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Infants' Developing Understanding of Social Gaze

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Abstract

Young infants are sensitive to self-directed social actions, but do they appreciate the intentional, target-directed nature of such behaviors? We addressed this question by investigating infants' understanding of social gaze in third-party interactions (N = 104). Ten-month-old infants discriminated between two people in mutual versus averted gaze, and expected a person to look at her social partner during conversation. In contrast, 9-month-old infants showed neither ability, even when provided with information that highlighted the gazer's social goals. These results indicate considerable improvement in infants' abilities to analyze the social gaze of others towards the end of their first year, which may relate to their appreciation of gaze as both a social and goal-directed action.

Eye gaze is a central element of human social interaction that can reflect a person's feelings, her attitudes towards a social partner, and her goals for their interaction (Kleinke, 1986). Within an interaction, social partners attend to each other's gaze and use gaze to regulate both the immediate sequence of their exchange (Kendon, 1967) and their ongoing relationship (Ellsworth & Ross, 1975). Here we explore the origins of social gaze understanding, through studies of human infants.

Like adults, infants use their social partner's gaze to guide their social interactions (Murray & Trevarthen, 1985; Stern, 1974). Even newborn infants attend preferentially to faces displaying direct gaze (Farroni, Csibra, Simion & Johnson, 2002), and perform a rudimentary form of gaze-following (Farroni, Massaccessi, Pividori, & Johnson, 2004). These newborn behaviors appear to be based on a sub-cortical mechanism that draws attention to face-like stimuli (Johnson, Grossmann, & Farroni, 2008), while cortical mechanisms influencing responses to direct eye contact develop considerably over the first four months (Caron, Caron, Roberts, & Brooks, 1997; Samuels, 1985; Vecera & Johnson, 1995).

From very early on, infants seek eye contact in social situations. Four-week-old infants seek eye contact during nursing, and receiving eye contact potentiates the effect of sucrose delivery on quieting (Zeifman, Delaney, & Blass, 1996). From 9 weeks, infants fixate more consistently on an adult's eyes when she is speaking to them than when she is silent (Haith, Bergman, & Moore, 1977). Direct eye contact also influences young infants' social engagement. From three months, infants smile in response to eye contact and decrease smiling when a partner's gaze is averted (Hains & Muir, 1996). At four months, eye contact enhances face recognition (Farroni, Massaccesi, Menon, & Johnson, 2007), and engages neural areas associated with processing communicative signals in adults (Grossmann, 2008). By six months, direct gaze increases the rate of subsequent gaze-following behavior (Senju

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& Csibra, 2008). Despite all of these social responses, however, it is not clear how infants understand gaze and its social implications.

Since it is publicly visible, the gaze expressed between two people is also a potentially rich source of social information for third-party observers, and observers' abilities to interpret this information may provide clearer evidence of their gaze understanding. Adults use the extent and frequency of eye contact between two people to judge their relationship (Kleck & Nuessle, 1968; Thayer & Schiff, 1974, 1977), as do preschool children (Abramovitch & Daly, 1978; but see Nurmsoo, Einav, & Hood, 2009). Eighteen-month-old toddlers appear sensitive to the affiliation indicated by two puppets facing one another (Over & Carpenter, 2009). No studies, however, have yet investigated whether infants treat social gaze between two people as evidence concerning their relationship, or even whether infants detect mutual gaze between two people whose interaction they observe.

In order to detect and reason about mutual gaze between others, infants must first complete two distinct steps. First, they must follow the direction of a person's gaze to its target. Much research has investigated the development of infants' responses to another person's orientation of attention. Newborns shift their attention in alignment with the changing direction of gaze in a face before them (Farroni et al., 2004). From 3 months onwards, infants look in the direction of a person's attention ever more reliably (Scaife & Bruner, 1975), displaying steady improvement in their ability to locate a target over greater distances and in more difficult environmental conditions, well into the second year (Butterworth & Jarrett, 1991; D'Entremont, 2000; Moll & Tomasello, 2004). Although even 4-month-old infants respond selectively to directional motion of the eyes over other facial parts (Hood, Willen, & Driver, 1998), in other studies they have not distinguished “true” eye gaze from other cues for a person's attention, such as head or body orientation, until well into the second year (Caron, Butler, & Brooks, 2002; Moore & Corkum, 1998).

Second, infants must recognize that each person's looking behavior is fundamentally “about” its target, reflecting an intentional state that relates the looker to her social partner. Gaze-following studies alone cannot provide evidence for an intentional, target-directed understanding of gaze because the alignment of an infant's attention with that of another person could be based upon a wide range of rich and lean mechanisms. For instance, the response might be an innate reflex, performed with no explicit expectations for what is to be found in the newly attended location. It might also be performed in anticipation of finding an interesting outcome, but without any consideration for the connection gaze establishes between the looker and target. Or, it may reflect an intentional understanding of the looker's behavior, resulting in attributions of intentional states like perception of, desire for, goals towards, or communication to the infant about the target of gaze. A recent study provided clear evidence for a dissociation between gaze-following ability and an intentional understanding of gaze: 10-month-old infants' intentional gaze understanding was related to their participation in episodes of shared attention, but was unrelated to their gaze-following responses (Brune and Woodward, 2007).

Over the second half of the first year of life, a number of “triadic” abilities develop, which suggest attribution of intentional states connecting an adult social partner to a target (Tomasello, Carpenter, Call, Behne, & Moll, 2005). Infants begin to establish joint attention with an adult towards an object (Bakeman & Adamson, 1984), use her expressed emotions towards an object to guide their own behaviors (Mumme & Fernald, 2003), and even show and point to an object communicatively, for her benefit (Carpenter, Nagell, & Tomasello, 1998; Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004). Yet infants may treat people as intentional agents in some ways without understanding the intentional states that guide people's behavior in other situations; indeed, the degree to which individual 10-

month-old infants showed an intentional understanding of gaze was found to be unrelated to both their intentional understanding of pointing and to their own production of points for an adult (Brune & Woodward, 2007). For the case of social gaze understanding, it will be important not only to test infants' intentional evaluations directly, but also to consider just what intentional states infants may subsequently attribute to the looker (particularly, those reflecting the social intentions that people may have towards one another).

Studies that have tested specifically for an intentional, target-directed understanding of gaze find the earliest evidence around 8 or 9 months, but only under limited conditions. At 8 months, infants treat gaze to an object as target-directed if it is performed in a context in which the looker is constrained from producing a more familiar goal-directed action, such as reaching (Luo, 2010). At 9 months, infants also treat gaze as target-directed when a succession of acts of gaze are performed over multiple equifinal paths (Johnson, Ok, & Luo, 2007). Under these circumstances, however, infants will represent even novel actions as goal-directed (Bíró & Leslie, 2007; Csibra, 2003; Gergely, Bekkering, & Király, 2002). Thus, these findings do not reveal whether infants have a preexisting understanding of gaze as an intentional, target-directed action.

Evidence against such understanding comes from studies that test infants' evaluation of gaze under more natural conditions. When infants view a person who looks at one of two objects, they view the person's looking behavior as goal-directed at 12 months, but not at 9 or 10 months (Woodward, 2003; Brune & Woodward, 2007). At 9 months, moreover, infants register the congruence between a person's gaze direction and the location of an object's appearance only if the person first looks directly at the infant-a looking pattern that may cue the infant to the presence and location of an interesting object (Senju, Csibra, & Johnson, 2008), but does not always lead to a target-directed encoding of gaze (Woodward, 2003).

It is thus unclear when infants might first understand simple, ecologically valid instances of social gaze between others. The present studies seek to determine the earliest age at which infants encode social gaze between others (Experiments 1 and 2), and have expectations concerning its target (Experiment 3). We began our investigations with 9- and 10-month-old infants, as some experiments have revealed an intentional gaze understanding at these ages, while others have not.

Method

Experiment 1

We tested both 9- and 10-month-old infants in a habituation-of-looking-time procedure, to determine whether infants at either age would discriminate between presentations of mutual and averted gaze between two people.

Participants—Thirty-two infants were tested, half at 9 months (9 females; mean age = 275.0 days, range = 261-287) and half at 10 months (12 females; mean = 303.0 days, range = 292-317). All were full term (at least 37 weeks gestation). Additional infants were excluded due to fussiness (5 at 9 months, 4 at 10 months), or because the summed looking time across test trials was more than 2 SD from their age's mean for that trial type (1 at 9 and 2 at 10 months); for this and all subsequent experiments, the means for each age group were substantially unchanged if participants designated as outliers were included.

The families of participants were identified through commercially available lists and public records from the greater Boston area, and were initially recruited by letter. The majority of infants were from middle-class backgrounds; most were European-American, although a small number of Asian-, African-American, and Hispanic children also participated. A small toy and $5 travel reimbursement were provided for participation.

Materials—For each habituation and test presentation, infants viewed a movie composed of two video clips, presented simultaneously and side-by-side. Each clip featured one of two actors (one female, one male) against a black background (Figure 1). The arrangement of the two clips on the display screen gave the appearance of a single movie playing; we describe the clips here as distinct videos to better explain the construction of the different “overall” movies required by the study design. The clips were projected onto two of three adjacent 15 × 15 cm sections of a 47 × 58 cm projection screen located 1 m away from the infant's eyes (see below for how the selection of these two sections was made for each presentation).

In each clip, the actor appeared facing forward, turned to her or his left or right while smiling gently, and then remained motionless in this position. For mutual gaze presentations, clips were chosen and arranged so that, when they were viewed together on the screen, the actors appeared to look into each other's eyes. For averted gaze presentations, the actors looked away from one another. The timing of each clip was such that, in their combined presentation, the female actor first turned toward or away from the male actor (she faced forward for 5 s at the start of her clip, turned to the left or right (1s), and remained stationary at the latter, profile position), and then the male actor turned as her turn completed (he faced forward for 5.5 s and then turned to the left or right (1 s), remaining stationary in this profile position).

In sum, for all habituation and test presentations infants viewed a movie of the two actors turning toward or away from each other. After this short movie had played, its final frame, in which the actors could be seen in profile, remained on the screen until the end of the trial.

Procedure—Infants sat on a caregiver's lap. Between trials, a panel occluded the screen. The testing room was dim but not dark, and the LCD projector was set to a brightness setting that allowed the infant to easily view the video stimuli. A hidden video camera, centered below the presentation display and utilizing a “night-vision” setting to achieve a clear image of the participant's face and eyes, sent a live video feed to an adjacent coding room. From a television monitor in the coding room, a live coder, blind to condition, indicated the infant's looks to the display by pressing a button-box. From the coder's responses, a computer running the Xhab64 software program (Pinto, 1995) determined the end of each trial and when to move from habituation to test, and sent a signal to the experimenter in the testing room to do so. The caregiver closed her eyes during the test phase.

Looking times were recorded from after the first actor turned her head. The duration of both habituation and test trials was infant-controlled: trials lasted until the infant looked away for more than 2 seconds, or for a maximum of 60 seconds. Infants proceeded from the habituation to test phase after the sum of their looking times for three successive trials was less than half the sum of the first three trials, or after 12 habituation trials.

Design—During habituation, infants viewed only presentations of mutual gaze. During the test phase, infants viewed six trials, alternating between mutual and averted gaze. In order to expose infants to both actors turning in both directions, the positioning of the clips of individual actors varied across trials. During habituation, the female actor occupied the center section of the three sections that comprised the screen, and the male actor alternated between the left and right positions. During test, the male actor always occupied the center position and female actor's position alternated, creating a visual change from habituation for both gaze types. Mutual and averted gaze presentations featured the same pairs of clips with the relative positions of the actors reversed. Thus, both mutual and averted gaze test trials presented people in novel positions turning in a familiar direction. The gaze type of the first test trial (mutual or averted), side of the female actor's first test trial appearance, and side of her second appearance were orthogonally counterbalanced across infants.

Coding—For 28 infants, a secondary coder was present. Reliability between coders was 92.5%, calculated by comparing their button-box responses every .1 seconds during each trial.

Results and Discussion—Nine-month-old infants viewed an average of 7.6 habituation trials (standard error = 0.6), averaging a sum of 31.9 seconds (SE = 4.6) across the first three habituation trials and 13.1 seconds (SE = 2.0) across the last three habituation trials. Ten-month-old infants viewed an average of 8.7 habituation trials (SE = 0.8), averaging a sum of 31.3 seconds (SE = 3.4) across the first three habituation trials and 11.8 seconds (SE = 1.1) across the last three habituation trials. Two 9- and three 10-month-old infants failed to reach habituation criterion. There was no significant difference between age groups in the number of habituation trials witnessed or the sums of looking for the first or last three habituation trials. Since preliminary analyses of both Experiment 1 and 2 showed the same pattern of results for infants who did and did not habituate, and also found no main effects of sex nor interactions involving sex and gaze type, final analyses used all infants and collapsed across sex.

Infants showed sensitivity to mutual gaze at 10 months, but not at 9 months (Figure 2). A 2 (Age) × 2 (Gaze type: mutual vs. averted) × 2 (Order: mutual or averted gaze first) × 3 (Trial pair) ANOVA revealed a main effect of Gaze type, $F(1,28) = 4.659, p = .04$, qualified by an interaction of Gaze type and Age, $F(1,28) = 5.622, p = .025$. Separate follow-up analyses indicated no effect of Gaze type at 9 months, $F(1,14) < 1$, and a significant effect at 10 months, $F(1,14) = 6.268, p = .025$. Mean total looking to mutual and averted gaze presentations was 17.1 (SE = 2.3) and 16.6 seconds (SE = 2.3) for 9-month-old infants, and 13.9 (SE = 1.6) and 25.1 seconds (SE = 4.2) for 10-month-old infants. Thirteen 10-month-old but only six 9-month-old infants looked longer at the averted gaze presentations overall (respective *Zs = 2.59, p = .01 and .362, n.s.*, Wilcoxon test).

Ten-month-old infants, but not 9-month-old infants, clearly discriminated presentations of mutual and averted gaze between two people. As these stimuli included prior infant-directed gaze, a full head turn, and adjacent positioning of the face and target, all known to facilitate gaze-following (D'Entremont, 2000; Lempers, 1979; Senju & Csibra, 2008), and given 9-month-old infants' successful gaze-following for more difficult angles (Woodward, 2003), failure to follow gaze does not likely explain the younger infants' performance. Instead, it appears that 10-month-old infants encoded the gaze of at least one actor as directed towards or away from the other, while 9-month-old infants did not.

Experiment 2

As discussed in the Introduction, 8- and 9-month-old infants encode gaze as target-directed if it is accompanied by additional information highlighting the looker's goal in looking. This information may indicate that a general teleological attribution is appropriate, as when the gaze is performed over multiple equifinal paths (Johnson et al., 2007), or when the looker is constrained from reaching (Luo, 2010). It may also indicate the looker's referential intent, as when other cues suggest that it is performed as a communicative act (Senju et al., 2008). Experiment 2 investigated whether 9-month-old infants will show sensitivity to mutual gaze if additional information highlights the social goals of the mutually gazing actors. We tested both 9- and 10-month-old infants with the same study design as in Experiment 1, but now the actors greeted each other verbally as they turned.

Participants—Thirty-two infants from the same population as Experiment 1 were tested, half at 9 months (8 females; mean = 275.3 days, range = 262-288) and half at 10 months (7 females; mean = 299.2 days, range = 289-320). Additional infants were excluded due to fussiness (3 at 9 months, 4 at 10 months) or because they were outliers using Experiment 1's criteria (1 at each age).

Procedure and Coding—The experiment was identical to Experiment 1, except that the actors now greeted each other verbally. The female actor, turning first, said, “Hey, there!”; the male actor responded, “Oh, hi!”.

A secondary coder was present for 23 of the 32 infants. Reliability between coders was 94.2%.

Results and Discussion—Nine-month-old infants viewed an average of 10.4 habituation trials (SE = 0.6), averaging a sum of 35.5 seconds (SE = 4.9) across the first three habituation trials and 22.2 seconds (SE = 2.3) across the last three habituation trials. Ten-month-old infants viewed an average of 10.8 habituation trials (SE = 0.5), averaging a sum of 24.0 seconds (SE = 2.9) across the first three habituation trials and 18.1 seconds (SE = 2.8) across the last three habituation trials. Six 9- and eight 10-month-old infants did not habituate. There was a marginally significant difference between age groups in looking at the first three habituation trials, $t(30) = 2.02$, $p = .052$, but no significant difference for the last three trials or the total number of habituation trials witnessed.

As in Experiment 1, infants looked longer at the averted gaze displays at 10 but not 9 months of age (Figure 3). The 2 (Age) × 2 (Gaze) × 2 (Order) × 3 (Trial) ANOVA revealed only a main effect of trial pair, $F(2,56) = 8.681, p = .001$, but not of gaze type, $F(1,28) = 1.132, p = n.s.$, and a marginally significant interaction between age group and gaze type, $F(1,28) = 3.560, p = .070$. Follow-up analyses at each age indicated a significant effect of trial pair at 9 months, $F(2,28) = 4.867, p = .015$, reflecting infants’ tendencies to look less as the experiment continued. In contrast, the 10-month-old infants showed a significant effect of both trial pair, $F(2,28) = 4.436, p = .021$, and gaze type, $F(1,14) = 9.957, p = .007$. Mean total looking to mutual and averted gaze presentations was 22.5 (SE = 3.1) and 21.0 seconds (SE = 2.4) for 9-month-old infants, and 14.2 (SE = 1.3) and 19.6 seconds (SE = 1.4) for 10-month-old infants. Again, 13 of the older infants looked longer at the averted gaze test displays, whereas only 7 younger infants did so (respectively, *Wilcoxon* $Z = 2.59, p = .01$, and *.465, n.s.*).

To evaluate whether 9-month-old infants showed any sensitivity to gaze type across Experiments 1 and 2, we combined data from both in a 2 (Age) × 2 (Gaze) × 2 (Order) × 3 (Trial) × 2 (Experiment) ANOVA. There were main effects of trial pair, $F(2,112) = 4.443, p = .014$, and gaze type, $F(1,56) = 5.605, p = .021$, but the latter was qualified by an interaction with age, $F(1,56) = 9.171, p = .004$. An analysis of just 9-month-old infants revealed only an interaction between trial and experiment, $F(2,56) = 5.078, p = .009$. Ten-month-old infants, however, showed a main effect of gaze type, $F(1,28) = 12.018, p = .002$. An interaction between trial, gaze type, and experiment, $F(2,56) = 3.410, p = .04$, also indicated that the verbal greeting in Experiment 2 had led older infants to dishabituate to averted gaze most strongly in the first test trial pair.

Notably, nearly half of infants in Experiment 2 did not reach the habituation criterion. This was not likely the source of the difference between 9- and 10-month-old infants’ performances, as roughly the same number of infants at each age did not habituate; moreover, both habituators and non-habituators showed the same patterns of response. The large number of non-habituators is, however, consistent with the suggestion that 10-month-old infants' longer looking to averted gaze test presentations may have been based on more than a preference for the more novel test stimuli relative to the mutual gaze habituation presentations (that is, the conclusion best licensed by the habituation design). It is possible that older infants were more interested in averted gaze presentations because they portrayed an unusual event: two people turning away from, rather than towards, one another. In either case, however, Experiments 1 and 2 provide evidence for a consistent developmental change in infants' sensitivity to mutual gaze in third-party interactions.

In sum, as in Experiment 1, infants discriminated between presentations of mutual and averted gaze at 10 but not 9 months. The verbal greeting between actors did not lead 9-month-old infants to a target-directed assessment of either person's social gaze. This finding suggests that an intentional understanding of social gaze may develop towards the end of the first year, but that suggestion must be qualified in light of the very similar displays and methods of these two experiments. In the next experiment, we tested for developmental changes in social gaze understanding using a different method tapping more central, cognitive processing of social gaze.

Experiment 3

Experiment 3 tested whether 10-month-old infants' ability to discriminate instances of mutual and averted gaze is accompanied by expectations concerning when such events should occur. The experiment builds on the finding that infants as young as 8 months expect objects to be present at the location to which a person is looking (Csibra & Volein, 2007), and it asks whether infants have expectations about the nature of the object that should appear at that location when gaze occurs in a social context. For an infant to learn *why* people display different forms of social gaze, she must first determine the contexts in which people typically perform it. Experiment 3 used a violation-of-expectation procedure to investigate whether 10-month-old infants expect one person to look at another while they converse. We also tested 9-month-old infants, to determine whether the onset of such expectations coincides with the developmental change documented in the above experiments.

Participants—Forty infants were tested, half at 9 months (12 females; mean = 272.5 days, range= 261-287) and half at 10 months (9 females; mean = 309.8 days, range = 290-326). Five more infants were excluded due to fussiness (1 younger, 2 older) or because their looking time on a test trial type was more than 2.5 SD from the mean for their age group (1 from each group).

Materials—All displays consisted of filmed events played on a video monitor that had been divided horizontally into three sections, each covered by an animated panel (Figure 4). All sounds were played monaurally through a centrally located speaker. For the familiarization events, the two side panels slid outwards, revealing a toy tractor truck behind one and a forward-facing woman (the "social partner") behind the other. On each trial, one of two events occurred: either the woman smiled and said, "Hi, baby!" or the truck moved its shovel down and up as a mechanical noise played. Afterwards, both figures remained as static images.

The test events began with the same panel display as before, but with the middle panel replaced by a second woman (the "central actor") with her head facing down. Never making eye contact with the infant, she turned to one side and had a 12-second conversation with the social partner. The social partner was not visible, but her voice was heard responding. After this conversation, the central actor turned her head back down and was occluded by a panel from above. Next, the two side panels slid out, revealing static images of the truck and social partner, as in the familiarization trials.

Procedure—The procedure was the same as in Experiments 1 and 2 except as follows. Infants sat on a caregiver's lap, 65 cm from a 30” video monitor. Looking time measurement began as the side panels slid out, revealing the positions of the truck and social partner.

Trials lasted until the infant looked away for more than 2 seconds, or for a maximum of 60 seconds. Between trials, a curtain covered the display. The caregiver closed her eyes during test.

Design—Across four familiarization trials, the positions of the truck and social partner switched from left to right, in a counterbalanced ABBA design. The order of events (truck vs. talking) was orthogonally counterbalanced across infants.

There were two test trials, featuring one consistent and one inconsistent outcome. Both test trials began with a conversation between the central actor and unseen social partner. The order of test trial outcomes, the central actor's turning direction, and the final arrangement of the truck and social partner were counterbalanced across infants. Consequently, half of infants saw the central actor turn in the same direction on both trials, while half saw her switch directions across trials.

Coding—Using the same coding setup as described in Experiment 1, a primary online coder's measurements determined the duration of each trial. For 32 infants, a secondary online coder was also present. Both online coders were blind to condition, and reliability between them was 92.6%. Following Csibra & Volein (2007), an offline coder then examined videos of each test trial (resolution: 15 fps) and assigned every look made by an infant to one of four categories (looking to the left, center, and right portions of the display, and looking away). A secondary offline coder coded 12 infants from each age; the correlation between offline coders’ overall scores was .96. Both offline coders were naive to the hypotheses of the experiment, including the predicted age difference. Scores from the primary offline coder were used for analyses of gaze-following during the conversation and for test trial looking time.

Results and Discussion—Looking during familiarization was similar for both ages. An ANOVA of familiarization trial looking times, with age group, sex, and familiarization order (person or truck on first trial) as between-subject factors and video type (person or truck) and trial position within presentation sequence (first or second presentation of a given type) as within-subject factors revealed no effect of age group, nor any significant interactions between it and other factors.

Infants also showed similar looking patterns during the conversation, when the target of the central actor's looks was occluded. Infants looked at the central actor during 86.7% and 90.0% of the conversation phase, at 9 and 10 months respectively ($t < 1$, n.s.). For all infants but two (1 at each age), all looks away from her were away from the display. There was thus no overt gaze-following response, likely due to the visible actor's salience and lack of a visible target.

For the critical test trials, in contrast, infants’ looking time data showed strikingly different patterns at 9 and 10 months (Figure 5). Preliminary analyses revealed no significant main effects or interactions involving sex, familiarization order, or test order (whether the consistent or inconsistent outcome was shown first), and so final analyses collapsed across these factors. A 2 (Age) × 2 (Outcome: consistent vs. inconsistent) ANOVA revealed no main effects and a significant interaction between factors, $F(1,38) = 4.305, p = .045$. Whereas 9-month-old infants looked equally to consistent and inconsistent outcomes (means = 9.60 and 8.75, SEs = 1.39 and 1.28, respectively), $t(19) < 1$, *n.s.*, 10-month-old infants distinguished between them (means = 7.0 and 10.76, SEs = .79 and 1.26, respectively), $t(19) = 2.56, p = .019$. Longer looking at the inconsistent outcome was shown by 15 of 20 older but only 8 of 20 younger infants (respectively, $Z = 2.69, p < .01$, and *.87, n.s.*).

In sum, 10-month-old infants looked markedly longer when it was revealed that the central actor had been looking at the truck while speaking, rather than at the other person. Nine-month-old infants were insensitive to the relationship between the central actor's gaze and the location of her social partner, consistent with the suggestion of our earlier experiments that such infants do not view social gaze as target-directed.

Previous studies provide evidence that younger infants understand that a person should speak to another person but not to an inanimate object (Legerstee, Barna, & DiAdamo, 2000; Molina, Van de Walle, Condry, & Spelke, 2004). The present findings build on and extend this finding by showing that between 9 and 10 months, infants begin to use a person's gaze direction to determine the location of her conversational partner. Their increased looking during inconsistent outcomes thus appears to reflect the integration of new knowledge about social gaze with an already present understanding of the appropriate participants of a social interaction.

General Discussion

In Experiments 1 and 2, 10-month-old infants detected the mutual gaze between two people in a brief social interaction, and they discriminated mutual from averted gaze over changes in the people's positions. In Experiment 3, 10-month-old infants expected a person to look at her social partner while conversing with her, and they showed longer looking—a novelty or surprise reaction—when the person was revealed to have been looking away from her social partner in the direction of a truck. In stark contrast, 9-month-old infants revealed neither sensitivity towards, nor expectations about, social gaze in these third-party presentations, despite the central role of social gaze in their own dyadic interactions.

Infants’ successful reasoning at 10 months provides a strong demonstration of a target-directed understanding of gaze in the first year. This understanding is integrated with other knowledge about people's social looking behaviors. Whereas previous research has demonstrated that 8-month-old infants expect an unseen entity to be in the location given by a person's gaze (Csibra & Volein, 2007), and that 8- and 9-month-old infants encode the link between gaze and its visible target under restricted conditions (Johnson et al., 2007, Luo, 2010, Senju et al., 2008), Experiment 3 further required that infants reason about the specific identity of a hidden target of gaze. Ten-month-old infants know not only that people look at things, but also that they look at other people while engaging them in conversation.

The pattern of 9-month-old infants’ responses across these three experiments suggests that they lack an understanding of the intentional, target-directed nature of social gaze between two people whom the infants observe behaving in a natural, social manner. Of course, it remains possible that a more sensitive measure would reveal a competence that escaped detection in the present experiments; therefore, the present studies cannot conclude that 10-month-old infants’ successful reasoning about social gaze developed wholly in the space of one month. It should be noted, however, that the methods of these experiments were simple and straightforward, and that all of them yielded clear effects at 10 months. Moreover, no experiment yielded effects in the correct direction at 9 months, and an analysis combining participants from Experiments 1 and 2, thus doubling the sample size, revealed no indication that 9-month-old infants had discriminated between presentations of mutual and averted gaze. Although other cognitive processes, developing over multiple months prior to this window, may have contributed to 10-month-old infants' achievements, it appears from the current data that 10-month-old infants understand social gaze in a general way that 9-month-old infants do not.

The present studies only document knowledge about the intentional relation between looker and social partner established by social gaze, and do not directly reveal attribution of a specific intentional mental state explaining the looker's gaze behavior. To explore the possibility that third-party social gaze understanding may be related to the development of understanding social or communicative intentions, we now consider whether 10-month-old infants' performance might instead have resulted from attributing either of two other gaze-relevant intentional states (goal-directed action and perception).

Previous studies suggest that 9-month-old infants may already view gaze as a goal-directed action, but only if it is performed in a manner (Johnson et al., 2007) or context (Luo, 2010) that invokes the teleological reasoning system with which they also judge novel actions as goal-directed (Csibra, 2003). 10-month-old infants' superior performance therefore cannot be explained as an application of the general principles of teleological reasoning: all looks occurred without equifinal variation, and the situational constraints of the actors were identical for both age groups.

Alternatively, 10-month-old infants may better understand the relationship between gaze and perception. One prior study found that 9-month-old infants follow the gaze of a person with open or closed eyes equally, whereas 10-month-old infants limit gaze-following to open-eyed lookers, a development which the authors attribute to a new understanding of looking as seeing (Brooks & Meltzoff, 2005). Starting around 10 months, infants also show objects to a social partner by lifting them in front of her face (Carpenter et al., 1998), and by 11 months they appreciate that information gained through visual access can influence a person's actions (Xu & Denison, 2009). Despite a growing appreciation of looking as seeing, however, 10-month-old infants do not generally encode the intentional relation between a looker and target inanimate object (Brune & Woodward, 2007). This result suggests that 10-month-old infants in the present studies did not succeed because they better encoded the perceptual consequences of the actors' gazes.

Future studies should directly contrast 10-month-old infants' reasoning about looks to inanimate objects versus social partners to determine whether their discrepant performance in Brune and Woodward (2007) and the present studies is due to procedural differences, or whether it reveals a domain-specific improvement in understanding social gaze. Evidence for the latter possibility would support the possibility that 10-month-old infants newly appreciate the *social goals* that gaze may be used to achieve, such as the desire to establish and maintain social contact with another person, or to communicate with her. To our knowledge, there is no clear evidence that infants younger than 10 months understand how social goals may shape the social behavior of one agent towards another (Woodward, 2009), despite clear abilities to reason about communicative or social partners and their social relations (e.g., Csibra & Gergely, 2006; Hamlin et al., 2007; Kinzler et al., 2007) and about goal-directed agents and their physical actions (e.g., Gergely, Nádasdy, Csibra, & Bíró, 1995; Woodward, 1998).

Beyond their implications for the development of infants' gaze understanding, the present results provide a foundation for further studying the development of infants' and young children's social psychological reasoning. Ten-month-old infants encode simple, natural instances of third-party social gaze, know that people look at others in particular social contexts, and generate inferences about the target of a person's social gaze. Future studies should explore whether infants at this age also use social gaze to make mature inferences about a person's social goals, or her social relationships with other people.

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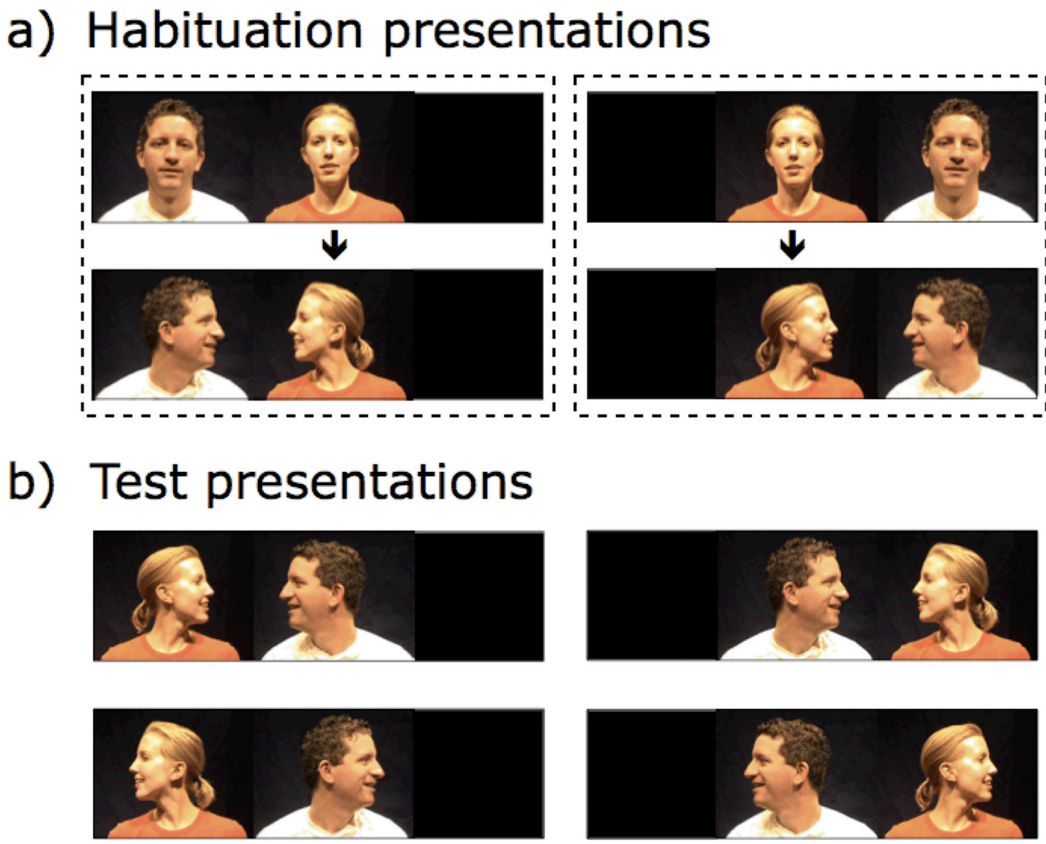

Figure 1.
Example displays and design for Experiments 1 and 2. (a) During habituation, the position of the man switched from left to right on successive presentations. Figure includes both the starting and ending frame for each of the two alternating habituation movies. (b) During the test phase, the man now occupied the center of the screen. The test sequence featured alternating presentations of mutual and averted gaze, drawn from the four movies shown. Test movies also featured both actors facing forwards and then turning, but only the ending frames for each of the four test movies are shown here.

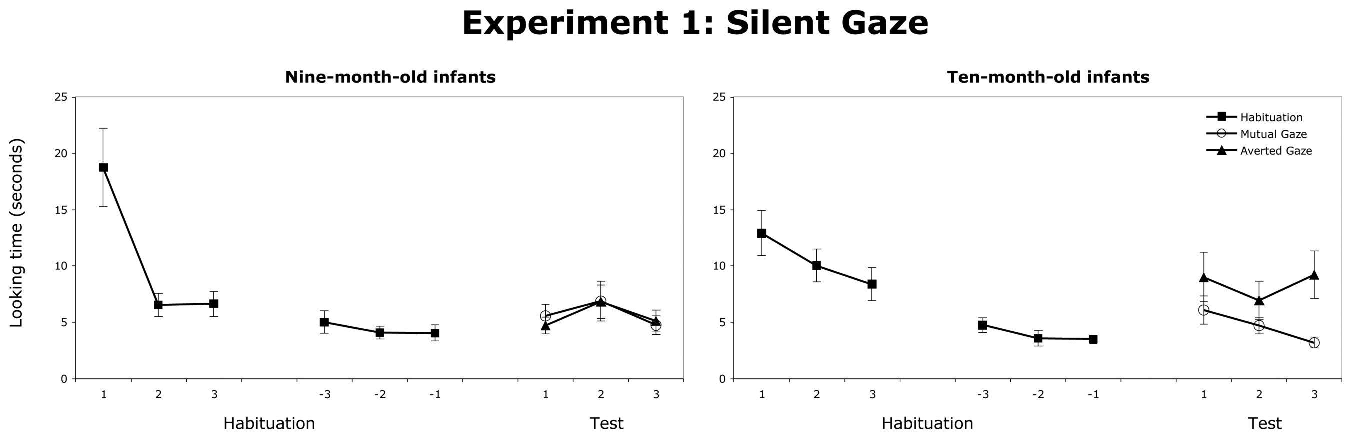

Figure 2.
Results for Experiment 1. Infants viewed the two actors turn silently. Error bars represent standard error.

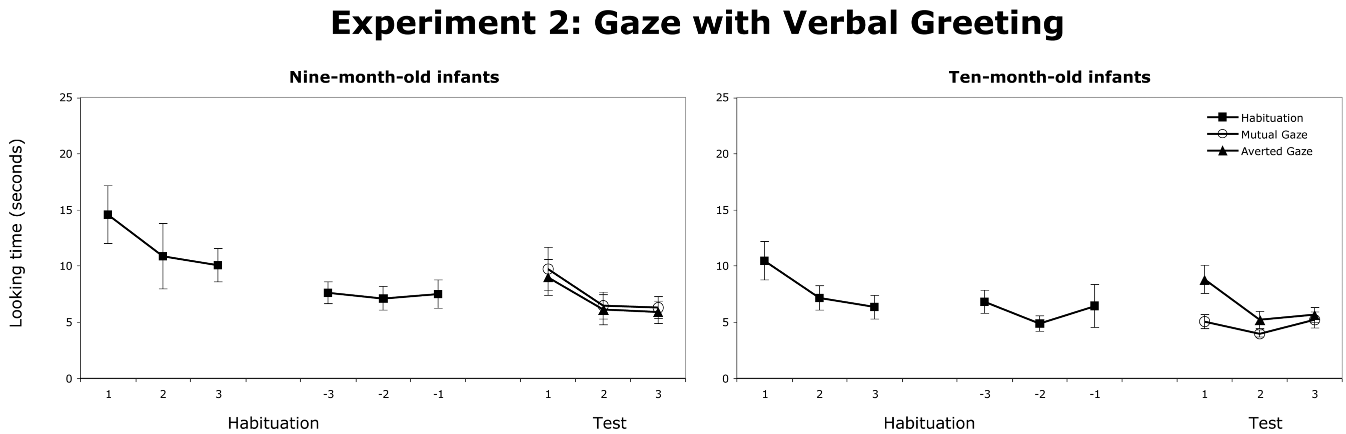

Figure 3.

Results for Experiment 2. Infants viewed the two actors turn and greet each other verbally. Error bars represent standard error.

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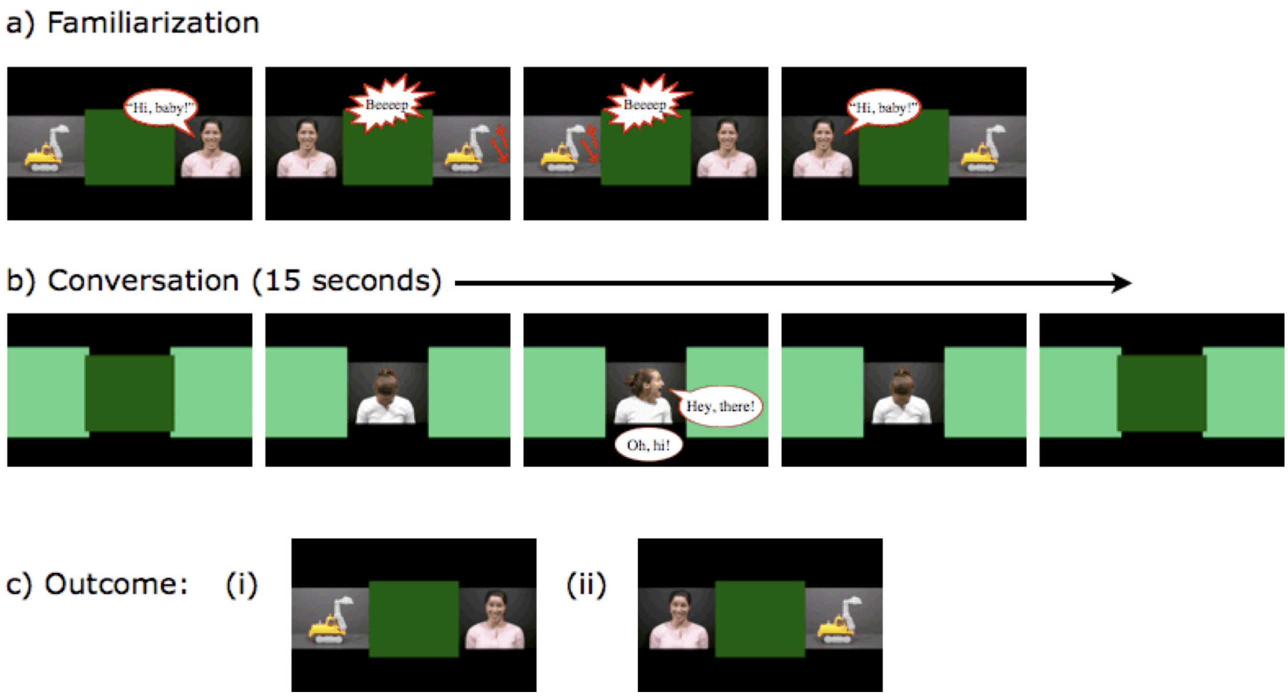

Figure 4.

The design of Experiment 3. a) Across four familiarization trials, the social partner and the truck appeared in each location twice. b) At the start of each test trial, the central actor appeared on her own and turned left or right (shown) to have a brief conversation with the hidden social partner. c) Following the conversation, the central actor was occluded and the social partner again appeared, in an arrangement that was either (i) consistent or (ii) inconsistent with the central actor's prior direction of social gaze.

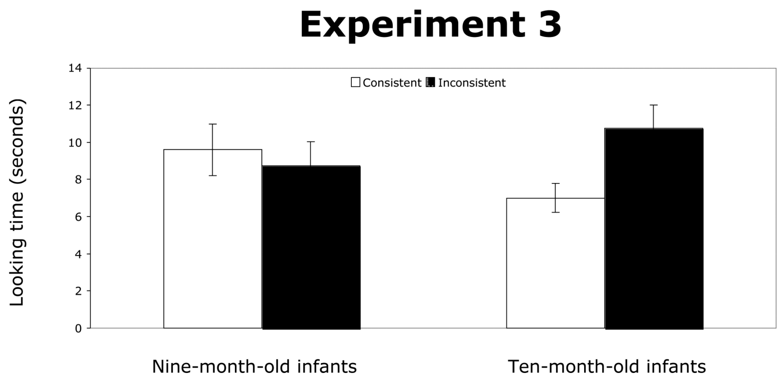

Figure 5.
Results for Experiment 3. Error bars represent standard error.