different ages. However, more stringent measures of gaze-following indicate that infants are becoming more skilled during this age span. When infants are required to turn to the correct side before looking anywhere else, when they are required to turn to the correct side within a brief time window, when the object is not in the infants' immediate visual field, or when infants are required to locate the correct target from an array of several objects, 12-month-olds generally out-perform younger infants (Butterworth & Jarrett, 1991; Carpenter et al., 1998; Moore & Corkum, 1998; Scaife & Bruner, 1975). Moreover, during the second year of life, gaze-following becomes embedded in rich joint attention interactions, in which infants actively seek to manipulate the attention of others, and seem to check to see whether their efforts have been successful (Bates, Benigni, Bretherton, Camaioni & Volterra, 1979; Carpenter et al., 1998; Schaffer, 1984). Unlike the measure of gaze-following used in the current studies, these more advanced aspects of gaze-following might be correlated with infants' developing sensitivity to the link between looker and object. It is possible, for example, that infants' ability to follow gaze to objects outside the immediate visual field would be correlated with, and perhaps dependent on, their emerging understanding of the link between a person who looks and the object of her gaze. Additional studies are needed to explore this possibility.

The current findings indicate that 12-month-olds attend to the relation between a person and the object of her gaze, but they do not tell us how infants understand this relation. As was discussed earlier, mature understanding of gaze is multifaceted, including knowledge about the experience of seeing, the ways that gaze can affect mental states such as knowing, and the likely behavioral consequences of gaze. While it may not be the case that infants' first understanding of the relation between looker and object is based in this full range of knowledge, it is possible that it is continuous with one or more of these mature notions.

One possibility is that infants first understand the relation between looker and object in terms of the phenomenological experience of seeing. Corkum and Moore (1994) proposed this, suggesting that this insight results from the repeated experience of engaging in joint visual attention on an object with an adult. Infants begin by associating their own experience of seeing an object during joint attention with the gaze behavior they observe in the adult during these interactions. With development, infants come to understand that the other person is phenomenologically connected to the object, independent of the infant's own perceptual experience.

The current findings, along with other recent work, suggest another route by which infants could become sensitive to the relation between looker and object – via the behavioral regularities associated with gaze. When infants observe people grasping objects, they also generally observe gaze that is coordinated with the grasp. Based on Study 2, as well as earlier findings (Woodward, 1998, 1999; Wellman & Phillips, 2001), infants understand grasping as involving a relation between actor and object before they understand gaze in this way. If infants sought to integrate information about simultaneous observed actions, they might thus interpret gaze, on analogy with grasping, as a behavior that involves a relation between actor and object. Other findings indicate that by 12 months infants seek to relate manual actions when these actions occur in sequence (Woodward & Sommerville, 2000), and that they may do this for gaze and grasping in some situations (Spelke, Phillips & Woodward, 1995; but see Sodian & Thoermer, 1999). Therefore, infants younger than 12 months may be able to relate gaze to grasping when they occur simultaneously. The possibility that infants begin to understand the looker–object relation in terms of behavioral regularities and the possibility that they do so in terms of the experience of seeing are not mutually exclusive. In fact, the combination of these two insights about gaze may be a particularly powerful starting point for development.

Even if infants' understanding of the relation between looker and object is initially quite limited, attending to this relation would set the stage for further discoveries about gaze. Indeed, recent work indicates that in the months following their first birthday, infants begin to understand several important aspects of the looker–object relation. For one, the literature on social referencing indicates that early in the second year, infants

understand that emotional expressions can concern the object of a person's gaze. Although infants under 12 months respond to emotional expressions in social referencing tasks, it is not until infants are 12 to 14 months that there is evidence that they use gaze to relate these expressions to particular objects (Baldwin & Moses, 1994, 1996; Repacholi, 1998). In addition, by 16 to 18 months infants understand the link between gaze and language use (Baldwin, 1991, 1995). Babies at this age interpret new words as naming objects that are the target of the speaker's gaze, rather than objects that are not the target of the speaker's gaze. Recent evidence suggests that even younger infants, 12- to 14-month-olds, may understand the relevance of gaze for making sense of words (Baldwin & Tomasello, 1998; Hirsh-Pasek, Golinkoff & Hollich, 2000; Woodward, 2000). Finally, early in the third year, children understand something about the role of gaze in determining a person's epistemic states. O'Neill (1996) found that 2-year-olds gave their mothers more information about an event she had not seen than about an event she had seen.

In summary, the current findings raise several critical issues for further study, including the possible relation between infants' understanding of the looker–object link and their increasing skill at managing joint attention, and the exact nature of infants' initial understanding of the link between looker and object. These issues aside, the findings shed light on the long-standing question of the significance of infants' gaze-following. They suggest that infants initially follow gaze without understanding the relation between a person and the object of her gaze. Between 9 and 12 months, perhaps based on the experiences of observing gaze behavior in others and following gaze during joint attention, infants become sensitive to this relation.

Acknowledgements

References

Baldwin, D.A. (1991). Infants' contribution to the achievement of joint reference. *Child Development*, **62**, 875–890.

Baldwin, D.A. (1995). Understanding the link between joint attention and language. In C. Moore & P. Dunham (Eds.), *Joint attention: Its origins and role in development* (pp. 131–158). Hillsdale, NJ: Erlbaum.

Baldwin, D.A., & Moses, L.M. (1994). Early understanding of referential intent and attentional focus: evidence from language and emotion. In C. Lewis & P. Mitchell (Eds.), *Origins of an understanding of mind* (pp. 133–156). Hillsdale, NJ: Erlbaum.

Baldwin, D.A., & Moses, L.M. (1996). The ontogeny of social information gathering. *Child Development*, **67**, 1915–1939.

Baldwin, D.A., & Tomasello, M. (1998). Word learning: a window on early pragmatic understanding. In E.V. Clark (Ed.), *Proceedings of the twenty-ninth annual Child Language Research Forum* (pp. 3–23). Stanford, CA: CSLI.

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

Brooks, R., Caron, A.J., & Butler, S.C. (1998). Infant comprehension of looking as an intentional behavior. Presentation at the International Conference on Infant Studies, Atlanta, GA.

Butterworth, G. (1998). Origins of joint visual attention in infancy: commentary on Carpenter *et al*. *Monographs of the Society for Research in Child Development*, **63** (4), 144–166.

Butterworth, G., & Jarrett, N. (1991). What minds have in common is space: spatial mechanisms serving joint visual attention in infancy. *British Journal of Developmental Psychology*, **9**, 55–72.

Caron, A.J., Caron, R.F., Caldwell, R.C., & Weiss, S.J. (1973). Infant perception of the structural properties of the face. *Developmental Psychology*, **9**, 385–399.

Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development*, **63** (4).

Corkum, V., & Moore, C. (1998). The origins of joint visual attention in infants. *Developmental Psychology*, **34**, 28–38.

D'Entremont, B., Hains, S.M.J., & Muir, D.W. (1997). A demonstration of gaze following in 3- to 6-month-olds. *Infant Behavior and Development*, **20** (4), 569–572.

Driver, J., Davis, G., Ricciardelli, P., Kidd, P., Maxwell, E., & Baron-Cohen, S. (1999). Gaze perception triggers reflexive visuospatial orienting. *Visual Cognition*, **6**, 509–540.

Flavell, J.H. (1988). The development of children's knowledge about the mind: from cognitive connections to mental representations. In J.W. Astington, P.L. Harris & D.R. Olson (Eds.), *Developing theories of mind* (pp. 244–267). Cambridge: Cambridge University Press.

Guajardo, J.J., & Woodward, A.L. (under review). Is agency skin-deep? Infants use surface features to interpret goal-directed action.

Hains, S.M.J., & Muir, D.W. (1996). Infant sensitivity to adult eye direction. *Child Development*, **67**, 1940–1951.

Haith, M.M., Bergman, T., & Moore, M.J. (1977). Eye contact and face scanning in early infancy. *Science*, **198**, 853–855.

Hirsh-Pasek, K., Golinkoff, R.M., & Hollich, G. (2000). An emergentist, coalition model for word learning: mapping

words to objects is a product of the interaction of multiple cues. In R. Golinkoff, K. Hirsh-Pasek, N. Akhtar, L. Bloom, G. Hollich, L. Smith & A. Woodward (Eds.), *Becoming a word learner: A debate on lexical acquisition* (pp. 136–164). Oxford: Oxford University Press.

Hood, B.M., Willen, D., & Driver, J. (1998). Adult's eyes trigger shifts of visual attention in human infants. *Psychological Science*, **9**, 131–134.

Kingstone, A., Friesen, C.K., & Gazzaniga, M.S. (2000). Reflexive joint attention depends on lateralized cortical connections. *Psychological Science*, **11**, 159–166.

Langton, S.R.H., & Bruce, V. (1999). Reflexive visual orienting in response to the social attention of others. *Visual Cognition*, **6**, 541–567.

Maurer, D., & Salapatek, P. (1976). Developmental changes in the scanning of faces by young infants. *Child Development*, **47**, 523–527.

Moore, C., & Corkum, V. (1994). Social understanding at the end of the first year of life. *Developmental Review*, **14**, 349–372.

O'Neill, D.K. (1996). Two-year-old children's sensitivity to a parent's knowledge state when making requests. *Child Development*, **67**, 659–677.

Pinto, J. (1994). MacXhab. Stanford, CA.

Povinelli, D.J., & Eddy, T.J. (1996). What young chimpanzees know about seeing. *Monographs of the Society for Research in Child Development*, **61** (Serial no. 247).

Pratt, C., & Bryant, P. (1990). Young children understand that looking leads to knowing. *Child Development*, **61**, 973–982.

Repacholi, B.M. (1998). Infants' use of attentional cues to identify the referent of another person's emotional expression. *Developmental Psychology*, **34** (5), 1017–1025.

Scaife, M., & Bruner, J.S. (1975). The capacity for joint visual attention in the infant. *Nature*, **253**, 265–266.

Schaffer, H.R. (1984). *The child's entry into a social world.* London: Academic Press.

Sodian, B., & Thoermer, C. (1999). Infants' understanding of looking and reaching as cues to goal-directed action. Unpublished manuscript.

Spelke, E.S., Phillips, A.T., & Woodward, A.L. (1995). Infants' knowledge of object motion and human action. In A.J.

Premack, D. Premack & D. Sperber (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 44–77). Oxford: Clarendon Press.

Symons, L.A., Hains, S.M.J., & Muir, D.W. (1998). Look at me: five-month-old infants' sensitivity to very small deviations in eye-gaze during social interactions. *Infant Behavior and Development*, **21** (3), 531–536.

Vecera, S.P., & Johnson, M.H. (1995). Gaze detection and the cortical processing of faces: evidence from infants and adults. *Visual Cognition*, **2**, 59–87.

Wellman, H.M., & Phillips, A.T. (2001). Developing intentional understandings. In B. Malle, L. Moses & D. Baldwin (Eds.), *Intentionality: A key to human understanding* (pp. 125–148). Cambridge, MA: MIT Press.

Winer, G.A. (1991). Children's understanding of perception and perceptual processes. *Annals of Child Development*, **8**, 177–213.

Woodward, A.L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition*, **69**, 1–34.

Woodward, A.L. (1999). Infants' ability to distinguish between purposeful and non-purposeful behaviors. *Infant Behavior and Development*, **22**, 145–160.

Woodward, A.L. (2000). Constraining the problem space in early word learning. In R. Golinkoff, K. Hirsh-Pasek, N. Akhtar, L. Bloom, G. Hollich, L. Smith & A. Woodward (Eds.), *Becoming a word learner: A debate on lexical acquisition* (pp. 81–114). Oxford: Oxford University Press.

Woodward, A.L., & Guajardo, J.J. (2002). Infants' understanding of the point gesture as an object-directed action. *Cognitive Development*, **17**, 1061–1084.

Woodward, A.L., & Sommerville, J.A. (2000). Twelve-month-old infants interpret action in context. *Psychological Science*, **11**, 73–76.

Woodward, A.L., Sommerville, J.A., & Guajardo, J.J. (2001). How infants make sense of intentional action. In B. Malle, L. Moses & D. Baldwin (Eds.), *Intentionality: A key to human understanding* (pp. 149–170). Cambridge, MA: MIT Press.