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The Origins of Joint Visual Attention in Infants

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Two experiments examined the origins of joint visual attention with a training procedure. In Experiment 1, infants aged 6–11 months were tested for a gaze-following (joint visual attention) response under feedback and no feedback conditions. In Experiment 2, infants 8–9 months received feedback for either following the experimenter's gaze (natural group) or looking to the opposite side (unnatural group). Results of the 2 experiments indicate that (a) joint visual attention does not reliably appear prior to 10 months of age, (b) from about 8 months of age, a gaze-following response can be learned, and (c) simple learning is not sufficient as the mechanism through which joint attention cues acquire their signal value.

It is perhaps no exaggeration to suggest that all intrinsically human experience is grounded in its shared nature. In infancy, joint attention to objects and events in the world provides the initial means whereby the child can share experiences with others and negotiate shared meanings. Episodes of joint attention provide the context for the development of both knowledge about the world and knowledge about others as experiencers. In this way, joint attention plays a central role in the development of the young child's understanding of both social and nonsocial worlds and in the development of the communicative interplay between child and adult (see Adamson & Bakeman, 1991; Moore & Dunham, 1995, for surveys). Specifically, joint attention serves an important communicative function during the prelinguistic period in that it permits information about objects of interest or desire to be conveyed (Butterworth, 1991). Further, joint attention provides the foundation of shared experience necessary for language acquisition (Baldwin, 1995; Bruner, 1983; Tomasello, 1995). Joint attention is also implicated in a number of other social behaviors that are first seen toward the end of the first year of life, including social referencing, whereby emotional information about an ambiguous object or situation is conveyed from adult to infant because the infant can follow the adult's attention (e.g., Feinman, 1982; Hornik, Risenhoover, & Gunnar, 1987; Sorce, Emde, Campos, & Klinnert, 1985), and prelinguistic communicative acts, such as protodeclarative and protoimperative gestures (e.g., Bates, Camaioni, & Volterra 1979) in which the infant directs the attention of an adult to some common focus.

By virtue of its involvement in these early social and communicative acts, joint attention is a central component of triadic interaction (Bakeman & Adamson, 1984), in which infants coordinate their attention toward both a social partner and an object of mutual interest. This coordination, which is the hallmark of secondary intersubjectivity (Trevarthen & Hubley, 1978), signals the beginnings of a very different type of infant social awareness. For now, infants appear to show that they are aware of the possibility for sharing, with others, activities that are directed at objects. This kind of understanding indexes the origins of intentional understanding and lays the foundation for later forms of mental understanding (Moore & Corkum, 1994; Tomasello, Kruger, & Ratner, 1993).

Although, strictly speaking, attention does not depend on visual fixation, and a number of forms of joint attention are possible (e.g., Tomasello, 1995), perhaps the simplest form is joint visual attention, or "looking where someone else is looking" (Butterworth, 1991, p. 223). Joint visual attention requires that one interactional partner follow the other's direction of gaze by turning to look in the same direction. The earliest episodes of joint visual attention between adult and child probably occur because of the adult's ability to recognize where the infant is looking (Schaffer, 1984). At this point, however, the infant plays no active role in establishing joint visual attention, and it is likely that the infant does not even recognize that attention is shared. Later, infants will start to follow the gaze of the adult and thereby bring about joint visual attention themselves, although the extent to which infants recognize that attention is shared, even at this stage, is an issue of some debate (Moore & Corkum, 1994).

Scaife and Bruner (1975) were the earliest investigators to explore the emergence of such active gaze following in infants. In their study, an experimenter, after first establishing eye contact with an infant, turned head and eyes together 90 degs to fixate for 7 s a target not visible to the infant. The experimenter presented each infant with two trials of change in gaze direction (i.e., one to each side). Infants were judged as having estab-

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lished joint attention if they turned to look in the same direction as the experimenter on one out of the two trials. Scaife and Bruner found that 30% of infants as young as 2 months turned their heads to follow a model's line of regard. The percentage of infants turning to follow the model's gaze increased steadily with age so that by 11–14 months of age, 100% of the infants tested demonstrated head turning in the appropriate direction on at least one of the two experimental trials.

Butterworth and colleagues (Butterworth & Cochran, 1980; Butterworth & Grover, 1990; Butterworth & Jarrett, 1991) followed up this early work to examine the accuracy with which infants of different ages could localize the targets of another's attention. Butterworth and colleagues documented three age-specific mechanisms for joint visual attention between 6 and 18 months. At 6 months of age, infants reliably turn their heads to the correct side of the room for targets within their own visual field but only locate the correct target if it is first within their path of scanning (ecological mechanism). At 12 months of age, infants correctly pinpoint both the direction and the location of targets, regardless of positioning along the path of scanning (geometric mechanism); however, they fail to search for targets located behind them. Finally, at 18 months of age, infants not only correctly pinpoint both the direction and the location of targets, regardless of positioning along path of scanning, but they also search for targets that are located behind them; however, they only do so when their own visual field is empty of targets (spatial representational mechanism).

A similarity in this early work (Butterworth & Cochran, 1980; Butterworth & Grover, 1990; Butterworth & Jarrett, 1991; Scaife & Bruner, 1975) is that these investigators did not take into account the extent to which infants produced head turns in the opposite direction when presented with an adult reorientation of gaze. As a result, Butterworth and colleagues may have underestimated the age at which infants reliably are able to follow gaze. More recent work on joint visual attention (Corkum & Moore, 1995; Morissette, Ricard, & Gouin-Decarie, 1995) has used a more stringent operational definition of joint visual attention, whereby both matches and mismatches with the model's direction of gaze (or direction of point) are taken into consideration. According to this new criterion, infants are required to turn in the same direction as the model significantly more frequently than they turn in the opposite direction for joint visual attention to be reliably demonstrated. These studies have pointed to about 10–12 months as a more likely age of onset for reliable gaze following (and point following), indicating that, certainly by the end of the first year of life, infants are quite able to note the reorientation of gaze of an adult and turn to look in the same direction.

One last area of research on joint visual attention has been the cues that infants use to follow gaze. Although direction of gaze is most accurately given by the orientation of the viewer's eyes, it may be secondarily indicated by other signs, such as head orientation and body posture, as well as by communicative gestures, such as pointing. Research varying the cues provided by the adult has shown that infants initially use only secondary cues to follow another's gaze. For example, Lempers (1979) and Corkum and Moore (1995) found that infants below 12 months use head orientation information and ignore information about eye orientation to follow the adult's "gaze." In fact, it is not until about 18 months of age that gaze following is reliably produced when the adult cue is eye movement alone (Butterworth & Jarrett, 1991; Corkum & Moore, 1994).

In the present study, our concern was one that has so far remained unaddressed in the joint visual attention literature; that is, the developmental origins of the gaze-following response. In exploring this issue, we revisited the age-old nature–nurture debate. As it pertains to joint visual attention, the debate might go something like the following (see also Moore & Corkum, 1994). Proponents of the nativist side might propose the existence of an innate orienting response whereby infants, cued by the head turn of another, would be compelled to align with the other's gaze in the absence of any prior experience with it or any understanding of its significance. Given the universality of the gaze-following response and its developmental importance, such a mechanism might make sense. In contrast, proponents of the nurture or learning side might suggest that gaze following comes about simply through the experience of repeated exposures to cues (such as the head turns of others), followed by reinforcers (such as seeing interesting sights). This also may occur in the absence of any particular understanding of the significance of the cues or the events (see Moore & Corkum, 1994, for an expanded account). The two experiments contained herein represent an initial attempt to document the relative contributions of nature and nurture to the development of the joint visual attention or gaze-following response. In undertaking this task, we reasoned that a good place to start would be to investigate whether learning of a gaze-following response is even possible, and, if it is, at what age and under what conditions. In Experiment 1, we began this investigation by testing, quite simply, if it would be possible, through the provision of contingent feedback, to train infants who were not showing joint visual attention to follow the gaze of a model. To address this issue, we introduced a relatively small but significant change into the joint visual attention paradigm used by previous researchers (e.g., Butterworth & Cochran, 1980; Butterworth & Grover, 1990; Butterworth & Jarrett, 1991; Morissette et al., 1995; Scaife & Bruner, 1975). This change involved providing the infant with an interesting sight to the side after the adult had produced the head turn movement. In this way, the direction of the adult's head turn predicted the appearance of the interesting sight. Our interest was in whether infants effectively could learn, in an experimental session, to use the adult cues to turn to look at the interesting sight and, in so doing, align with the adult's direction of gaze. In Experiment 2, we examined the origins of the signal value of the cues for joint attention, that is, whether the physical characteristics of the cues are critical to the gaze-following response.

Experiment 1

Method

Participants. The participants were 77 infants who were between 6 and 11 months of age. All of the infants were full term (over 37 weeks gestation), of normal birth weight (over 3200 gm), and had experienced no birth complications or major health problems. Testing was not completed with 14 infants who became fussy or too active to remain seated on the parent's lap: 4 from the 6–7-month group, 6 from the 8–9-month group, and 4 from the 10–11-month group. The final sample of 63 infants was subdivided into three groups (6–7-, 8–9-, and 10–11-month-olds), each of which comprised 21 infants. The mean age and age range for each of the groups were as follows: 6–7 months (M = 6 months 27 days; range = 6 months 1 day to 7 months 29 days), 8–9 months (M = 9 months 3 days; range = 8 months 6 days to 9 months 29 days), 10–11 months (M = 10 months 23 days; range = 10 months 3 days to 11 months 27 days). At 8–9 months, 11 girls and 10 boys were tested, whereas at 6–7 and 10–11 months, the groups comprised 12 girls and 9 boys.

Setup and procedure. Sessions took place inside a cubicle enclosed with plain curtains to minimize distractions. The only targets present inside the cubicle were two toys used as targets (one located on each side of the cubicle). The toys were identical black-and-white stuffed dogs with a height of approximately 22.5 cm. Each toy rested on a 32.5-cm diameter turntable located inside a 45- × 45- × 45-cm black box that was mounted on the far side of a black plywood wall approximately 77.5 cm from the floor and 1.35 m away from the chair on which the parent and infant sat. A 45- × 45-cm Plexiglas window on the front of the box permitted viewing of the toy. When activated, a light (mounted on the ceiling of the box) better illuminated the toy while the turntable on which the toy rested rotated. An observer located in an adjacent room watched the proceedings of the session on a video monitor and was responsible for remote control of the toys. Both toys were visible to the infant at all times, but activation was contingent on the behavior of both the experimenter and the infant as well as the particular phase of the session.

During the session, the experimenter participated in a face-to-face interaction with the infant while the infant was seated on the parent's lap. The distance between experimenter and infant was .60 m. All infants were tested in an alert state. Specific state changes were monitored by the experimenter during the course of the session. If infants became restless or fussy, the session was terminated. Parents were asked to close their eyes for the duration of the testing to prevent cuing the infant. Both prior to and following each trial, the experimenter used a combination of vocalization and touch (e.g., calling the infant's name or tickling the infant's tummy) to engage the infant in a social interaction and to reestablish eye contact at midline. Each session consisted of a maximum of 28 trials or changes in the experimenter's direction of gaze either to the right or to the left. The change in gaze direction was achieved by the experimenter's reorienting her head and eyes approximately 90 degs to fixate the toy located to the side. This reorientation of gaze was maintained for a duration of 7 s. During the trials, the experimenter did not vocalize or touch the infant, and she did not point toward the target. The experimenter used a signal light during the session (that was not visible to the infant but appeared on camera) to indicate the beginning and the end of each trial. This signal permitted the coder to score the videotapes, blind to the direction of the cue demonstrated by the experimenter.

Each session comprised three phases. During Phase I (baseline), there were four trials of a change in the experimenter's direction of gaze (two trials to each side), throughout which the targets remained inactive. This phase permitted assessment of spontaneous gaze following. During Phase II (shaping), there were also four trials (two to each side), but this time, regardless of the infant's behavior, the target to which the experimenter turned was activated approximately 2 s after the change in the experimenter's direction of gaze. This phase assisted in shaping the gaze-following response. Finally, during Phase III (test), there were a maximum of 20 trials (10 to each side) during which a toy was activated only if the infant made a head turn that matched the direction of the experimenter's gaze. This phase was subdivided into five, four-trial blocks; within each block, there were two trials to each side. Phase III allowed for further shaping of the joint attention response and a test of learning. Although a maximum of 20 test trials was possible, the exact length of the test phase varied as a function of individual performance. On the basis of pilot work, we determined that infants who mastered the demands of the task early in the session subsequently became bored and fussy (with a concomitant deterioration in performance) prior to completing the session. Consequently, we decided that for those infants who demonstrated reliable gaze following, we would terminate the session early. A criterion measure was used by the observer online in each session, such that the test phase was terminated at the end of the four-trial block in which the infant demonstrated reliable gaze following. To demonstrate reliable gaze following, the infant was required to make five consecutive alignments with the experimenter's direction of gaze (with an estimate of the probability of an infant engaging in five consecutive matches at $p < .05$). If no such response was demonstrated, the test phase continued to a maximum of 20 trials. To implement this criterion measure, during the test phase, the observer kept track of infant head turns that aligned with the experimenter's gaze. Once five consecutive alignments with the experimenter were demonstrated, the observer signaled the experimenter by activation of a signal light. Prior to terminating the session, the experimenter then proceeded to complete the remaining trials in the current block. During coding of the videotapes, the accuracy of the observer's judgment regarding the session termination criterion was checked. No errors were detected. Thirty-two infants were exposed to all 20 test trials, whereas 31 infants had an abbreviated session (18 had 8 trials, 8 had 12 trials, and 5 had 16 trials). A full face view of the experimenter and a full body view of the infant were recorded with separate video cameras, and the two images were combined on a split screen. The session lasted approximately 6–8 min.

Scoring. A coder, blind to the nature of the cues demonstrated by the experimenter and naive to the hypotheses of the study, scored the videotapes for the direction of the first infant head turn in the horizontal plane to occur during each trial. Each infant head turn was then designated either a target or a nontarget response, depending on whether the infant turned to look at the correct target or the incorrect target, respectively. In keeping with Butterworth and Cochran (1980), infant head turns in other than the horizontal plane were not scored (e.g., a look up or down would be ignored). The rationale for ignoring these head movements was that they did not seem to be purposeful responses to the cues generated by the experimenter but rather behavior in response to other elements in the setup (such as the lights, the carpeting, the mother), and we wished to be generous in providing infants with an opportunity to demonstrate an organized gaze-following response. A difference score was calculated by subtracting the frequency of nontarget responses from the frequency of target responses demonstrated in each four-trial block of the session. Trials on which "no relevant response" occurred were not included in the calculation of the difference score. If infants aligned more often than they misaligned with the model, we would expect a difference score in the positive direction. Conversely, a negative difference score would be obtained if infants misaligned more often than they aligned with the model. Finally, if infants were behaving in a "random" fashion, then we would expect a difference score on the order of zero. A sample of 30% of the videotapes (7 infants from each age group) was randomly selected for reliability coding by a second coder. Coefficient kappas calculated for each age group were as follows: 6–7 months (k = .95); 8–9 months (k = .95); 10–11 months (k = .97).

Results

To evaluate the influence of the conditioning procedure on the incidence of gaze following, the session was broken down into four-trial blocks; performance during three critical blocks (baseline, first four test trials, last four test trials) was compared. This subdivision of the session was necessary for the analysis because the length of the test phase varied as a function of individual performance. The mean numbers of test trials completed at each age were (out of a possible total of 20 test trials): 6–7-month-olds, 20 trials; 8–9-month-olds, 14.5 trials; 10–11-month-olds, 12 trials.

A two-way analysis of variance (ANOVA) was conducted with age (three levels: 6–7, 8–9, and 10–11 months) as a between-subjects variable and block (three levels: baseline, first test block, and last test block) as a within-subjects variable. The target minus nontarget difference score (described earlier) was used as the dependent measure in this analysis. Table 1 outlines the mean difference scores calculated for each age group during each of the baseline, first, and last test blocks.[1]

Results of the Age × Block ANOVA indicated a significant age effect, $F(2, 60) = 14.04$, $p < .001$, such that 8–9-month-olds and 10–11-month-olds both had higher difference scores than 6–7-month-olds; 8–9 months, $t(1, 60) = 3.27$, $p < .01$; and 10–11 months, $t(1, 60) = 7.36$, $p < .001$. In addition, 10–11-month-olds were also found to have higher difference scores than 8–9-month-olds, $t(1, 60) = 4.09$, $p < .001$. A significant block effect, $F(2, 120) = 9.51$, $p < .001$, was also found, in which infants demonstrated greater difference scores in the test blocks than in the baseline portion of the session; first test block, $t(1, 120) = 3.78$, $p < .001$; last test block, $t(1, 120) = 3.78$, $p < .001$. The Age × Block interaction was not significant.

Although this analysis illustrates performance differences among age groups and session blocks, of equal importance is whether the patterns of performance demonstrated are at all systematic rather than random. If infants did turn their heads in a systematic rather than a random fashion in relation to the cues demonstrated by the model, then we would expect the difference scores obtained to be significantly different from zero. To evaluate the extent to which infants in each age group were performing in a systematic way during each block of the session, a series of t tests was conducted in which the difference scores obtained were compared with zero. Results of these post hoc tests indicated that during baseline, only the 10–11-month-olds showed a difference score that was significantly greater than zero, $t(1, 19) = 4.25$, $p < .001$. In contrast, all three age groups obtained difference scores that were significantly greater than zero in the first test block: 6–7 months, $t(1, 19) = 2.30$, $p < .05$; 8–9 months, $t(1, 19) = 5.34$, $p < .001$; 10–11 months, $t(1, 19) = 6.08$, $p < .001$. Finally, during the last test block, only the two older age groups showed difference scores that were significantly greater than zero: 8–9 months, $t(1, 19) = 4.32$, $p < .001$; 10–11 months, $t(1, 19) = 6.21$, $p < .001$.

Table 1
Mean Difference Scores for Each Age Group During Each Block of Testing in Experiment 1

Age (mos)	Block					
	Baseline		First test		Last test	
	M	*SD*	*M*	*SD*	*M*	*SD*
6–7	0.095	0.889	0.667*	1.317	0.667	1.494
8–9	0.476	1.436	1.762***	1.513	1.619***	1.717
10–11	1.619***	1.746	2.571***	1.938	2.714***	2.004

* $p < .05$. *** $p < .001$.

Although the difference score analysis revealed both a significant age effect and a significant effect of the conditioning procedure, on the basis of our observations of performance, we realized that infants in the three age groups tested were demonstrating qualitatively different response patterns that were not captured by the quantitative difference score measure. Consequently, a second type of analysis, based on a categorization of individual infant performance according to one of three qualitatively different response types, was conducted. Although this new categorical measure allowed us to capture an additional dimension of infant performance, the foundation for the criteria adopted still rested firmly on the notion that infants must demonstrate more target than nontarget responses to be judged as reliably engaging in gaze following.

Our observations suggested three primary patterns of response: spontaneous gaze following, learning, and perseveration. In keeping with the basic logic of the operational definition adopted by Corkum and Moore (1995), infants who demonstrated a pattern of spontaneous gaze following engaged in more target than nontarget responses during the baseline phase; that is, there was a target minus nontarget difference score of two or greater in the four trial baseline phase. In addition to satisfying this baseline requirement, spontaneous gaze followers went on to reach a criterion of five consecutive target responses during the test phase (as stated earlier, an estimate of the probability of infants engaging in five consecutive matches is $p < .05$). In contrast, infants who demonstrated a pattern of learning did not meet the baseline criterion for spontaneous gaze following but did go on to meet the test phase criterion of five consecutive target responses. Finally, infants who demonstrated a pattern of perseveration failed to reach both the baseline and test phase criteria outlined earlier. However, perseverators did meet an alternative criterion during the test phase whereby they engaged in either a majority of head turns in one direction (70% or greater) or several sequences of turns in the same direction (three or more sequences of three or more consecutive turns in the same direction). Because these three response categories were not exclusive, decisions regarding categorization were made in a conservative fashion. That is, because it was possible for an infant to meet the criteria for both learning and perseveration, such infants were assigned to the perseveration category. In addition, it should be noted that the response categories were not exhaustive (i.e., 3 out of the 63 infants tested did not meet criteria for any of the patterns). However, all of the infants demonstrating an "other" response pattern fell into the youngest (6–7 month) age group.

A chi-square test, $\chi^2(4, N = 60) = 26.66$, $p < .001$, performed on the data indicated clear developmental differences in the response patterns. Figure 1 illustrates the number of infants

[1] Because two aspects of our analyses were unprecedented in the area (i.e., the use of a difference score measure and the analysis of only a portion of the total trials conducted), two alternative analyses were undertaken: (a) an ANOVA using the percentage of correct responses as the dependent measure in lieu of the difference score measure and (b) an ANOVA comparing the first four test trials and second four test trials in lieu of the first four and last four. The pattern of results obtained in these analyses was the same as that for the analyses presented in the text.

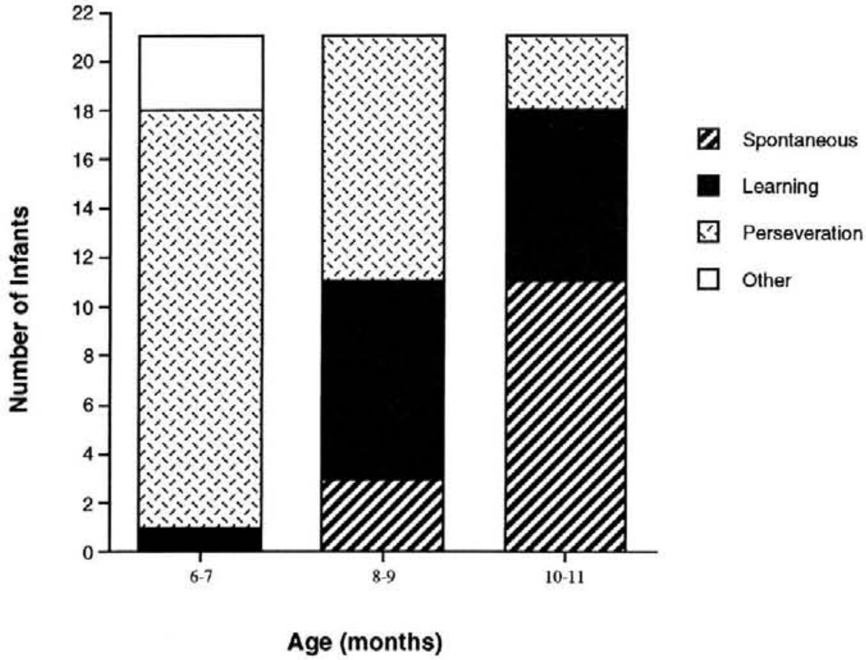

Figure 1. Number of infants demonstrating each response pattern as a function of age in Experiment 1.

in each age group exhibiting each response pattern. In the 6–7-month age group, the majority of infants (17 out of 21) engaged in a pattern of perseveration. Only 1 infant in the 6–7-month group showed a pattern of learning, whereas no infants demonstrated spontaneous gaze following. In contrast, in the 8–9-month age group, there were far fewer perseverators (10 out of 21) and far more learners (8 out of 21) than at 6–7 months. In addition, there were a few infants (3 out of 21) demonstrating spontaneous gaze following in the 8–9-month group. Finally, in the 10–11-month age group, there were even fewer perseverators (only 3 out of 21) than in the 8–9-month group, but roughly the same number of learners (7 out of 21). However, the pattern demonstrated by the greatest number of infants in the 10–11-month group (11 out of 21) was one of spontaneous gaze following.

Discussion

In line with recent findings (Corkum & Moore, 1995; Morissette et al., 1995), the pattern of results obtained in the baseline phase of this study clearly indicates that gaze following is first seen reliably toward the end of the first year of life. Only in the 10–11-month-old group were the infants more likely, even during baseline, to turn in the same direction as the adult than they were to turn in the opposite direction. However, infants at all ages studied did show some evidence of acquiring gaze following over the course of the experimental session. Even the youngest infants were more likely to follow gaze in the test trials than they were in the baseline phase, although only a very small proportion of them (less than 5%) followed the experimenter's gaze well enough across the test trials to have reliably acquired gaze following by the end of the session. Like the youngest group, the 8–9-month-olds did not show gaze following in baseline but did acquire gaze following at above chance levels during the first block of test trials. Unlike the youngest group, however, the 8–9-month-olds tended to maintain their above chance performance throughout the test trials.

The categorical analysis of individual performance was consistent with the analysis of difference scores but added further information on how infants in each age group performed in the session. The large majority of infants in the 6–7-month-old group tended to turn for the most part in one direction only. Thus, even though the analysis of difference scores showed some ability to acquire gaze following at 6–7 months, the effect cannot be considered to be particularly robust, in that their pattern of head turns does not fully reflect the reliable link between the model's head turns and the appearance of the moving toy to the same side. Although about half of the 8–9-month-olds showed a perseveration pattern, a considerable number (about 40%) were able to acquire gaze following reliably, given feedback. Of the 10–11-month-olds, a small majority showed spontaneous gaze following, and most of the rest were able to acquire gaze following reliably during the session. Although allowing for developmental variability, these results imply that it is not until about 8–9 months of age that infants are ready to acquire gaze following.

Clearly, it is important to allow for developmental variability in the age of emergence of specific skills. The timetable for the emergence of joint attention is no exception. Consequently, rather than focusing on absolute ages of emergence, perhaps the most important information to be gleaned from Experiment 1 is the notion of a definite developmental progression in the emergence of gaze-following behavior. Initially, infants seem to show a basic awareness of (a) the changes in behavior that accompany the reorientation of the model's attention and (b) the movement of the targets. However, at this stage, they seem unable to use the information provided by the model's behavior to produce differential responding (even with the assistance of feedback). Later in development, infants are able to respond differentially to the model's cues for change in gaze orientation. However, at this point, feedback seems necessary in scaffolding the integration of model and target information. Finally, infants are able to spontaneously generate differential responses to the model's cues for change in gaze orientation, without the need for specific feedback. These results suggest that the onset of gaze following, in line with general sensorimotor development, may be tied to infants' emerging ability to respond flexibly to two separate spatial locations on the basis of different cues.

Experiment 2

The results of Experiment 1 are clearly consistent with the view that infants' gaze following might be acquired through learning in that some infants who did not show gaze following at the start of the experimental session were showing it by the end of the session. It is possible that in the natural world, infants learn that adult head turns happen reliably to predict the appearance of interesting sights. If the acquisition of gaze following amounts simply to learning that interesting sights will reliably appear after certain adult actions, then it should be the case that the particular cues provided by the adult are essentially unimportant. If so, the only important factor would be the association between the adult cues (in our case, left and right head turns) and the appearance of an interesting sight in a distinct location. In other words, all that would be required is that one head turn predicts the appearance of the moving target in the other location reliably, and the other head turn predicts the appearance of the moving target in the other location reliably. Although the results of the first experiment are certainly consistent with this sort of explanation, this first study alone cannot establish the extent to which gaze following is purely a learned phenomenon of this kind. It is equally possible that the characteristics of the cues for gaze reorientation are not unimportant. In fact, the actual physical form of the cues may be critical for the response associations that are possible. In this way, nature may have placed some constraints on the contingencies that may be learned.

One way to test this question of the importance of the cue characteristics is to examine the relative ease of training an infant to turn his or her head in response to a cue that is a natural signal for the direction of another's gaze versus another cue that is not such a natural signal. If it is the case that the characteristics of the cues for gaze following are unimportant for the acquisition of the head turn response, then one would predict that it would be just as easy for infants to learn to make a head turn response when the stimulus is an unnatural cue as when it is a natural one. Conversely, if the actual form of the adult's behavior is not unimportant, then it may be more difficult to train a head turn response to an unnatural cue than to a natural one.

One practical problem in conducting Experiment 2 was the identification of an unnatural cue that would be similar enough (perceptually) to the natural one so that any differences in ease of training that might be obtained would not be due to a difference in the ease of detectability or perceptibility of the cues. Because we planned on using the same cue as in Experiment 1 (i.e., a 90-deg head-and-eyes turn toward a moving target) for the natural cue, then the logical choice for the unnatural cue was a head-and-eyes turn in the direction opposite to the moving target. The latter cue seemed appropriate because a head-and-eyes turn in the direction opposite to the moving target is equivalent in overall physical form to the natural cue, so it would be just as easy for infants to detect. However, this cue would differ from the natural cue in one critical aspect: The direction of movement relative to the targets would be reversed. In this way, any differences in ease of training that resulted would be attributable to a difference in the ease of learning the predictive relationship between the cues and the targets rather than to a difference in the ease of detection of the cues.

On the basis of the selection of these cues, two conditions were created. Infants assigned to the natural group were presented with a condition in which head turn cues predicted the appearance of moving targets on the side to which the model's head turn was made (just like the infants in Experiment 1). Infants assigned to the unnatural group were presented with a condition in which head turn cues predicted the appearance of moving targets on the opposite side to which the model's head turn was made. If, on the one hand, we found no significant differences between the natural and unnatural groups in terms of the ease with which they learned to turn toward the moving targets, then we could conclude that the form of the adult's behavior is unimportant and that the relation between the head turn cue and the infants' own head turns is an essentially arbitrary one and likely the product of learning. If, on the other hand, infants in the natural group acquire their target response more easily than those in the unnatural group, then we could conclude that infants' acquisition of gaze following is facilitated by physical characteristics, in this case movement direction, of the model's gaze behavior.

Method

Participants. The participants were 59 infants who were between 8 and 9 months of age. All of the infants were full term (over 37 weeks gestation), had normal birth weights (over 3200 gm), and had experienced no birth complications or major health problems. Twenty-seven infants were excluded from participation in this study because they demonstrated spontaneous gaze following in the first part of the session (see *Procedure* section for description of criteria used for designating spontaneous gaze following). Because of an error in the application of the baseline exclusion criterion, 1 infant who demonstrated spontaneous gaze following was tested but was subsequently excluded from the final sample. An additional 3 infants, 1 assigned to the natural condition and 2 assigned to the unnatural condition, did not complete testing because they became fussy or too active to remain seated on the parent's lap. The final sample consisted of 28 infants, 14 assigned to each condition: natural (*M* age = 9 months 4 days; range = 8 months 4 days to 9 months 26 days) and unnatural (*M* age = 9 months 6 days; range = 8 months 15 days to 9 months 28 days). Equal numbers of boys and girls were tested in each condition.

Procedure. The basic setup and procedure described for Experiment 1 were used for both groups of infants (natural and unnatural) in Experiment 2 as well. As in Experiment 1, the session contained a maximum of 28 trials of change in the experimenter's direction of gaze, with each session comprising three experimental phases (baseline, shaping, and test). The primary procedural modification made in Experiment 2 was exclusively related to experimental condition. Infants assigned to the natural group experienced an exact replication of the conditions presented in Experiment 1. Infants assigned to the unnatural group, however, were exposed to a condition in which the toy that was activated was on the side opposite to the model's head turn in both shaping and test phases.

The only other modification incorporated into the Experiment 2 procedure (which applied to both experimental conditions) was the addition of an online evaluation of infant performance during the baseline phase to exclude from the study infants who were spontaneously engaging in gaze following. Because, in this experiment, we were interested in the conditions for the acquisition of the gaze-following response, infants who had already acquired the response were not included. Therefore, an evaluation of infant performance during the baseline phase was conducted by the observer who watched the proceedings of the session on a video monitor from an adjacent room. During the baseline phase, the observer was responsible for noting the direction of the first infant head turn to occur during each trial and subsequently computing a target minus nontarget response difference score for the four-trial baseline phase. It was on the basis of this difference score that infants were then judged to be demonstrating or not demonstrating spontaneous gaze following. In keeping with the baseline criterion for a designation of spontaneous gaze following used in Experiment 1, infants who demonstrated a difference score of 2 or greater during baseline were judged to be demonstrating spontaneous gaze following and were excluded from the present study. After the completion of the baseline phase, but prior to entering the shaping phase, the observer indicated to the experimenter the nature of the infant's baseline performance through activation of a signal light. This permitted the experimenter (online) to continue the session as planned, if the infant met the inclusion criterion. Those infants not meeting the inclusion criterion were exposed to a different procedure not described here. Further, as in Experiment 1, the test phase was terminated at the end of the four-trial block in which the infant demonstrated five consecutive target responses. This judgment was made by the observer in the same manner described for Experiment 1. The accuracy of the observer's judgments concerning the baseline and test phase criteria were checked when the videotapes were scored. One error was detected in the application of the baseline criterion, and this infant was excluded from the final sample.

Scoring. Videotapes were coded in the same manner as in Experiment 1, with infant head turns first being scored for direction, then designated as target responses or nontarget responses, and, finally, a difference score calculated by subtracting the nontarget responses from the target responses that were demonstrated in each four-trial block of the session. In light of the differences between Experiments 1 and 2, some further explanation of the criteria used for designation of infant head turns as target or nontarget responses is in order. As in Experiment 1, a target response was scored during the test phase if the infant's first head turn was toward the activated target, whereas a nontarget response was scored if the infant's first head turn was away from the activated target. Such a scoring procedure meant that for infants in the natural group, target responses also followed the model's gaze, whereas for infants in the unnatural group, target responses were in the opposite direction to the model's head turn. In addition, for an analysis of performance during baseline to be carried out, infant head turns during this phase were also coded. In the baseline period, for both natural and unnatural groups, targets were present but not activated, so target and nontarget responses were determined by looking at alignments with the model's gaze. This meant that for both groups, during baseline, infant head turns that aligned with the model's were scored as target responses, and infant head turns in the opposite direction to the model's were scored as nontarget responses.

A sample of 30% of the videotapes (5 infants from each group) was randomly selected for reliability coding by a second coder. Coefficient kappas calculated for each group were as follows: natural ($k = .94$); unnatural ($k = .96$).

Results

To evaluate the influence of the training procedure on the incidence of producing a head turn response in each group, the session was broken down into four-trial blocks, and the performance of each group during three critical blocks (baseline, first four test trials, and last four test trials) was examined. As with Experiment 1, this subdivision of the session was necessary for the analysis because the length of the test phase varied as a function of individual performance. The mean number of test trials (out of a possible total of 20 test trials) completed as a function of group were the following: natural, 18; unnatural, 20. Because the criteria for target and nontarget responses differed during the baseline and test phases of the session (as outlined above), two separate analyses were conducted: one to examine performance differences between groups during the baseline phase and the other to examine the same issue during the test phase. Table 2 outlines the mean difference scores calculated for each group during each of the baseline, first, and last test blocks.

First, a one-way ANOVA was conducted on the difference scores for the two groups (natural and unnatural) during the baseline phase. Results of this analysis indicated no significant effects, $F(1, 26) = .85$, *ns*.

Second, a two-way ANOVA was conducted with group (two levels: natural and unnatural) as a between-subjects variable and block (two levels: first test block, and last test block) as a within-subjects variable. The difference score was also used as the dependent measure in this analysis. Results of this analysis indicated a significant group effect, $F(1, 26) = 19.88$, $p < .001$, such that infants in the natural group demonstrated greater difference scores than did infants in the unnatural group. Further, a significant block effect was found, such that infants demonstrated higher difference scores during the last compared with the first test block, $F(1, 26) = 4.22$, $p < .05$. The Group × Block interaction was not significant.

Third, as in Experiment 1, post hoc tests were conducted to

Table 2
Mean Difference Scores for Each Training Group During Each Block of Testing in Experiment 2

	Block					
	Baseline		First test		Last test	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*
Natural	0.071	0.475	0.714	1.541	1.714**	1.939
Unnatural	0.286	0.726	−1.643*	2.170	−0.929	1.685

Note. Criteria for target and nontarget responses differed in baseline and test blocks. See *Scoring* section for details.
* $p < .05$. ** $p < .01$.

compare, against 0, the difference scores obtained by each age group in each block of the session. Results of these post hoc tests indicated that neither group was performing in a systematic fashion during the baseline portion of the session. In contrast, during the first contingent block, the unnatural group demonstrated a difference score that was significantly greater than 0, $t(1, 13) = 2.83$, $p < .05$, whereas only the natural group demonstrated a difference score that was significantly greater than 0 during the last contingent block, $t(1, 13) = 3.30$, $p < .01$.

In keeping with the categorical analysis conducted for Experiment 1, performance of infants in the present study was also evaluated with respect to the response types identified in Experiment 1. The criteria used for examining the response patterns in Experiment 2 were parallel to those outlined in Experiment 1; however, because infants demonstrating spontaneous gaze following were necessarily excluded from participation in Experiment 2, only the incidence of the learning, perseveration, and other response patterns in each of the experimental conditions was compared. For the purposes of Experiment 2, the criteria for perseveration were the same as those used in Experiment 1 (i.e., during the test phase, either 70% or more head turns to one side or three or more sequences of three or more turns to the same side). Likewise, as in Experiment 1, infants who demonstrated a pattern of learning (i.e., acquisition of their target response) in Experiment 2 demonstrated five or more consecutive head turns that resulted in activation of the target during the test phase of the session. Finally, as was the case in Experiment 1, these response patterns were not exhaustive in that a number of infants did not meet criteria for any of them.

A chi-square test, X^2 (3, N = 28) = 10.24, $p < .01$, performed on the data indicated significant group differences in these three response patterns. The top panel of Figure 2 illustrates the number of infants in each conditioning group exhibiting each response pattern. Exactly half of the infants in the natural group (7 out of 14) demonstrated a pattern of learning to align with the experimenter's orientation of gaze. The other half of the infants in the natural group were split between demonstrating a pattern of perseveration (5 out of 14) and another response pattern (2 out of 14). In contrast, whereas only 1 of the infants in the unnatural group demonstrated a pattern of learning to misalign with the experimenter's orientation of gaze, 4 of them showed a pattern of perseveration, and the remainder showed an other response pattern (9 out of 14).

The above pattern of results is seen when we examine the numbers of infants who successfully located the contingently moving target. If, instead, we examine how frequently infants in both groups actually aligned with the experimenter's orientation of gaze, a different pattern of results emerges. Now, target responses in both groups are those for which the infant followed the model's head turn, whereas nontarget responses are those for which the infant turned in the direction opposite the model's turn. The bottom panel of Figure 2 illustrates the distribution of performance patterns in each group assuming such a common target response. The results for the natural group, of course, remain unchanged because turning to the contingently moving target is the same as aligning with the experimenter's direction of gaze. In contrast, those for the unnatural group are quite different. Although the same number of perseverators (5 out of 14) is evident in the unnatural group with this new criterion, there are far fewer infants who demonstrate other response patterns (only 2 out of 14 rather than 9 out of 14). Instead, 7 of the 14 unnatural group infants, who formerly demonstrated other response patterns, now reach the criterion set for learning to align with the experimenter's gaze (in that they engaged in five or more consecutive matches during the test phase). This is exactly the same number of infants who demonstrated a pattern of learning in the natural group.

Given this result, a one-way ANOVA was conducted, with group as a between-subjects variable (two levels: natural and unnatural) and number of trials to reach criterion for learning to align with the experimenter's gaze as the dependent measure. This analysis revealed no significant effects, $F(1, 26) = 0.87$, *ns*.

Discussion

The results from the natural condition in this experiment replicate those from the 8–9-month-old group of Experiment 1. Half of the infants exposed to a model's head turn, followed by the appearance of the moving target on the same side, learned to turn to find the target after seeing the head turn. Allowing, of course, for individual variability, both experiments suggest that given the appropriate experience, a large proportion of 8–9-month-olds are able to acquire gaze following.

Comparing performance in the two experimental conditions showed that the two groups demonstrated difference scores that were equivalent during the baseline phase, with neither group showing reliable gaze following prior to conditioning. However, during the test phase, the infants exposed to activation of the target on the same side as the model's head turn were able to locate the target significantly more easily than the infants exposed to activation of the target on the side opposite to the model's head turn. This result implies that the particular cues provided by the adult are not unimportant. Rather, infants' acquisition of gaze following is facilitated by physical characteristics—in this case, movement direction—of the model's gaze behavior.

Not only was the target response assigned to the unnatural group significantly more difficult for infants to acquire, they did not acquire it at all. However, these infants did acquire something during the session. When performance in relation to the model's head turns was examined, it was found that as many of the infants in the unnatural group as in the natural group followed the model's gaze by the end of the session. Therefore, despite completely opposite patterns of in-session experience, infants in the two groups were equally likely to acquire a gaze-following response during the experimental session. Furthermore, the analysis of trials to criterion for matching with the experimenter's orientation of gaze showed that the infants in the unnatural group acquired the gaze-following response as efficiently as those in the natural group. Together, these results show that the movement direction of the cues is a very important factor in the acquisition of gaze following.

Before moving on to a general discussion of the findings from these experiments, it is important to consider explanations that would render the pattern of results from Experiment 2 relatively trivial. One possible explanation is that our participants could follow gaze correctly all along; they just did not show it during

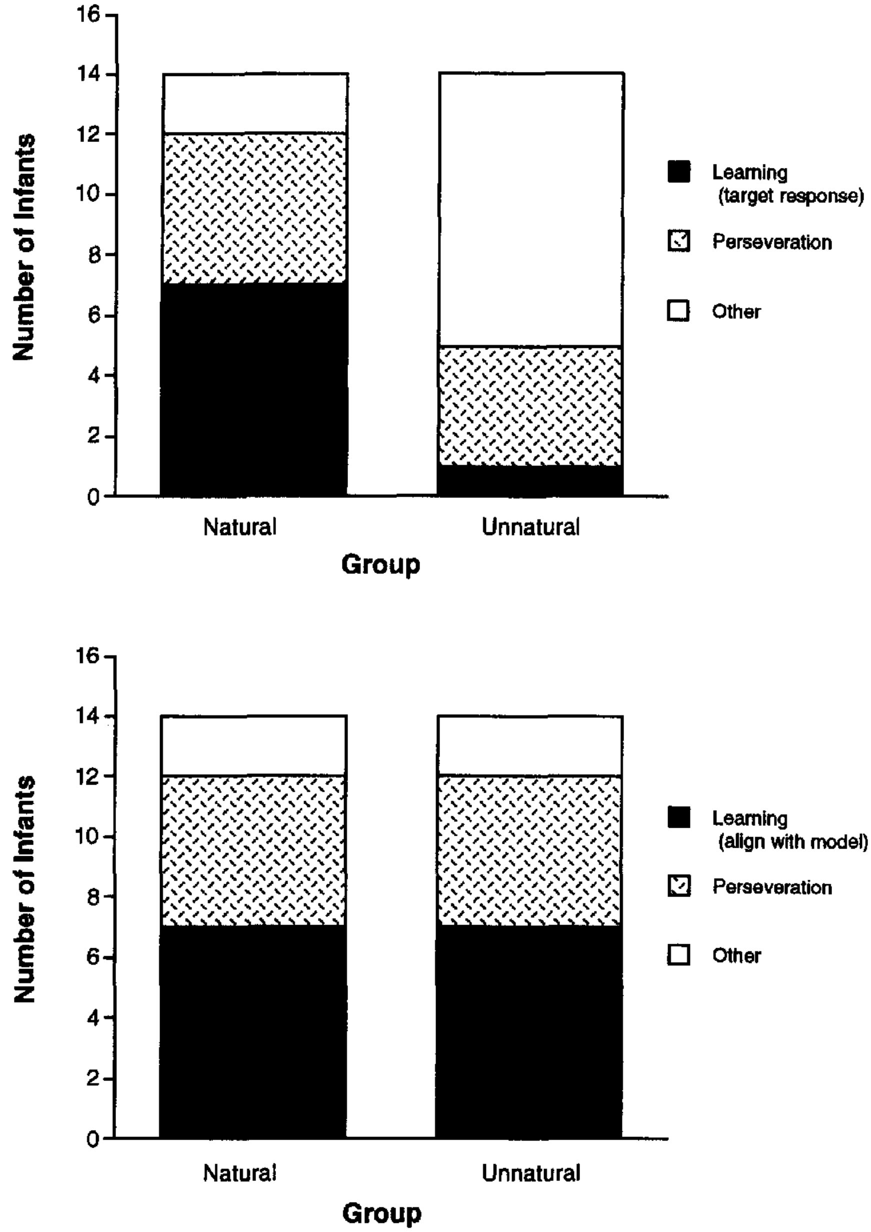

Figure 2. Number of infants demonstrating each response pattern as a function of group in Experiment 2. Top illustrates distribution of performance patterns in light of the target response designated for each group. Bottom illustrates distribution of performance patterns assuming a common target response (align with model) for both groups.

the baseline phase. This criticism amounts to saying that our exclusion criterion was too weak. Perhaps these infants just needed time to "warm up" to the laboratory environment and the strange experimenter to demonstrate gaze following. Or, perhaps after seeing the interesting sights of the toys being activated, the infants were motivated to use skills that were dormant during baseline. In either case, it would then be no surprise that there was no difference between the groups in their gaze-following behavior during the test phase. An empirical test that would help to rule out this simplistic interpretation would involve presenting infants of the same age with a longer baseline phase to determine whether a simple warm-up period leads to an increase in the proportion of 8–9-month-old infants who demonstrate gaze following by session end. In any case, although it is impossible to rule out these kinds of explanations, on the basis of the present data alone, three facts make us doubt their plausibility. First, in both groups, there were a number of infants who showed a perseveration pattern. These infants too showed no sign of gaze following in baseline and were motivated to find the target after seeing the toys being activated in the shaping phase. Yet they did not acquire gaze following during the session; instead, they tended to look to only one side. Therefore, for these infants, it cannot simply be the case that a warm-up period or activation of the targets stimulated an interest in gaze following that was absent while the targets were inactive during baseline. Second, the results from Experiment 1 showed that whether infants showed gaze following during baseline was dependent on age. Older infants (10–11 months) were more likely than younger infants (6–9 months) to show the spontaneous gaze-following pattern, implying that the baseline phase was suitable for eliciting gaze following but that this ability tends to develop after about 9 months. Third, a comparison of the proportion of infants who met the baseline criterion for spontaneous gaze following in Experiments 1 and 2 suggests that the screening procedure adopted in Experiment 2 was more likely to be stringent than lenient. Only 14% of the infants (3 out of 21) tested at 8–9 months in Experiment 1 met the baseline criterion for spontaneous gaze following and went on to also fulfill the test phase criterion for this designation as well. By comparison, the proportion of 8–9-month-olds excluded from participation in Experiment 2 as a result of meeting the baseline criterion was much higher at 47% (27 out of 59).

General Discussion

The present work examined the origins, in infancy, of the gaze-following response necessary for joint visual attention. In Experiment 1, we examined gaze following in infants from 6- to 11-months-old, using a training procedure. In line with recent research (Corkum & Moore, 1995; Morissette et al., 1995), the findings of Experiment 1 indicate that gaze following is not naturally acquired until about 10 months of age, somewhat later than a number of earlier investigators have reported (Butterworth & Cochran, 1980; Butterworth & Grover, 1990; Butterworth & Jarrett, 1991; Scaife & Bruner, 1975). However, given the assistance of contingent feedback, infants are able to learn, within an experimental session, to produce a gaze-following response from about 8 months on. It appears, then, that the acquisition of the gaze-following response, in infants who are not already capable of joint visual attention, seems to depend on two factors. First, infants must be at an appropriate developmental or maturational level at which they are able to respond flexibly to two spatial locations, given two cues. Allowing for individual variability, our group results suggest that infants reach this stage at approximately 8–9 months. Second, infants must be made aware that the appearance of interesting sights is predictable from adult behavior. Infants are stimulated to use the gaze reorientation cue only after they have seen that an interesting event (i.e., target movement) is available, following the adult head turn.

In light of the findings of Experiment 1 that illustrated that learning could be involved in the acquisition of gaze following, we wondered if the acquisition of gaze following might depend purely on observed contingencies or if the characteristics of the cues might play an important role. The pattern of findings produced in Experiment 2 discount the learning of a purely contingent association as the mechanism through which gaze following is acquired. Two facets of the results are of particular importance. First, although we were successful in training a significant proportion of infants in Experiment 2 to align with the direction of a head turn demonstrated by an experimenter, we were quite unsuccessful in training infants to misalign with this same cue. Second, despite the presence of reinforcement for misaligning with the direction of the experimenter's gaze (as well as the absence of reinforcement for aligning with it), the infants in the unnatural group were just as likely as those in the natural group to align with the experimenter's head turn by the end of the session. Together, these two findings indicate that the characteristics of the cues that are associated with a gaze-following response are critical. They imply that there is some information contained in the head reorientation cue that conveys powerful information about target location.

The mechanism by which the infants are able to acquire gaze following is still left open, however. One possibility is that the infants are learning the associations between the adult's cue and the head turn response but that the possible associations that can be learned are constrained such that only a head turn in the same direction as the adult's is "allowed." An alternative possibility is that once the infant has discovered during the shaping phase that there are interesting sights to be seen, she or he attempts to predict where the interesting sight will appear next. In the latter case, the gaze-following scenario becomes a kind of attentional cuing paradigm in that a central stimulus can be used to predict the appearance of a target to one or the other side. If the central stimulus has directional properties, then it will serve to cue attention in the specified direction. Under this description, one could think of the natural and unnatural conditions in Experiment 2 as providing "valid" and "invalid" cues, respectively.

As a first attempt to discriminate between these two type of mechanisms, we tested another group of 15 infants who were 8 to 9 months old in our procedure. None of these infants demonstrated spontaneous gaze following during the baseline portion of the session. For these infants, during the shaping phase, the targets were activated twice on each side, but no adult head turns were provided. In this way, the infant discovered that there were interesting sights to be seen to each side but that these sights were not presented in conjunction with the adult head turn. In the test phase, the adult produced head turns and, as in the previous experiments, the targets were activated only if the infant made the appropriate response, in this case, a head turn in the same direction as the adult. Scoring of the infants' performance in the same way as in the previous experiments resulted in 9 of the 15 reaching criterion for "learning." Thus, even without observing the relation between the adult's head turn and the target during the shaping phase, the infants still started to use the direction of the adult's turn to predict the location of the target. These results speak against the learning of a simple association between the adult cue and the infant's head turn but are consistent with the idea that the adult's head turn cues the infant's attention in the direction of the turn.

The question that is raised by these results is, What is the nature of the information that cues the infant's attention? There are a number of plausible alternatives. First, it is possible that the static physical form of the cue indicates general target location in much the same way that an arrow might for an adult. Second, it is possible that the salient feature of the cue is the dynamic component. Thus, infants may be drawn to follow the direction of the model's head turn, but the fact that this cue involves a head and eyes may be quite unimportant. Third, it is possible that a combination of static form and dynamic components is required. Thus, perhaps moving body parts (such as head and eyes) are particularly effective in eliciting the response. An empirical test of this analysis would involve using a training paradigm and exposing infants separately to the various component features outlined previously. Such a study would allow the effects of the various features of the head-and-eyes-turn cue to be effectively isolated and the important information to be identified. In any case, what we have demonstrated here is that at about 8–9 months, infants are able to take advantage of available social cues to gather information about the location of events in the world. These social cues have natural properties that allow infants more easily to pick up such information.

Our results also speak to the issue of the nature of an infant's developing social cognition. Joint visual attention has been taken as an important component of early social understanding in that some have assumed it demonstrates that infants have an awareness of others' attention to objects and of the prospects for sharing such attention (e.g., Bretherton, 1991). There can be little doubt that such awareness is in place at some point during the second year of life when, for example, infants start to use conventional symbols (e.g., Tomasello, 1995). For now, however, there is good reason to doubt that such awareness is necessary for the earliest manifestations of joint attention (see Moore & Corkum, 1994). The present results support the idea that infants can and probably do follow gaze and thereby share attention without an understanding of attention in others or self. If so, then these results are also consistent with the position that rather than requiring an understanding of attention in others, engaging in joint visual attention with others through gaze following may instead actually provide the kinds of experiences necessary for infants to acquire such an understanding (Moore & Corkum, 1994).

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