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# Infants can infer the presence of hidden objects from referential gaze information

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Infants' apparent failure in gaze-following tasks is often interpreted as a sign of lack of understanding the referential nature of looking. In the present study, 8- and 12-month-old infants followed the gaze of a model to one of two locations hidden from their view by occluders. When the occluders were removed, an object was revealed either at the location where the model had looked or at the other side. Infants at both ages looked longer at the empty location when it had been indicated by the model's looking behaviour, and this effect held up even when their first look after gaze following was discounted. This result demonstrates that even young infants hold referential expectations when they follow others' gaze and infer the location of hidden objects accordingly.

One of the most noticeable signs of infants' developing understanding of the social world is their increasing tendency to follow the gaze direction of interactive partners. This behaviour emerges spontaneously in the second half of the first year (Butterworth & Jarrett, 1991; Carpenter, Nagell, & Tomasello, 1998) but can also be demonstrated in younger infants (D'Entremont, Hains, & Muir, 1997) and even in newborns in rudimentary forms (Farroni, Massaccesi, Pividori, Simion, & Johnson, 2004). Although gaze following is an inherently social behaviour, it is still controversial how much and what kind of social understanding it reflects.

It is frequently stated that young infants' gaze following is a kind of reflexive orientation that does not rely on any understanding of the relation between an agent and the object she is looking at. For example, Butterworth and Jarrett (1991) found that when infants younger than 12 months follow someone's gaze shift, they tend to end up looking at the first object that they find in the indicated direction rather than locating the object targeted by the model. On the basis of these and other results, Moore and Corkum (1994) concluded that infants process perceived gaze shifts exclusively in terms of the agent's action, and it is only their own reflexive gaze-following behaviour that connects that action to an object. Similarly, Woodward (2003) found that 7- and 9-month-old infants' attention did not recover when the target of an agent's gaze

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changed from one object to another, and concluded that their gaze-following response was not accompanied by an understanding of gaze as an action that relates a person to a certain object.

These observations are complemented by findings that suggest that young infants, who do follow others' gaze, do not fully understand the conditions of visual access. For example, Butler, Caron, and Brooks (2000; see also Caron, Kiel, Dayton, & Butler, 2002) demonstrated that 14-month-old infants tend to follow an actor's gaze to an object that she would not have been able to see because her view was blocked by an opaque barrier. Similarly, Brooks and Meltzoff (2002, 2005) observed that 12-month-olds would follow the head movement of a blindfolded model, and 9-month-olds would follow head turns even when the actor's eyes were closed.

One possible interpretation of these results is that young infants follow others' gaze shifts without conceiving those actions in referential terms, that is, without interpreting gaze as 'object-directed' (Butler *et al.*, 2000). This interpretation is based on the assumption that genuine, non-reflexive gaze following is, in fact, 'attention following' and so understanding the referential nature of looking behaviour implies an understanding of vision and/or attention. This reasoning entails that unless one can accurately identify the attentional/perceptual state of another person, one cannot interpret her behaviour as referring to something.

There is, however, another way in which a relation between a person and an object can be understood as referential, namely, if the looking behaviour of the actor is interpreted as a communicative act. If gaze shifts are conceived as acts of referential communication (i.e. the same way as we interpret pointing) the referential relation between the actor and a potential referent is *presumed*, regardless of the receiver's ability to evaluate the conditions of visual access between the actor and an object. This hypothesis is consistent with the findings that it is almost impossible to make infants repeatedly follow an actor's gaze to empty locations (Churcher & Scaife, 1982), and when infants fail to locate the real target of an agent's gaze, their eyes always land on an object rather than at an empty point in space (Butterworth & Jarrett, 1991; Flom, Deák, Phill, & Pick, 2004). This aspect of young infants' gaze-following performance has been explained by the fact that objects are more likely to capture infants' attention (are more 'salient') than empty locations, but it could also indicate their expectation to find a referent for the gaze they have followed.

The most direct test of referential expectation for looking behaviour was performed by Moll and Tomasello (2004). In that study, an experimenter attracted the 12- and 18-month-old infants' attention, and then conspicuously looked at a location that was hidden from them (behind a wall, inside a drawer, etc.). In response, the infants in both age groups tended to locomote to the indicated location to get a sight of it, presumably because they expected to find an interesting object there. However, one could still argue that infants approached the indicated location simply because the looking behaviour of the experimenter had drawn their attention to that hidden part of the space, and their action provided no evidence which they inferred that an object should be found there. One way to test that expectation would be to compare infants' behaviour when they do or do not find an object in the indicated location. Another disadvantage of the Moll and Tomasello (2004) paradigm is that it requires infants to be able to locomote, and this excludes the possibility of using the task with younger or motorically less developed infants.

To overcome these limitations, we have developed a task that contrasts situations where an object is or is not present at the location indicated by an actor's gaze, and

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measures infants' expectation by their looking behaviour rather than locomotion. Infants were presented with video clips in which a woman looked at one of two locations that were hidden from the infants' view by opaque barriers (Figure 1). Then a curtain came down in front of her and the two barriers moved away revealing a single toy behind one of them. This toy either appeared at the location where the woman had previously looked (consistent gaze) or at the other side (inconsistent gaze). We reasoned that if infants interpreted the looking behaviour of the woman as a referential act and inferred the presence of an object behind the barrier, they would be surprised to see a conflicting outcome, which might be manifested in a more persistent visual search at the location of the referred but missing object.

Several cues can be used to determine the target of someone's referential gaze. Infants tend to rely more on head orientation and head motion than on eye position and eye shift when they follow gaze (Caron, Butler, & Brooks, 2002; Corkum & Moore, 1995). Nevertheless, in the laboratory, young babies also follow gaze defined by eye movement only (e.g. Farroni *et al.*, 2004). In everyday interactions, further gaze cues are provided by body orientation and body motion. Since the present study addressed questions about the consequences, rather than the preconditions of gaze following, we did not intend to separate the effects of these cues. Rather, we tried to create stimuli that, like the normal communicative interactions with infants, incorporated all these cues of referential gaze.

## Method

### *Participants*

Infants were recruited by advertisements in local magazines. Sixteen 8-month-old (4 female and 12 male) and sixteen 12-month-old (6 female and 10 male) infants completed the study. Their mean age was 251.6 days (range 224–257 days, 8-month-olds) and 374.4 days (range 367–381 days, 12-month-olds). An additional 18 infants were

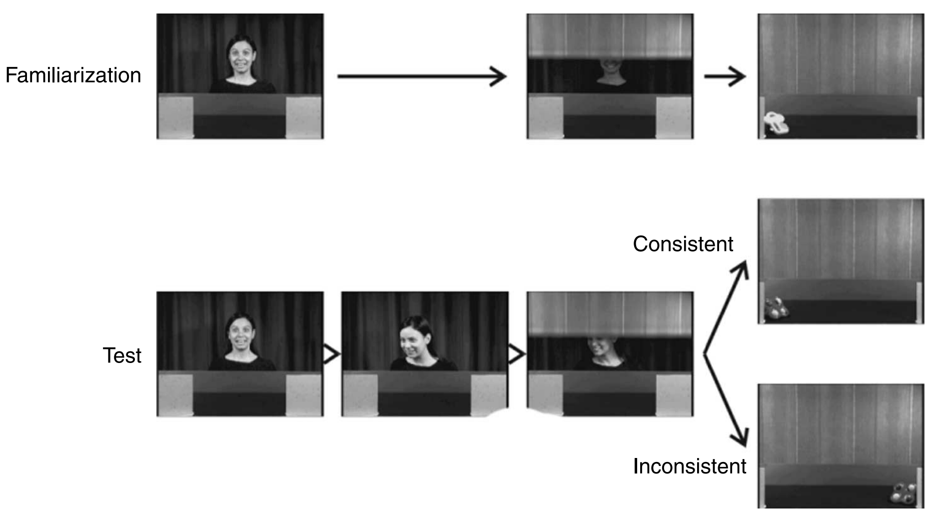


**Figure 1.** Selected frames from the video clips used in the study. The last frame remained on screen as long as the infant was looking at it.

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excluded from analysis because (a) they did not complete the study due to fussiness (three 12-month-olds); (b) their behaviour could not be coded from the video-recording due to extensive movements (one 12-month-old and two 8-month-olds); (c) parental interference (one 12-month-old and two 8-month-olds); (d) experimenter error (three 8-month-olds) and (e) failure to follow gaze in the test trials (six 8-month-olds). Since the main question of the study was not whether infants would follow gaze but to explore why they do so, the 8-month-old infants who did not follow the model's gaze at least two out of the four test trials were excluded from further analysis. No 12-month-olds were excluded according to the same criterion.

### *Apparatus*

Infants sat on their parent's lap in a dimmed room approximately 100 cm away from a plasma screen (100 cm diagonal size), on which the stimuli were presented. A remote control infrared video-camera was located above the screen. The camera and the stimuli were controlled by an experimenter from behind a panel, where she could monitor the infant behaviour on a video monitor. The whole session was videotaped for off-line Coding.

### *Stimuli*

The infants were presented with short, digitally edited video clips (see Figure 1). Each clip started with a woman (the model) appearing at the middle of the screen, looking directly at the viewer. In the foreground of the scene, two neutrally coloured panels occluded the bottom left and bottom right corners of the screen from view. In the familiarization clips, after a pause of 1 second, the model cheerfully exclaimed, 'Hi, baby!' (1.5 seconds), and then a bright orange curtain came down, occluding her (1.5 seconds). As soon as the curtain was down, the two occluders started to move outwards, revealing a toy behind one of them (1 second). The test clips started and ended the same way as the familiarization clips. However, after greeting the viewer ('Hi, baby!'), the model turned and leaned towards one side looking behind one of the occluders and said, 'Wow!' She then looked back at the viewer, still smiling, and looked behind the same occluder again. These acts lasted for about 5 seconds. After the second look behind the occluder, the curtain came down and the occluders moved away the same way as in the familiarization clips. In the test clips, the toy appeared either from behind the occluder where the model had looked (consistent gaze), or from behind the other occluder (inconsistent gaze). The clips were digitally edited so that they contained exactly the same actions whether or not the object was revealed consistently or inconsistently with the model's looking behaviour. The familiarization and test clips lasted for about 6 and 10 seconds, respectively. The model's face on the plasma screen was about life size ($6.8^\circ \times 8.5^\circ$ visual angle), the toys were of graspable size (about $4^\circ$ visual angle) and the toys' horizontal eccentricity from the midline of the screen was approximately $14^\circ$ visual angle.

### *Procedure*

Before presenting infants with four test trials, they were shown four familiarization trials. The purpose of the familiarization trials was to make sure that infants would understand the physical arrangement of the scene and that the occluders may hide an object. The video clip revealed a different toy object in each trial. The object appeared

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twice on the right and left side in the familiarization trials in ABBA order, side of the first trial counterbalanced across participants. During the four test trials, consistent and inconsistent gaze clips were alternating, with half of the subjects starting with consistent and the other with inconsistent gaze trials. The object sides during the test trials were also in ABBA order, independently from the familiarization sides. Before every trial, the infants' attention was drawn to the screen by small animations and computer sounds. When the infant looked at the screen, the clip was started. If the infant looked away during the presentation of the clip (which happened very rarely), the trial was repeated. The clip stopped at the last frame, showing the infant a single object on the screen. The trial terminated when the infant looked away from the screen for at least 2 seconds. The parents were asked to close their eyes during the test trials.

### *Data analysis*

Video-recordings of the infants' behaviour were coded frame-by-frame with half-frame (20 ms) accuracy. The gaze direction of the infants was coded starting from the frame when the occluders began to move outwards to the end of the trial into four categories: left side of the screen, right side of the screen, middle of the screen and off-screen. In every trial, this Coding yielded measures of total looking times to each side of the screen, a total looking time at the screen (the sum of the first three measures) and a number of gaze switches between the right and left side. In the test trials, we also recorded whether the infant followed the model's gaze, that is, looked at the same side as the model before the curtain came down. The recordings of a quarter of the participants (four 8-month-olds and four 12-month-olds) were also coded by a secondary coder, who was blind to the experimental hypothesis, to check reliability. Aggregated looking times (four measures per trial in each infant) were correlated between coders with $r = .983$.

## Results

### *Familiarization*

The average looking times in familiarization trials were 14.4 and 12.7 seconds in 8- and 12-month-olds, respectively, and they did not differ statistically either across trials or between age groups.

### *Gaze following*

In most of the test trials, the gaze shift of the model elicited a gaze-following response. Eleven of the sixteen 12-month-olds followed the gaze in every single trial, and the average number of trials with gaze following was 3.56 (out of 4) in this age group. The average number of gaze following in all twenty-two 8-month-olds (including the ones who were excluded because of too few gaze-following responses) was 2.77. The difference between 8- and 12-month-olds in the number of trials that elicited gaze following was marginally significant: $t(36) = 1.97, p < .06$. However, the 8-month-olds' performance was also well above the chance at $p < .001$, even if we consider the task as a two-alternative forced choice (2AFC) task (follow vs. not follow), which is a much more conservative assumption than what is generally applied in gaze-following studies. Out of the sixteen 8-month-olds included in the study, 11 infants followed the gaze in every trial and the average number of gaze following was the same as in 12-month-olds (3.56).

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### Gaze position when the occluders moved away

We recorded the participants' eye location at the point when looking time measurement started in the test trials, that is, when the occluders started to move away. In the majority of the trials (59.4 and 64.1% in 8- and 12-month-olds, respectively) infants at this point looked at the centre of the screen where the curtain had just come down. In about a quarter of the trials (23.4 and 26.6%, respectively), infants' gaze stayed at the occluder that the model had been looking at and in the remaining trials they switched to the other side before the occluders started to move away.

### Looking behaviour in the test trials

We analysed the total looking times, looking times to the object, looking times to the empty side, proportion of looking at the empty side and number of switches across sides in three-way ANOVAs with age group (8- vs. 12-month-olds) as a between-subject factor, trial (first vs. second pair) and gaze (consistent vs. inconsistent) as within-subject factors. The analysis on total looking times resulted only in a main effect of trial ($F(1, 30) = 7.21$, $p = .012$, $\eta_p^2 = .19$), showing that the average looking times decreased from 12.8 s to 10.0 s from the first to the second pair of test trials. Although the 8-month-olds tended to look longer in the test trials than did the 12-month-olds (see Table 1), the main effect of age group did not reach statistical significance ($F(1, 30) = 3.66$, $p = .065$, $\eta_p^2 = .11$). The analysis on the looking times at the object did not yield any significant effect. In contrast, the ANOVA on the looking times at the empty side of the screen revealed a significant main effect of the age group ($F(1, 30) = 8.87$, $p = .006$, $\eta_p^2 = .23$), indicating longer looking times in 8- than in 12-month-olds, a significant main effect of trials ($F(1, 30) = 5.97$, $p = .021$, $\eta_p^2 = .17$) and a significant main effect of gaze ($F(1, 30) = 12.55$, $p = .001$, $\eta_p^2 = .30$). This latter effect showed that infants looked longer at the empty side in the inconsistent gaze trials than in the consistent gaze trials (see Table 1). None of the interactions was significant in this analysis. Similar results were obtained from the analysis of the proportion by looking at the empty side. Eight-month-olds spent relatively more time looking at the empty side than 12-month-olds (age group effect: $F(1, 30) = 7.39$, $p = .011$, $\eta_p^2 = .20$), and infants spent a significantly higher proportion of their time by looking at the empty side in the

**Table 1.** Mean (and standard error of) measurements of looking behaviour as a function of age group and gaze condition

| | | Looking at the object side | | Looking at the empty side | | |
|---|---|---|---|---|---|---|
| Age group/condition | Total looking time at the screen (s) | Time (s) | Proportion (%) | Time (s) | Proportion (%) | Number of gaze switches across sides |
| 8-month-olds | | | | | | |
| Consistent gaze | 13.52 (2.43) | 7.20 (1.23) | 55.8 (3.0) | 2.91 (0.51) | 21.0 (1.6) | 4.81 (1.01) |
| Inconsistent gaze | 14.48 (2.53) | 7.89 (1.64) | 56.2 (3.6) | 3.89 (0.73) | 27.6 (2.9) | 5.94 (1.04) |
| 12-month-olds | | | | | | |
| Consistent gaze | 8.43 (1.06) | 6.24 (0.88) | 72.5 (3.0) | 1.11 (0.26) | 12.3 (2.1) | 3.28 (1.20) |
| Inconsistent gaze | 9.30 (1.39) | 6.58 (1.21) | 66.6 (3.8) | 1.69 (0.38) | 20.6 (3.3) | 4.16 (1.29) |

*Note*. Measurements are averaged across test trial pairs.

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inconsistent than in the consistent gaze trials (gaze main effect: $F(1, 30) = 11.80$, $p = .002$, $\eta_p^2 = .28$). This result was also confirmed in a non-parametric sign-test: 24 out of 32 infants looked at the empty site (averaged across the two pairs of trials) at a higher proportion in the inconsistent than in the consistent gaze trials, $p = .007$.

The ANOVA on the number of switches between the two sides yielded a main effect of trial ($F(1, 30) = 6.27$, $p = .018$, $\eta_p^2 = .17$), indicating that infants tended to switch more in the first (5.4) than in the second (3.7) pair of trials. This analysis also revealed a significant main effect of gaze ($F(1, 30) = 5.93$, $p = .021$, $\eta_p^2 = .17$), because infants performed more switches across the sides in the inconsistent (5.0) than in the consistent (4.0) gaze trials (see Table 1). No other effect was significant.

The above analyses suggest that infants in both age groups spent more time looking at the empty side and switched more times across sides, after the object was revealed at the opposite side to the model's gaze. However, it is possible that this result was a mere by-product of the fact that the infants followed the model's gaze and were more likely to look at the indicated occluder than the other one when the occluders moved away. In other words, the looking times and the number of switches were perhaps biased by the initial eye position of the infants at the time frame when looking time measurement started. To explore this possibility, we corrected the looking time measurements in all trials in which infants were looking at the occluder that had no object behind at the moment when the occluders started to move away. This correction simply involved starting the measurement at the later video frame when the infant looked away from the empty side, usually towards the object appearing at the other side of the screen. Note that this correction biases heavily against our hypothesis because it tends to discount the first looks after gaze following in the inconsistent gaze trials but not in the consistent gaze trials. Measurements from 28 of the 128 trials were corrected this way.

The analysis on the looking times at the empty side resulted in the same main effects with the corrected as with the uncorrected data. Eight-month-olds' looking times were longer than twelve-month-olds' looking times (age group main effect: $F(1, 30) = 8.15$, $p = .008$, $\eta_p^2 = .21$), and infants tended to look longer at the first than at the second pair of trials (trial main effect: $F(1, 30) = 7.04$, $p = .013$, $\eta_p^2 = .19$) and at the inconsistent (2.48 s) than at the consistent (1.85 s) gaze trials (gaze main effect: $F(1, 30) = 6.41$, $p = .017$, $\eta_p^2 = .18$). No other effect was significant. The difference in the proportion of looking times at the empty side between inconsistent (20.7%) and consistent (15.1%) trials also remained statistically significant ($F(1, 30) = 5.29$, $p < .029$, $\eta_p^2 = .15$) after data correction. Finally, infants switched their gaze between the two sides reliably more times in the inconsistent (4.8) than in the consistent (3.9) trials, even after data correction ($F(1, 30) = 4.79$, $p = .037$, $\eta_p^2 = .14$).

## Discussion

This study was designed to test the hypothesis that infants would expect to find a referent object whenever they follow others' gaze. Our infant participants did follow the model's gaze: the 12-month-olds hardly missed a trial and even the 8-month-olds' performance was well above the chance. This may sound surprising given that some researchers have claimed that reliable gaze following cannot be elicited before the end of the first year of life (e.g. Corkum & Moore, 1998). Young infants' good performance in the present study was probably due to the fact that the target location, indicated by the opaque barrier, was well within their field of view, while gaze following in naturalistic laboratory studies is usually tested with distant objects that require head rotation to locate them (Corkum & Moore,

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1998; Moore & Corkum, 1998; Thoermer & Sodian, 2001). In an experimental setup that employed similar agent–object distance to the present study, Woodward (2003) also reported reliable gaze following in 7- and 9-month-old infants.

The crucial test of our hypothesis contrasts infants' looking behaviour between the consistent and inconsistent test trials. Not surprisingly, infants spent the best part of test trials by looking at the single object present on the screen, and this was not different between trial types. The results also showed, however, that infants in both age groups spent more time with looking at the *empty* side of the scene in the inconsistent than in the consistent test trials, that is, they explored more thoroughly at the empty location after it had been the target of the model's looking behaviour. The most plausible explanation of this behaviour is that our participants did indeed infer the presence of an object at the location indicated by the models' gaze and attempted to find it after it failed to appear. The fact that infants switched their gaze more times between the sides in inconsistent than in consistent trials also supports this interpretation. Neither the more switching nor the longer looking could be simply due to gaze-following response because these effects remained statistically significant after discounting the first looks at the empty side. Moll and Tomasello (2004) found that infants tend to search at locations indicated by someone's gaze. Our results complement this finding by showing that infants seem not to be satisfied when they do not find anything at the indicated location, even if an object is available at an alternative location.

Note that, although 8-month-olds were less likely to follow the model's gaze than did the 12-month-olds, when they did so, their looking behaviour was not different from the older infants. In fact, 8-month-olds tended to explore the empty side more than the 12-month-olds both in absolute and relative terms, independent of the gaze condition. The crucial contrast between the measures of looking behaviour in the consistent and inconsistent trials, however, did not differ across the age groups. The absence of an age effect indicates that as young as 8-month-old infants follow the gaze of others with the expectation that the looking behaviour of communicative partners refers to objects.

What is the source of this expectation? One possibility is that gaze following is an instrumental response learnt by infants during natural interactions with others (Moore & Corkum, 1994; Triesch, Teuscher, Deák, & Carlson, 2006). If this behaviour is normally rewarded by the sight of an interesting object, infants may develop an expectation for the presence of an object at the indicated location. This could explain why they keep going back to the empty location searching for a 'reward'. Note, however, that even if the referential expectation demonstrated in the present study has been learnt by operant conditioning, such a behaviour suggests that, by 8 months of age, the perception of a gaze shift generates not only an appropriate response (i.e. gaze following) but also the representation of a hypothetical object, of which the infants have had no perceptual evidence.

Alternatively, referential expectation may also originate from conceiving gaze shifts as communicative acts (Csibra, 2003). Gaze is commonly used by humans as a deictic device during communication with or without additional deictic gestures like pointing (Kita, 2003). Accordingly, referential interpretation of gaze, even if it points to a hidden location, implies the existence of a referent. The infants in the present study may have concluded that the woman on the screen, who apparently attempted to communicate with them, referred to, and implicitly indicated the presence of an object *for* them.

Whatever the origin of infants' referential expectation, it entails that 8-month-old infants can infer the presence and approximate location of an object merely on the basis of social information. Baillargeon (1994) hypothesized and then demonstrated

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(Augiar & Baillargeon, 2002) that 3.5-month-old infants would posit a hidden object in order to explain an apparent violation of a physical principle, spatiotemporal continuity. One-year-olds have also been shown to be able to posit a hidden object to justify a goal-directed action of a computer-animated geometric shape by satisfying an efficiency principle (Csibra, Bíró, Koós, & Gergely, 2003). As far as we know, the present finding is the first to demonstrate that even 8-month-olds can do the same trick in a communicative-referential context.

Our results support the hypothesis that infants may presume the presence of a referent object when they follow others' gaze. Further studies will be required to determine what contexts and what behavioural cues are required to elicit such a referential expectation. The present study employed, beyond eye-gaze, head shifts and body orientation, a verbal greeting ('Hi, baby!') and a comment ('Wow!') in the model's behaviour. We included these cues because we had found in pilot experiments that infants were reluctant to follow the gaze of the woman on the plasma screen without such communicative actions. The fact that infants are more likely to follow gaze in an unambiguously communicative context is consistent with the idea that they interpret gaze shifts as referential acts. It is also clear that only the gaze direction, and not these additional behavioural elements, could have specified the *location* of the expected referent object. However, it is possible that these additional cues played not only the role of defining the gaze shift as a communicative action, but also contributed to elicit a referential expectation. For example, if infants interpreted the woman's emotional comment ('Wow!') as a *reaction* to something, this may have induced the expectation of an object as the cause of the reaction.

Nevertheless, it is clear that the infants in the present study created the representation of an object that they had not seen before on the basis of behavioural cues alone, and localized it by gaze information. This conclusion raises the question of why infants below 12 months of age did not demonstrate a referential understanding of gaze in previous studies (Phillips, Wellman, & Spelke, 2002; Woodward, 2003). The answer to this question would likely be found in the fact that these earlier studies tested referential understanding by requiring infants to make inferences on the actor's subsequent actions. For example, after habituating infants to a certain actor–object relation established by gazing, Woodward measured whether their attention recovered when the actor looked at another object. This task requires, beyond an understanding of a referential relation, that infants represent the referent object in terms of its visual features, and assume that further referential actions be directed to the same kind of object. In contrast, the present study demonstrated only that infants interpret looking behaviours in referential terms, without requiring them to process the referred object further or to display expectations about the subsequent actions of the actor.

The present study was generated by the hypothesis that infants could interpret gaze in communicative–referential terms even if they cannot yet understand visual access and visual attention. Note, however, that we have not tested this hypothesis. The results of the present experiment would also allow the interpretation that the infants expected to find an object at the location where the model had looked *because* they understood that she had attended, seen and reacted to something over there. This seems unlikely, however, when we consider infants' failure in studies of gaze following. Nine-month-old infants tend to stop at the first object that they find when they follow the gaze of others (Flom *et al.*, 2004), and would follow the head turn of the model even when her eyes are closed (Brooks & Meltzoff, 2005). This suggests that gaze following at this age may not be dependent on understanding of visual attention, and makes it unlikely that the

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referential expectation demonstrated in the present study would be based on such an understanding either.

We speculate the fact that even young infants, who have only limited understanding of the conditions of visual access, show evidence of such an expectation which suggests that infants follow the gaze of others *not* in order to find out what the other *can see* but in order to find out what the other *is communicating about*. This interpretation of the present results imply that the slow development of accuracy of gaze following in infancy may reflect not a gradual understanding of the referential nature of others' looking behaviour but a gradual understanding of how vision works and how this can help to locate the referent of referential acts.

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