The Emergence of Referential Gaze and Perspective-Taking in Infants

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Abstract

To understand the development of infant comprehension of visual obstructions and perspective-taking, this study tested the ability of $N = 28$ infants at 14, 16, and 18 months to adapt attention-sharing to visual constraints. An experimental task investigated how infants modify gaze following behaviors when an adult's line of sight is obstructed by a barrier. From 14 to 18 months, infants gradually learned to modify their search behavior when an adult looked toward a referent hidden behind a barrier from the infant's perspective. This suggests development of perspective-taking during this period. It also reveals age-related changes in infants' understanding of contextual effects on others' referential gaze in visually complex environments. Furthermore, the results address debates about "rich" versus "lean" theories of shared attention and intentionality.

Keywords: Perspective-taking; referential gaze following; visual obstruction; intentionality; cognitive development; social cognition.

Introduction

Infants learn socio-cultural routines and communicative patterns by sharing attention with adults. As they move into early childhood, 1- and 2-year-old infants gradually learn how another's attention can differ from their own; that is, they learn to take other people's visual perspectives in a shared environment. A critical component of this ability is *attention-following*, whereby infants follow the direction of attention of a more experienced person (e.g., a parent) to shift focus to interesting features of the environment. The clearest manifestation of this is referential gaze following, a type of triadic interaction which involves at least two people and a common referent. Referential gaze following is a two-part process: 1) one person directs her own attention toward a referent by orienting her eyes and usually her head, and 2) another person sees this behavior and consequently shifts attention in the direction of that referent (Butterworth & Jarrett, 1991; Scaife & Bruner, 1975). It is well established that referential gaze following plays a critical role in social learning, communication, and mental-state inferences (Argyle & Cook, 1976; Deák et al., 2008; Kleinke, 1986).

A question that has generated interest is how attention-following in general, and gaze following in particular, supports our inferences and predictions about the mental states of others. When one person subjugates her current interest to follow another person's attention, it may be assumed that the former is taking the latter's visual perspective. This implies that the follower imputes a mental or physiological state to the "looker." Indeed, adults attribute another person's direction of gaze to an internal state—their attention. However, it is difficult to tell what inferences infants make, or mental states they attribute to the people whose gaze they follow. Because infants cannot articulate their inferences, we can only observe their behavioral responses to other people's behavior (i.e., gaze-shifts). More generally, we do not know whether and how infants understand "seeing." Thus, the manner in which infants come to understand the "mental experience of seeing something" in others remains controversial (Caron, Butler, & Brooks, 2002).

"Rich" versus "Lean" Interpretations

One controversy about how children understand another person's looking behavior focuses on two distinct developmental interpretations. At one end, "rich" interpretations of gaze following assume that the follower explicitly represents the looker's intention to look in a particular region (Baron-Cohen, 1995; Woodward, 2003). At the other end, "lean" interpretations assert that gaze following emerges from simpler perceptual and learning processes, and structured social information (D'Entremont, 2000; Nagai et al., 2003; Triesch et al., 2006). Yet other positions focus on the transition from lean to rich inferences about others' gaze (Butterworth, 1998).

The rich interpretation refers to evidence that infants understand adults' gaze following behind visual obstructions (Brooks & Meltzoff, 2002, 2005). It also considers evidence that by 2 years, toddlers use adults' patterns of looking and emotional display to interpret their intentions (Tomasello, 1999). By contrast, the lean interpretation refers to evidence that infants' gaze following is modulated by factors such as target salience and the salience of an adult's head turn (Deák, Flom, & Pick, 2000). Also, earlier studies showed that infants follow an adult's head angle, but not eye direction (Corkum & Moore, 1998; Triesch, Jasso, & Deák, 2007). This is noteworthy because if infants do not know that the eyes mediate visual attention, then they do not grasp the basic mechanics of *seeing*. However, this conclusion has been challenged (Brooks & Meltzoff, 2002, 2005), as we review below. Given the diversity of evidence, we must consider the task paradigms used to test infants' knowledge. Since people eventually develop rich beliefs about looking and seeing, the controversy is inherently developmental. The question is at what age, and by what process, do children make mentalistic inferences about looking? Such inferences relate to the origins of perspective-taking (Flavell, 1977). We now consider research evidence for age-related changes in infants' responses to looking and visual perspective-taking.

Age of Emergence

Recent studies have debated the age at which referential gaze following and perspective-taking emerge. Between 6 and 12 months of age, infants begin following an adult's direction of gaze (Adamson & Bakeman, 1991; Butterworth & Cochran, 1980; Butterworth & Jarrett, 1991; Corkum & Moore, 1998; D'Entremont, Hains, & Muir, 1997; Morissette, Ricard, & Décarie, 1995).

However, the age at which infants develop *referential* gaze following (i.e., knowing that someone's gaze is directed toward a percept, by virtue of seeing) is disputed. Brooks and Meltzoff (2005) reported that infants as young as 10 months start to realize that others are "'visually connected' to the external world." However, this is the only study showing such early ability, and the data are equivocal. There is more convergent evidence that referential gaze following emerges sometime between 12 and 18 months (Brooks & Meltzoff, 2002; Butler, Caron, & Brooks, 2000; Caron et al., 2002; Dunphy-Lelii & Wellman, 2004; Moll & Tomasello, 2004). For example, Deák et al. (2000) found that under optimal conditions, 12-month-olds follow gaze to targets located behind them. This is evidence of referential gaze following since it entails the representation that the looker is behaving in a way "toward" something, which the infants cannot detect. However, computer simulations show that this ability can be learned without high-level mental representations (Triesch et al., 2007).

By 18 to 24 months, there is substantial evidence for robust referential gaze following, particularly to targets that are visually occluded. That is, infants infer the existence of unseen objects and make inferences about others' visual perspectives. Notably, this is the same age that they begin to make inferences about other's mental states (Dunham & Dunham, 1995; Tomasello, 1999; Wellman, 1993).

The most active debate, then, centers on 12 to 18 months: if infants show referential gaze following by 12 or 14 months, it will suggest that gaze following is perhaps the earliest form of inferring others' mental states. If, however, referential gaze following does not emerge until 18 months, it will suggest that multiple forms of mentalistic inference emerge around the same time.

Problematic Occlusions

Many studies of referential gaze following in infants use large, distal occlusions (e.g., screen-like barriers) to obstruct either the infant's or adult's direct line of sight to a referent (Dunphy-Lelii & Wellman, 2004; Moll & Tomasello, 2004). Butler et al. (2000) compared infants' responses to transparent versus opaque barriers that were placed between a target referent and the experimenter. They found that 18-month-olds responded to the presence of an opaque barrier, whereas 14-month-olds did not reliably infer whether or not the adult could see the target through the barrier.

However, Dunphy-Lelii and Wellman (2004), who also used transparent and opaque barriers, found no change from 14 to 18 months. Infants by 14 months followed the experimenter's gaze more often when the barrier was transparent than when it was opaque.

In addressing this divergence of results, Moll and Tomasello (2004) charged that the task was too unnatural. They therefore used a different paradigm in which the target was placed behind a barrier from the infant's perspective. If the infant followed the experimenter's gaze, she would only see a boring opaque barrier. However, if the infant understood that the adult was looking at something, she would move around to peer behind the barrier. Results suggested that this behavior starts to emerge in some 12-month-old infants, and is more robust in 18-month-olds. This goes beyond Butler et al.'s (2000) results to suggest that 12-month-olds do basic referential gaze following.

Goals of the Current Study

We sought to resolve uncertainties about the development of referential gaze following in the second year. Since no study has examined the *process* of emergence, we tested infants at 14, 16, and 18 months, as a part of a longitudinal study. By testing at 3 bi-monthly ages, we might resolve conflicting results from previous studies of widely differing age groups. We can also test the stability and predictability of individual differences in development, which has not yet been studied.

Similar to Moll and Tomasello (2004), we used opaque barriers in a distal barrier paradigm, but added some improved controls. With a barrier on each side, one barrier occluded a target from the infant while the other displayed a target to both infant and adult. By making one target visible, we assessed each infant's baseline gaze following. We compared this to each infant's tendency to move and peer around the blank barrier when the adult looked toward it. This verified that the infant could visually orient to the experimenter's head and eye direction, thus making interpretable the "more demanding response" (Moll & Tomasello, 2004) of peering around when the adult's looking behavior was ambiguous. That is, in actively leaning forward or moving to look around a barrier to an occluded object, the infant's behavior signals her awareness of the implications of the adult's looking behavior.

In sum, the current investigation seeks to: 1) establish age-related trends in infants' acquisition of referential gaze following when the physical environment suggests that another person has a different visual perspective; and 2) relate the results to prior, simpler gaze following skills. Therefore, the goal of this study is to establish the validity of referential gaze following tasks and examine their implications for perspective-taking.

Method

Participants

Twenty-eight infants (17 males, 11 females) participated at 14 months (mean age = 427 days, *SD* = 7), 16 months (*M* =

491 days, *SD* = 13), and 18 months (*M* = 550 days, *SD* = 8). All infants were walking independently by 12.3 months (*SD* = 1.4). Infants were primarily of middle-class households from the San Diego area.

Materials

Two featureless, rigid brown barriers (92 cm x 58 cm) were placed side-by-side 1.2 m apart. Two 2D foam shapes (10.2 cm x 10.2 cm) were used as target stimuli. The control target was a red circle and the experimental target was a red duck. A researcher ("cue-giver" or CG) interacted directly with the infant in a quiet, controlled testing room (4.0 m by 3.6 m). A second researcher ("observer" or OB) monitored and recorded the infant's behavioral responses from an adjacent room. Target cues and locations were given by the OB to CG using a two-way radio and earpiece. A metronome was used to accurately time cue-length and inter-trial intervals. To control the visual scene, the CG wore a gray sweatshirt and tied her hair in a ponytail. Both the CG and parent were seated on the floor on cushions.

Procedure and Design

All infants participated in three sessions at 14, 16, and 18 months of age. Before each session, informed consent was obtained from the parent. Each session consisted of eight 10-second test trials.

Before the session, the barriers were placed on either side of the CG and the infant, who sat facing one another approximately 61 cm apart. Targets were attached to the middle of each barrier 46 cm above the floor. The control target was placed on the front of one barrier and the experimental target on the back of the other, relative to the infant. Barriers were angled so that both targets were visible to the CG, but only the control target was visible to the infant (Figure 1). The parent sat with the infant in her lap such that the infant could freely rise to walk around at will. The parent was instructed to provide no cues, and the infant remained seated between trials. The CG sat with her hands in her lap and displayed an open friendly expression.

To orient the infant to the target locations, the CG first held the control target at eye-level and said "[infant's name], look!" As she placed the target on the front of one barrier, she said "I'm going to put it there." The CG then held up the experimental target, saying "[infant's name], look!" She then placed the target on the back of the second barrier, saying "I'm going to put it here."

In each trial, OB gave the CG the onset cue, and the CG began the trial with an open-mouth smile. She called the infant's name until eye contact was made, and after two seconds said, "[infant's name], look!" The CG immediately turned to look directly at the target for four seconds. Then, CG looked back to the infant, establishing eye contact if possible, and said "Can you get it for me?" while executing another gaze cue to the target for four seconds.

After four trials (2 experimental, 2 control) in one left-right configuration, the barriers were switched between sides and the last four test trials were given. Between sessions the barrier sides were counterbalanced. Across trials, condition (control, experimental), direction (left, right), and target (circle, duck) were also counterbalanced.

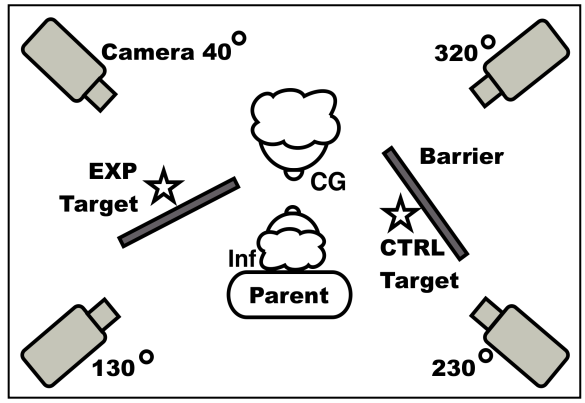

Figure 1: One configuration of the experimental setup.

Each session was recorded at 30 fps with four video cameras placed in the corners of the room at infant eye-level. The cameras recorded onto on-board hard drives, and simultaneously pushed video to be time-stamped and captured on a Level 5 RAID. In addition, a video camera with a fisheye lens was mounted above the infant's head, and was time-stamped and captured in the same manner.

Coding

Videos of infant behaviors were examined frame-by-frame. The infant's first look after each cue by the CG were coded (i.e., anticipatory looks were not examined). Furthermore, trials were coded only if the infant saw the CG's cue. Possible visual directions included looks to the correct target, incorrect target, front of the barrier that hid the target in experimental trials, CG, and "other" (i.e., anything else in the room). Success in referential gaze following was defined as the infant looking to the correct target location (i.e., specified by the CG's cue versus looking to the other target location or not looking at all). In a control trial, this meant looking toward the visible target after the CG's cue. In an experimental trial, this meant leaning or moving forward to peer around the back of the appropriate barrier.

An *incorrect* look was coded if the infant looked at the wrong target or to the front of the appropriate barrier in the experimental condition. A *non-look* was coded if the infant did not look to any target, but instead looked at the CG or at an irrelevant feature of the room.

Results

Proportions of correct looks were submitted to a 3 (age: 14, 16, 18 months) x 2 (condition: experimental vs. control) analysis of variance (ANOVA) within subjects. There was a significant main effect of age $F(2, 25) = 2.56$, $p < .09$; 18-month-olds looked proportionately more ($M = 0.55$, $SD = 0.39$) to the correct targets than 14- ($M = 0.41$, $SD = 0.44$) or

16-month olds (M = 0.48, SD = 0.40). There was also a significant effect of condition $F(1, 25) = 147.70$, $p < .001$. Infants looked more to the correct targets when they were visible in the control condition (M = 0.75, SD = 0.31) than when they were hidden behind barriers in the experimental condition (M = 0.20, SD = 0.29). However, there was no significant effect for the age x condition interaction, $F(2, 25) = 0.46$. Separate Student's t-tests were used to compare the factors of age and condition in looking behaviors (see Table 1). As expected, there was a significant difference between the control and experimental conditions for correct looks and non-looks ($p < .001$) at each age.

Table 1: t-tests comparing conditions across age.

	Correct Looks				**Nonlooks**			
Age	*t*	*df*	*SD*	*p-value*	*t*	*df*	*SD*	*p-value*
14	-7.43	27	0.39	$p < .000$	7.55	27	0.34	$p < .000$
16	-10.87	27	0.29	$p < .000$	9.53	27	0.24	$p < .000$
18	-7.03	27	0.38	$p < .000$	5.13	27	0.36	$p < .000$

Longitudinally, 71% of the infants performed steadily well in the control condition, while 4% of infants performed similarly well in the experimental condition. Comparatively, 14% of infants in the control condition and 21% of infants in the experimental condition improved in their performance from 14 to 18 months. Across all 3 age groups, 11% of infants in the control condition and 25% of infants in the experimental condition showed mixed abilities.

In addition to significant effects of age and condition, as well as longitudinal performance, there were subtler developmental changes that occurred between 14 and 18 months. Generally, infants at 14, 16, and 18 months looked to the correct target in the control condition; this showed a trend of increasing consistency, with mean proportions of 0.69 (SD = 0.40), 0.77 (SD = 0.27), and 0.80 (SD = 0.25) at the three ages, respectively. In the experimental condition, the mean proportions of looks to the correct target also increased from 0.14 (SD = 0.27), to 0.18 (SD = 0.26), and 0.29 (SD = 0.34), respectively (Figure 2).

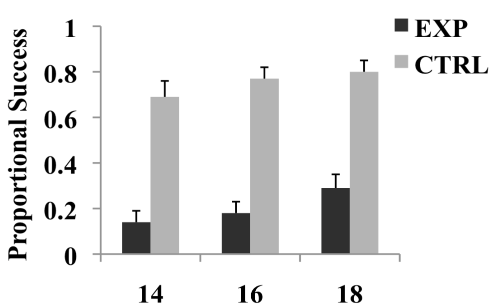

Figure 2: Mean proportions of success in looking behavior (with SE) in experimental and control conditions across age.

To understand these trends more fully, we examined the looking behaviors in each trial, distinguishing between correct looks, non-looks, and incorrect looks. Figure 3 displays these mean proportions at 14 months as a function of condition and looking behavior to illustrate the general pattern. While the general trends remained the same from 14 to 18 months, there was a decrease in the proportion of incorrect looks in the experimental condition from 0.52 (SD = 0.31) to 0.42 (SD = 0.32). Within the incorrect looks, looks to the front of the appropriate barrier in the experimental condition decreased from 0.39 (SD = 0.25) to 0.30 (SD = 0.29), and looks to the wrong target decreased slightly from 0.13 (SD = 0.18) to 0.12 (SD = 0.16).

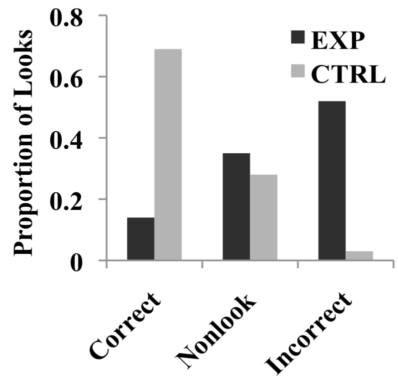

Figure 3: 14 month mean proportions of looking behavior.

However, one concern about these parametric data is that nothing compels infants to rise and peer around the barrier—especially after having done so once, since they may not be motivated to continue looking at such simple targets. To address this, we considered a less demanding measure of infants' understanding that the experimenter might be looking at something they could not see. The "1 Trial Pass" criterion defined an infant as "passing" if she looked to at least one correct target by moving or leaning forward to look behind a barrier. Since the active movement of searching for an unseen target indicates intentionality, this seems to show some basic level of understanding of visual obstructions and referential gaze. (In support of this, infants virtually never got up to look around the barrier in control trials.) Results showed a steady increase with age in the proportion of infants who looked to the correct target. In the control condition, 82% of the infants at 14 months, and 96% of the infants at 16 and 18 months, passed at least one trial (i.e., followed gaze to the visible target). In the experimental condition, 25%, 43%, and 54% of the infants, respectively, passed at least one trial. Thus, twice as many infants at 18 months followed blocked gaze successfully than at 14 months.

Discussion

The results show that some infants at 14 months are starting to develop an understanding of visual barriers and perspective-taking in referential gaze. This development goes beyond the ability to merely follow gaze, since infants were clearly able to do so by 14 months, as shown by the results in control trials. In the experimental trials, however, infants must determine that the adult is looking at a referent that the infants cannot see. At 14 months, some infants looked behind the barrier to the correct target, but did so much less than they looked to the front of the barrier. Yet at 18 months, infants peered behind the barrier to the correct target just as often as they looked to the front of the barrier. In addition, the "1 Trial Pass" analysis suggests that by 18 months, more than half of infants develop some Level 1 visual perspective-taking (Flavell, 1977), inferring an unseen target on at least one trial.

A longitudinal analysis suggests that a sizeable minority of infants improved in the experimental condition. Thus, there is some sort of learning from 14 to 18 months. However, there was also some within-infant variability between sessions, suggesting sources of unidentified situation-specific variability.

These results support Butler et al.'s (2000); 18-month-old infants respond significantly more than 14-month-olds to an adult looking behind barriers at hidden targets. Yet, possibly due to our more "natural" experimental design with multiple barriers and targets (inspired by Moll & Tomasello, 2004), our results showed a stronger effect than Butler et al. (2000). In their experiment, only 33% of 18-month-olds and no 14-month-olds leaned forward to look behind a barrier that obstructed a target. Thus, they concluded that infants at 18 months understand referential gaze and visual obstructions, whereas infants at 14 months do not. In the current investigation, 54% of the infants at 18 months and 25% of the infants at 14 months leaned forward to look behind the barrier. This demonstrates that visual perspective-taking develops considerably, and is clearly established, by 18 months, but it remains unclear whether 14-month-old infants have any functional capacity for visual perspective-taking. The current results suggest that some 14-month-olds are starting to develop an incipient understanding, as suggested by Dunphy-Lelii and Wellman (2004). However, we cannot say whether, for example, providing 14-month-old infants with additional training or reinforcement would increase their rate of responsiveness to an adult looking behind a barrier.

In order to better understand the developmental trajectory of referential gaze following, and to establish more precisely the age at which this understanding emerges, we considered results from a prior session in the longitudinal study. A subset of the infants (N = 18) who had performed simpler gaze following tasks at 12 months was compared to their performance at 14 months in the current task. Overall, the infants at 12 months occasionally followed gaze to visible targets (M = 0.43, SD = 0.19), but seldom followed gaze to targets located behind them (M = 0.11, SD = 0.27). This can be considered a "first step" towards referential gaze following. Furthermore, when subjected to the "1 Trial Pass" criterion, only 16% of the infants successfully looked to at least one target out of their direct view. By comparison, the same infants at 14 months made a similar proportion of successful looks to targets behind barriers (M = 0.14, SD = 0.25), but a higher proportion of them met the "1 Trial Pass" criterion (28%) in the experimental condition. Generally, infants at 12 months seldom followed gaze to unseen targets located behind them, therefore failing to show referential gaze following ability. Somewhat more infants showed at least minimal referential gaze perspective-taking at 14 months. Thus, our results do not support claims that infants even younger than 12 months have a concept of intentional behavior (Brooks & Meltzoff, 2002). Rather, our data suggest a shift from a leaner interpretation of gaze following in most 12-month-old infants, to a richer interpretation in most 18-month-old infants. Given this shift, we favor a learning-based account (in which gaze following begins perceptually, and then becomes referential as well as intentional), over accounts that assume strictly either a maturational onset of perceptual processes or an inherent understanding of the referential nature of gaze following.

Between their first and second birthdays, most infants develop the understanding that there may exist some object of interest at which an adult is looking, and that adult visual perspectives, in general, offer useful information. From 14 to 18 months, infants learn that acting on that information, via referential gaze following, can be rewarding. Even if that information consists of a referent that is visually occluded, infants will deliberately move to a proper viewing perspective to search for the inferred referent. Notably, the gradual differentiation of performance in the experimental and control conditions of the current investigation offers some insights into infants' growing capacity for detecting cues of others' perceptual states. This capacity is based in, and demonstrated by, their active search patterns, which for unseen targets might serve as an interim "trial and error" strategy that allows infants to test or verify the objective underlying adult looking behavior. However, this strategy is minimal at 14 months of age.

It is worth noting that the behavioral measures used in our study assess infants' performance and emerging ability, rather than level of competence. Indeed, all of the infants were capable of walking independently or crawling to look behind the barrier. This demonstrates that any possible differences in motor capabilities were not the primary source of divergence in the data between 14 and 18 months. As an additional factor, the manipulation of infants' motivational states highly influences competence, and may impede performance.

Finally, little is known about how infant gaze following skills relate to other spatial representational skills. However, referential gaze following provides a unique arena for studying how infants develop skills for simultaneously processing social and spatial information, and using these processing skills to support inferences about non-obvious events and ecological relations. Referential gaze following offers a new ability to synthesize information about other people's embodied actions in a shared environment to infer unperceivable states. This ability may be critical for impending changes in social and communicative knowledge.

The current study confirms developmental trends in referential gaze following from 14 to 18 months of age. Together with previous studies, this contributes to our understanding of infants' referential gaze following, perspective-taking, vision comprehension, and ultimately, theory of mind.

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