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Infant gaze following based on eye direction

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This experiment investigates the role of eye direction in infant joint visual attention. Sixty-three infants aged from 8 to 19 months participated in a training study in which they were shown adult eye turns in association with the appearance of an interesting sight to one or the other side. It was only at 18–19 months of age that infants showed a reliable ability to use the adult eye turns to predict the side of appearance of the target. this finding suggests that before 18 months of age, infants do not recognize the significance of eye direction for joint visual attention.

Joint visual attention, or gaze-following, occurs when one person looks in the same direction as another's head and/or eye orientation (Butterworth & Cochran, 1980; Corkum & Moore, 1995; Lempers, 1979; Morissette, Ricard & Gouin-Decarie, 1995; Scaife & Bruner, 1975). Infants show some ability to follow gaze to targets that are already within their visual field from the first 6 months of life (Butterworth & Cochran, 1980; Butterworth & Jarrett, 1991; D'Entremont, Hains & Muir, 1997). However, gaze following to targets that are outside the immediate visual field does not normally occur until towards the end of the first year (Corkum & Moore, 1995, 1998; see review by Moore, in press). Joint visual attention has been interpreted as one of the earliest and most significant signs of infants' developing social understanding because it appears to indicate that infants understand that others have a perspective on the world that is separate from their own (e.g. Bretherton, 1991; Scaife & Bruner, 1975).

As adults we know that it is eye orientation, rather than head orientation or posture, that determines direction of gaze because gaze is a manifestation of visual attention to an object. While it may be natural to assume that joint attention occurs through the infant detecting the orientation of others' eyes (see, e.g. Baron-Cohen, 1994), in fact, most studies examining joint attention have used both head and eye orientation as the cue for adult gaze direction and thus provide no basis for concluding that infants use eye orientation along (Butterworth & Cochran, 1980; Butterworth & Jarrett, 1991; Corkum & Moore, 1998; Morissette *et al.* 1995; Scaife & Bruner, 1975).

A small number of studies have examined infants' ability to follow eye direction. Lempers (1979) found that no 9-month-old infants but approximately 50 per cent of 12–14 month-old infants tested turned to look at a toy in the same direction as an adult's eye movement. However, because Lempers (1979) did not report how many infants turned in the opposite direction to the adult's movement, it is not possible to say whether

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the level of performance he found differed significantly from chance. Butterworth & Jarrett (1991, Exp 2) reported that 18-month-old infants would follow an adult's eye turns in order to search for a target out of view, but younger infants were not tested in this study so no information was provided on the developmental origins of following eye orientation.

Corkum & Moore (1995) studied infants from 6–7 months to 18–19 months of age, and in order to control for random infant head turning, used as the dependent variable a difference score of infant head turns in the same direction as the adult minus infant head turns in the direction opposite the adult. They examined infant head turns to four different cues, including a congruent head and eye turn, a head turn with the eyes remaining forward facing, an eye turn with the head remaining forward facing, and simultaneous head and eye turns in opposite directions. They reported that 12-month-old infants in face-to-face interaction with an adult would turn to follow the head reorientation to the side even when eye contact was still being maintained with the infant. In contrast, these infants would not reliably redirect their own gaze in the same direction when the adult shifted her eyes to look to the side but kept her head oriented to the infant.

One aspect of the design of the Corkum & Moore (1995) study makes the results somewhat difficult to interpret. Infants were exposed to eye alone trials along with trials involving head turns. This within-subjects design may have served to de-emphasize the value of eye direction as a cue within this experimental setting because head turns are considerably more salient. In other words, the infants may have been looking for head turns rather than for any available cue. Partial support for this idea comes from the fact that even at the oldest age studied, 18–19 months, the infants did not turn significantly in the same direction as the eye turns in contrast to the findings of Butterworth & Jarrett (1991). These oldest infants in the study showed their sensitivity to eye direction by not following head turns unless the head and eyes were congruent.

In the present study we examined infants aged from 8 to 19 months in order to investigate gaze following of adult eye orientation. To guard against masking of the eye orientation shifts, we used a design in which infants only saw eye turns. A second important feature of the design of the present work was the provision of a context in which infants would be truly motivated to use the available cues to generate a response. Examination of infant sensitivity to changes in eye direction alone clearly presents the infants with an artificial situation because such changes alone are rarely used when one of two interactive partners sees something of interest, unless perhaps there is a need not to give away information to some third onlooker. Thus, infants may not be tuned in to the signal value of eye movements in normal face-to-face interaction. One way to circumvent this problem is to set up a context in which the infant truly has a reason to pay attention to, and use, whatever cues the adult may provide. With this end in mind, in the present study we adopted the gaze-following training procedure employed by Corkum and Moore (1998). In this procedure, an interesting event can be made to occur on one or other side of the infant. This event is presented as a kind of operant reinforcement such that only if the infant turns in the same direction as the adult gaze shift cue, will they get to see the attractive event. If the infant can use eye direction information, then they should show it in circumstances where this is the only information that will help them find the interesting sight.

Method

Participants

The participants were 70 infants who were between 8 and 19 months of age. All the infants were full-term (> 37 weeks gestation), of normal birthweight (> 3200g), and had experienced no birth complications or major health problems. Testing was not completed with seven infants who became fussy or too active to remain seated on the parent's lap. The final sample of 63 infants was subdivided into five groups: 8–9-, 10–11-, 12–13-, 15–16-, and 18–19-month-old infants. Fourteen infants were tested at 8–9 months, 13 infants at 15–16 months, and 12 infants in each of the remaining three groups. The mean age and age range for each of the groups were as follows: 8–9 months (mean, 9 months 8 days; range, 8 months 14 days–9 months 26 days), 10–11 months (mean, 10 months 25 days; range, 10 months 1 day–11 months 21 days), 12–13 months (mean, 13 months 6 days; range, 12 months 4 days–13 months 29 days), 15–16 months (mean, 15 months 27 days; range, 14 months 20 days–16 months 29 days), and 18–19 months (mean, 18 months 24 days; range, 17 months 25 days–19 months 27 days).

Set-up and procedure

The experimental sessions were conducted in a 3.19m × 1.75m cubicle enclosed with curtains to minimize distractions. A target was located on either side of the cubicle. The targets were identical black and white stuffed dogs with a height of approximately 22.5cm. Each toy rested on a 32.5cm-diameter turntable located inside a 45cm × 45cm × 45cm black box that was mounted on the far side of a black plywood wall approximately 77.5cm from the floor and 1.35m away from the chair on which the parent and infant sat. A 45cm × 45cm plexiglass 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. From where the infant was seated the visual angle of the toys was about 80° from the midline and thus outside of the infant's peripheral vision when facing forward. 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 present at all times but activation was contingent upon the behavior of both the experimenter and 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 0.60m. 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 in order to prevent cueing the infant. Both prior to and following each trial, the experimenter used a combination of vocalization and/or touch in order to engage the infant in a social interaction and 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 left. The change in gaze direction was achieved by the experimenter reorienting her eyes as far as possible to the side while her head remained frontward. As in earlier work (e.g. Corkum & Moore, 1998; Scaife & Bruner, 1975) this reorientation of gaze was maintained for a duration of seven seconds. During the trials the experimenter did not vocalize or touch the infant, nor did she point toward the target. The experimenter employed a signal light during the session (which was not visible to the infant but appeared on camera) to indicate the beginning and 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 consisted of three phases. During the 'baseline' phase 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 following of eye direction. During the 'shaping' phase 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 two seconds after the change in the experimenter's direction of gaze. This phase was designed to inform infants that there were interesting sights to be seen on either side of the experimental cubicle. Through activation of the targets on the same side as the experimenter's gaze but after a slight delay, this phase assisted in shaping the infants' gaze-following response. All of the infants tested did turn to see the activated target on each side of the cubicle. In the case that infants did not see the target additional trials would have been presented. This was not necessary. Finally, during the 'test' phase there was a maximum of 20 trials (10 to each side) during which a toy was activated only if the infant made a head turn which matched the direction of the experimenter's eyes. This phase was subdivided into five, four-trial blocks within each of which there were two trials to each side. This third phase allowed for further shaping of gaze-following 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. Based on previous work (Corkum & Moore, 1998), it was 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, it was decided that for those infants who demonstrated a reliable joint visual attention response, the session would be terminated early. A criterion measure was employed by the observer on-line in each session such that the test phase was terminated at the end of the four-trial block in which infants demonstrated a reliable joint visual attention response. In order to demonstrate a reliable joint visual attention response 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. In order to implement this criterion measure, during the test phase the observer kept track of infant head turns which aligned with the experimenter's gaze. Once five consecutive alignments with the experimenter were demonstrated, the observer signalled the experimenter by activation of a signal light. The experimenter then proceeded to complete the remaining trials in the current block prior to terminating the session. In total, 18 subjects reached criterion during the test phase; 13 before the full 20 test trials had been delivered. Of these 13, eight were in the oldest group, three were in the 10–11 month-old group, one was in the 12–13 month-old group, and one was in the 15–16 month-old group. In coding the videotapes the accuracy of the observer's judgment regarding the session termination criterion was checked. No errors were detected. 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 six–eight minutes.

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. This judgment did not involve measuring degrees of deviation from midline but rather relied on the subjective judgment of the coder that a detectable head turn to the side had occurred. Each infant head turn was then designated either a match or a mismatch, respectively, depending upon whether the turn was aligned with (match) or in the direction opposite (mismatch) the orientation of the experimenter's gaze. Infant eye turns were looked for but were very infrequent. A difference score was then calculated by subtracting the frequency of mismatches from the frequency of matches demonstrated in each four-trial block of the session. A sample of 30 per cent of the videotapes (five from each age group) were selected randomly for reliability coding by a second rater. Coefficient kappas calculated for each age group were as follows: 8–9 months, $\kappa = .97$; 10–11 months, $\kappa = .95$; 12–13 months, $\kappa = .95$; 15–16 months, $\kappa = .97$; 18–19 months, $\kappa = .96$.

Results

Two mixed two-way ANOVAs with age as the between-subjects variable and block (baseline, first test block, last test block)[1] as the within-subjects variable were conducted. The first and last test blocks were compared because subjects did not all receive the same number of test trials. The first ANOVA was carried out with the match–mismatch difference score as the dependent variable.[2] This analysis showed a significant main effect for age, $F(4,58) = 3.30, p < .05$, but no other effects. The mean differences scores are

1 ANOVA comparing the first four and second four test trials in lieu of the first four and last four yielded the same pattern of results.

2 ANOVA employing per cent correct responses as the dependent measure in lieu of the difference score measure yielded the same pattern of results.

shown in Table 1. Post-hoc comparisons (Student Newman–Keuls, $p < .05$) revealed that the oldest age group had significantly higher difference scores than all of the other age groups, none of which differed from each other.

Table 1. Mean difference scores and total head turn scores (SD) for each age group as a function of session block in Expt 2.

		Four-trial block		
Age group	*N*	Baseline	First test	Last test
Difference score				
8–9 months	14	0.00 (1.75)	0.00 (1.47)	0.57 (1.60)
10–11 months	12	0.33 (1.23)	–0.17 (1.80)	0.75 (2.49)
12–13 months	12	0.67 (1.23)	1.00 (1.76)	0.00 (2.13)
15–16 months	13	0.46 (1.05)	–0.08 (1.80)	0.77 (1.54)
18–19 months	12	1.83 (1.34)	1.58 (2.28)	1.92 (2.50)
Total head turn score				
8–9 months	14	2.14 (1.66)	3.57 (0.65)	3.43 (0.85)
10–11 months	12	2.33 (1.23)	3.83 (0.58)	3.58 (0.67)
12–13 months	12	2.17 (1.40)	3.50 (1.00)	3.67 (0.65)
15–16 months	13	1.69 (1.38)	3.31 (1.03)	2.92 (1.32)
18–19 months	12	2.00 (1.04)	3.75 (0.45)	3.75 (0.62)

The second ANOVA was carried out with total head turns (matches + mismatches) as the dependent variable. The mean total head turns are shown in Table 1. This analysis resulted in only a main effect for block, $F(2, 116) = 55.69, p < .001$. Neither the main effect for Age nor the interaction were significant. Comparisons of least square means ($p < .05$) on the block effect showed that infants at all ages produced significantly more head turns in both directions in the test blocks than in the baseline block. The amount of head turning in the two test blocks did not differ.

In order to examine levels of performance against chance, one sample t tests were also conducted on difference scores for the baseline, first test, and last test blocks at each age group. All three t tests for the oldest group were significant ($p < .05$). No difference scores were significant at any other age ($p < .05$).

The numbers of subjects at each age reaching criterion of five consecutive correct matches during the test phase were also compared. These data are shown in Table 2. A small minority of infants in the four younger age groups did reach criterion, but it was only in the 18–19-month-old group that a majority of subjects were able consistently to turn to the correct side ($\chi^2(4) = 22.78, p < .001$).

Discussion

These results indicate that it is only at about 18 months of age that infants recognize the significance of eye direction for gaze following. The 18–19-month-old infants followed

Table 2. Number of subjects who did and did not reach a criterion of five correct head turns during the test phase of Expt 2.

		Reached criterion?	
Age group	*N*	Yes	No
8–9 months	14	1	13
10–11 months	12	3	9
12–13 months	12	2	10
15–16 months	13	2	11
18–19 months	12	10	2

the experimenter's eye movements in all phases of the session, including baseline. These infants, therefore, understood the value of eye direction when they entered the laboratory. Younger infants did not follow eye direction during baseline, nor did they acquire an appreciation of its significance during the session.

The finding that total head turning increased from baseline to test phase implies that once these infants had discovered that the target could be activated, they were motivated to try to find it. The total amount of head turning did not vary with age indicating that at all ages, infants found the target activation equally interesting. Despite this widespread interest in the target, it was only at the oldest age group that the participants were able to use the information provided by the adult to determine where the target would be activated.

The present result is consistent with earlier research by Butterworth and Jarrett (1991) who also found gaze following on the basis of eye direction at 18 months of age, although they did not test younger infants. In the present study, younger infants did not follow eye direction, even though in the context of the study they were motivated to find the interesting event and eye direction was the only cue that could be used as a reliable predictor of its location. This finding contrasts sharply with earlier work using head turns in this paradigm. Corkum and Moore (1998) found that significant numbers of 8- to 11-month-old infants could use head orientation reliably in order to locate the rewarding event. It appears then, that some months of development are required after first acquiring gaze following on the basis of head turns before infants start to follow eye direction alone.

Before considering this discrepancy further, it is important to consider whether infants are able to detect changes in another's eye gaze before 18 months of age. Research on infant perception confirms that from at least 6 months of age infants are able to detect the subtle changes in eye orientation presented in this experiment (Mayer & Dobson, 1982). Recently, Hains & Muir (1996) have shown that 4- to 5-month-old infants' smiling during face-to-face interaction is disrupted by adult aversion of eye gaze, even while all other aspects of the interaction are maintained. Thus, infants considerably younger than those tested in the present study are sensitive to eye direction in dyadic interactions.

Since the present study was completed, there has also been research showing a sensitivity to eye direction in young infants through the control of visual orienting. This research is especially relevant to the present work because the gaze following scenario which we and others have used can plausibly be viewed as a more natural form of attentional cueing paradigm in which a central cue (the adult's head or eye orientation) is followed by a peripherally presented target (see Moore, in press). Hood, Willen, & Driver (1998) presented 10- to 28-week-old infants with digitized video images of a female head in which eye shifts to the left or right occurred. These shifts were followed by peripheral targets within the visual field on either side. They reported that infants at all ages showed faster visual orienting to the targets presented on the same side as the eye shifts than to the targets presented on the opposite side. These results are consistent with recent work in the adult literature (e.g. Friesen & Kingstone, in press), in which it has been shown that adults detect a peripherally presented target more rapidly when it appears on the same side as a directional eye gaze shift than when it appears on the opposite side. Interestingly, in adults, the effect has the parameters associated with exogenous (or reflexive) visual orienting in that it occurs most strongly with very short delays between cue and target (100 milliseconds) and disappears at longer delays (1000 milliseconds). As such, the effect probably does not depend upon a representation of the eyes as attending to something.

There are, of course, many differences between our empirical approach and the attentional cueing method. Of these differences, we suggest that three are of particular relevance. First, given their location on the side walls of the room, the targets in our experimental set-up do not appear in the peripheral visual field when the infant faces forward as targets do in attentional cueing tasks. Second, the task does not assess reaction time to targets that automatically appear, rather the infant has to make an anticipatory response. Third, given the location of the toys, the response required is a head movement rather than an eye movement. These three differences are important because they mean that relatively low level exogenous control of visual orienting is unlikely to be responsible for the effects in our study. Rather the effects may be considered to be the product of more endogenous control, or, in other words, to depend upon the meaning of the stimulus cue.

So why does gaze-following based on eye direction occur so much later than gaze-following based on head direction, even though infants are sensitive to the eye direction cue? In explanation of younger infants' performance, the following points may be made. First, as Corkum & Moore (1998) have argued, the earlier form of gaze-following is probably not mediated by an understanding of the other's attentional connection to an object. Rather, infants use the other's head turn as an effective predictor of where an interesting event will occur when that event is outside the immediate visual field. Second, the class of cues that is recognized by the younger infant to be valuable predictors in gaze following contexts of this kind does not include eye direction.

When infants start to use eye direction to follow gaze, there are two plausible explanations. It could be that the infants still do not understand the attentional connection between others and distant objects, but have merely expanded the class of good predictive cues to include eye direction. In this case, our 18-month-old infants would be behaving similarly to chimpanzees (see Povinelli & Eddy, 1996; Povinelli & Prince, in press) in that they would follow gaze based on eye direction without understanding the attentional significance of the eyes. Alternatively, it is possible that the transition to using eye direction indexes the beginnings of an understanding of visual attention, at least in the very simple sense that people can look at things. It is not possible to decide firmly between these two explanations on the basis of the present work.

However, we favour the latter explanation for two reasons. First, there was no significant evidence of learning the predictive value of eye direction in this experiment. The transition to using eye direction was relatively abrupt, indicating perhaps a more conceptual change. Second, the timing of this development, midway through the second year, is consistent with some other early indices of the understanding of others' attentional connections to objects, such as word learning based on shared visual reference (Baldwin, 1991, 1993).

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