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When and Where Do Infants Follow Gaze?

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Abstract

Infants' processing of adult social cues develops late in the first year. Sensitivity before 6 months is limited to non-specific motion-cuing by lateral eye movements. Results from naturalistic and experimental studies show that learning is sensitive to factors including target location, target salience, gaze-cue salience, and the presence of distractors or non-gaze social cues. Those results are consistent with models in which incremental learning processes gradually learn to predict interesting events in allocentric space, and spatial attention networks learn to integrate predictive cues and memory traces to plan searches in complex environments.

Keywords: gaze-following; infancy; joint attention; motion perception; parenting; social development

Infant Gaze-Following: Disparate Views

Primates, including humans, use conspecifics' gaze-direction to modulate our social behaviors and to make social inferences (e.g., Itier & Batty, 2009). To understand this gaze-cuing capacity, we must know how it develops in infancy and childhood. Yet despite a wealth of studies on infant attention-sharing, there is considerable confusion about the development of gaze-following. At one extreme, some researchers claim that neonates can follow an adult's gaze, implying an 'innate' mechanism (Baron-Cohen, 1995; Csibra, 2010). Another view is that gaze-direction is a 'privileged' kind of social information that is learned early in infancy (3-6 months) and subsequently refined. A third view is that gaze-following emerges late in the first year (9-12 months), once infants recognize that adults' gaze, among other social cues, can facilitate social interactions.

These alternative views have quite different implications. The nativist view implies an encapsulated, specialized learning mechanism that functions differently from general learning systems, and it implies that developmental disabilities like ASD (Autism Spectrum Disorder) are specifically genetically constrained. By contrast, both of the non-nativist views imply that gaze-following might utilize the same learning processes as other behavioral skills. These views therefore imply that disorders of attention-sharing might be amenable to early intervention. Moreover, the three views make different assumptions about the evolution of gaze-following, about the role of early experience in the development of gaze-following skills, and, for the two learning-based view, about the role of functional similarity between early social cue-learning and later-emerging knowledge, including language comprehension.

Although a full treatment of all of these issues is not possible here, I will focus on the evidence regarding two fundamental aspects of gaze-following, and its implications for the alternative views: specifically, *when* does gaze-following emerge, and *where* do infants use it? Establishing when (i.e., at what age) and where (i.e., in what sorts of situations) infants follow others' gaze can constrain our theories of *how* the capacity develops.

When Can Infants Follow Gaze?

Different empirical studies imply that gaze-following emerges at very different ages. The discrepancies are partly rooted in different, often implicit definitions of what counts as 'gaze-following,' and in the paradigms used to measure the skill. One definition is very broad: gaze following is taken as any tendency to look in same visual hemifield as a real or depicted face, more than the other hemifield. Another definition is much more specific: gaze following is looking for a target in the specific region of space (smaller than a hemifield) inferred from the direction of a person's eyes.

Not surprisingly, claims that young infants can follow gaze usually cite evidence that rests on the broad definition, whereas claims that gaze-following emerges later usually cite evidence resting on the narrower definition. I will briefly review studies using both definitions, but make the nature of the underlying evidence clear, to evaluate the epistemic strength of the divergent views outlined above.

A historical reference point is Scaife and Bruner's (1975) initial report that 30% of 2-4-month-olds, and 38% of 5-7-month-olds, followed a model's left/right head turns. However, that result, though widely cited, is not interpretable because infants responded to only two trials, and their baseline looking tendencies were not assessed. Still, some authors have used the results to infer gaze-following by 2-4 months (e.g., Langton & Bruce, 1999).

Many subsequent studies have investigated infant gaze-following in more detail. I will first consider less-naturalistic paradigms in which infants respond to images of faces on screens, and then consider studies using more naturalistic, dynamic social stimuli—that is, live adults. Dividing the literature in this way makes sense in light of accumulating evidence that infants respond differently to live and video 'partners' (e.g., Wass, 2014). I will then describe preliminary results from an experimental study that corrects a pervasive problem in the literature. The results confirm that infants do not follow gaze before 6 months of age, but the ability emerges between 9 and 12 months.

Studies using artificial gaze cues

The seed planted by Scaife and Bruner's (1976) bore fruit in a report by Hood, Willen and Driver (1998), suggesting that young infants might show precocious gaze-following. They showed 2-4-month-olds an image of a frontal face that appeared to look center, blink, and then move its pupils to the left or right. It then disappeared, and a peripheral target appeared near where the head had been, on either the same or the opposite side as the direction of 'eye'-dot movement. Infants were faster and more likely to saccade to the target if it appeared in the direction of eye movement. Hood et al claimed that young infants "correctly interpret the direction of eye gaze [which is] unequivocal support…that an [gaze-following] mechanism is present…early in development (1998:132-3). Yet the results are not unequivocal: the stimuli rate produced apparent motion, making the eyes seem to shift left or right. This probably attracted infants' attention: infants, like other primates, tend to follow or orient attention to a moving object (e.g., Volkman & Dobson, 1976). For instance, 1-month-olds follow the motion of pupil-like dots presented within or without a face-like frame (Girton, 1979). A simple explanation for Hood et al's results, then, is that infants followed *motion,* not gaze.

D'Entremont (2000) and Gredeback, Fikke and Melinder (2010) have since argued that Hood et al were correct: infants did not simply track motion, because many of their saccades began more than 2 sec after the eye movement, yet infants can re-orient towards peripheral sounds within 1 sec. The implication, presumably, is that Hood et al's infants were making deliberate, 'top-down' re-orienting responses. Unfortunately this argument is specious: first, *tracking* the face (or part of it, e.g., the pupils) by smooth pursuit is behaviorally and neurologically distinct from motion-based re-orientation (e.g., Cavanagh, 1992; Krauzlis & Stone, 1999). Second, orienting to sounds uses different neural pathways (Bushra et al, 1999), and the timing of that reflex, in infants, is not known to be equal to the timing of visually-guided orientation to movement. Third, Cohen (1972) found that 4-month-olds may require up to 6-12 s to turn from a central to a peripheral target, and Hunnius, Geuze and van Geert (2005) found that 6-week-olds averaged almost 2 sec to turn from a central face to a sudden peripheral target. Thus, Hood et al's response time data do not disprove the claim that infants followed motion rather than eye-direction.

By contrast, findings reported by Farroni et al (2004) strongly support the possibility that young infants follow motion. They found that 1-5 day old infants viewing a face-drawing shifted faster and more often to a target (bulls-eye) that appeared in the direction that the face's 'eye'-dots had just moved, than to a target on the opposite side. When 'pupil' direction was presented without motion, the effect disappeared. Farroni et al (2000) also showed that 4-5-month-olds only followed pupil-dots that moved laterally: eliminating motion eliminated following. Most definitively, Farroni et al (2003) showed that infants follow directional motion even if it *reduces* gaze-following. For example, if the eye-dots shift from right to center (i.e., leftward), to end up 'looking' at the infant, infants tend to then look toward the left, further in the direction of apparent motion!

In sum, studies using artificial faces do not clearly show that infants below 6 months will follow gaze *per se*—contrary to the claims of some authors (e.g., Kinzler & Spelke, 2007). Rather, infants seem to follow directional motion of dots or other high-contrast shapes (e.g., faces). This motion-cuing yields a higher probability of gaze shifts from 2-8 sec after the onset of dot motion towards any nearby (i.e., within 10-15°) target along that trajectory. The effect is stronger if the face disappears before the target appears. Specific effects of *eye* direction has not been shown before 6 months. To the contrary, Corkum & Moore, 1995, found that 12-month-old infants follow a turning head even if the eyes keep looking at them, and Doherty, Anderson, and Howieson (2009) found that 2-year-olds can identify the target of adults' head turns but not their eye direction. Thus, the behavior shown in young infants is most confidently described as *Motion-Cued Scanning* (MoCS).

Studies of other cues confirm the robustness of MoCS: Rohlfing, Longo and Bertenthal (2012), for instance, found that 4-6-month-old infants were more likely to follow a pointing hand video if the hand moved, but only if it moved toward the target, and not if it moved away from the target.

The claim here is not that infants respond *only* to motion: for example, they also respond to verbal cues (e.g., Flom & Pick, 2003). The point is that all published findings of so-called gaze-following in infants under 6 months can be more parsimoniously explained by MoCS.

Studies using live human gaze cues

The studies reviewed above used artificial faces on video monitors. However, the relevant social stimuli for infants are not two-dimensional face-images but real humans. Artificial stimuli are convenient, but are unlikely to elicit everyday infant behavior. Perhaps, for example, the previous studies *under*estimate infants' ability to follow gaze with real humans. Fortunately, several other studies address this concern.

D'Entremont, Hains and Muir (1997) had infants aged 3-6 months watch an adult turn to oscillating puppets on either side of her head. Infants looked in the direction of E's head turns on ~70% of trials. This might indicate either MoCS or gaze-following. However, other findings suggest that it reflects MoCS, even in older infants: Moore, Angelopoulos and Bennett (1997) showed that 9 month olds followed the left or right gaze of an adult only if they saw the head move, but not if the head-turn was obscured. The final static head pose did not compel infants to follow gaze. Moreover, when infants saw *only* the movement but not the final head pose, infants turned more often than chance to the target. Thus, even infants of 8-10 months, watching live adults, seem to follow motion rather than eye direction.

A limitation of all of the studies so far discussed is that they used just two targets, one on each side of the (real or pictorial) head, and eliminated all other salient targets from the testing environment. Although this paradigm is simple, it is not reflective of everyday social contexts of infant social interaction. Also, the paradigm yields ambiguous or misleading data, because with nothing to look at except the head and targets, virtually any directional cue can elicit a weak head-turn tendency.

The paradigm can be made less ambiguous by providing not just a left and right target pair, but at least two targets on each side, to test infants' following to a *specific* target. This method, which supports the more focused definition of gaze-following, was explored in classic studies by Butterworth and Cochran (1980) and Butterworth and Jarrett (1991). Several real targets were placed on each side of a normally illuminated room, and infants saw a real adult's gaze cues. In this paradigm, 6-month-olds rarely followed gaze, and even 12-month-olds usually followed gaze only to targets already in front of them. Later studies using this paradigm showed that 12-month-olds can follow gaze to targets that are out of sight if the targets are complex and distinctive (Deák, Flom & Pick, 2000). This target distinctiveness effect is notable because it cannot be explained by motion cueing. Thus, by 12 months infants show 'true' head-direction following, in laboratory contexts.

Other results with live social partners and multiple target location confirm that gaze-following is rare and brittle at 6 months, and it emerges between 9 and 12 months (e.g., Flom et al, 2004), although specific following of eye-direction rather than head-direction does not consolidate until as late as 2-3 years (e.g., Doherty et a, 2009).

A possible objection to these conclusions is that younger infants might be *capable* of following gaze, but previous studies did not sufficiently motivated them to follow gaze. Some data hint at this: Leekham, López and Moore (2000) found that children with autism learned, if given extrinsic rewards, to follow an adult's gaze. Corkum and Moore (1998) also showed an effect of visual reward on 8-month-olds' gaze-following. Finally, target salience (which contributes to reward-value) modulates infants' gaze-following (Corkum & Moore, 1998; Deák et al, 2000), yet many studies have used boring targets or even no target. A stronger test of infants' gaze-following ability would be to motivate them to follow gaze, then measure their response. Such a test would approach an assessment of infants' capacity to follow gaze, rather than their proclivity to follow gaze in various artificial setting.

Do younger infants follow gaze when reinforced?

Based on this logic, we tested the emergence of gaze-following *capacity* in a longitudinal study of infants between 4 and 12 months. The goal was to determine when, and how reliably, infants follow gaze cues to specific targets. Pointing gestures were also measured as a control, because infants follow points more readily than gaze (e.g., Deák et al, 2000). Whereas previous studies gave infants little motive to follow gaze, we designed a reinforcement task. The logic was to give infants an interesting visual reward quickly if they followed the social cue. To avoid practice effects across sessions, all infants were shown that the target locations sometimes played reward videos. However, only by responding to gaze/point cues would infants get a rapid, response-contingent reward.

Method. A separate sample of pilot infants was recruited to select video rewards (i.e., visually attractive, spatially discrete audiovisual stimuli). From a larger set of candidate 8-sec video clips, we selected a subset that held infants' attention for relatively long. These clips, from the commercial *Baby Einstein* series, show high-contrast toys or animals moving to mid-tempo classical music.

Test setting. Infants in the main study were tested in a sound-attenuated testing room (4.02m x 3.57m) with six 33 cm monitors (Figure 1), three on each side (about 2m from the infant): two in front (|33°| from infant's midline), two to the side (at |78°|), and two behind the infant (at |126°|). The infant sat on mother's lap, facing a researcher (R) who produced cues, directed towards specific monitors in quasi-random order. In each of 20 trials R produced one of three cues (quasi-random order): (1) Gaze: turned head and eyes to look at the target monitor; (2) Point: extended arm and hand in a full index-point toward the target monitor; (3) Gaze+Point: simultaneously gazed and pointed. (In two baseline trials R looked down; these trials were used to estimate infants' tendency to look at the monitors when no directional social cue was given.)

Orientation trials. Before each session infants completed an orientation phase in which they were shown that each monitor played video rewards. One at a time, in a preset quasi-random order, R used multiple natural social cues to indicate a monitor (voice, gesture, gaze, touch) until the infant looked at it. A confederate (watching from an adjacent room) then turned on a video reward. (Each monitor played a different video, and videos changed in each session.) After the infant had seen each monitor play a reward video, test trials began.

Figure 1: Cue-following orientation trial. Five monitors are blank; one (left-side) is playing a video.

Test trials. In each test trial, R: (i) called the infant to get his/her attention; (ii) produced a cue for 4 sec; (iii) re-oriented to the infant (2 sec); (iv) repeated the cue for 4 sec; (v) turned back to the infant. Repeating the cue ensured that infants would detect the cue (see Deák et al, 2000).

On every trial except baseline trials, if the infant looked at the cued target monitor, the confederate turned on the video (1-2 sec delay). If the infant did not look at that monitor, or looked at any other location, the reward video was not turned on until the cue period ended and R ended the cue and turned back to the infant. This ensured that all infants saw the monitors playing reward videos the same number of times (to minimize practice effects); however, when infants followed a social cue they received a reward contingently and quickly. On baseline trials, no reward video was played.

Coding. Five video cameras (overhead and corners of room [Fig. 1]) captured synchronized videos to a computer RAID. Trained experimenters, blind to information about the infants and to specific hypotheses, coded, frame-by-frame (30 Hz), the time and location of: social cues, reward videos, infant visual fixations to any target or object in the room, and periods of infant visual scanning.

Results. For brevity, we present results only from *first fixations* after cue onset (but before video onset), at three of the monthly visits: 4 months (n=24), 9 months (n=29), and 12 months (n=35). (Attrition in earlier sessions was due to failure to complete all trials.) A more complete report is in preparation. First fixations (defined as static gaze direction for at least 180 msec) are a conservative index of cue-following. Chance responding was set as the mean probability of first fixations to one out of six monitors in baseline trials.

A summary is shown in Figure 2. The main result, for our purposes, is clear: at 4 months infants do not follow gaze (mean=4%, SD=9%), even after seeing that the target monitors show reward videos. Their low target-look rate (Figure 2) is not different from their low rate of looking at any given monitor during baseline trials (~0%).

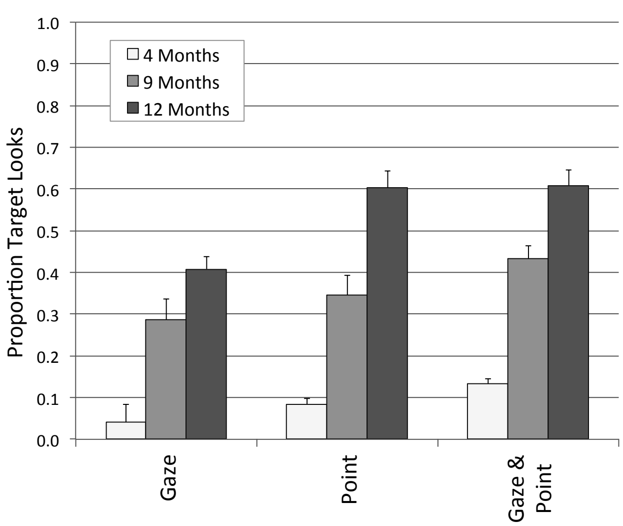

Figure 2: Preliminary results from 4, 9, and 12 mo, for gaze, point, and gaze+point cues. (Error bars: SEM)

One possible reason for this is that the task is simply too difficult for infants in general. However, the results from later months show that this is not the case By 9 months, infants followed gaze to target monitors on mean=29% of trials (SD=24%), and 43% (20%) of gaze+point trials—much higher (p=.009 and p<.001, two-tailed t-tests) than on baseline trials (i.e., 13% fixations on any given monitor). Thus, by 9 months infants responded to gaze cues. Still, responsiveness to gaze cues further increased from 9 to 12 months (mean=41%): $t(61)=2.2$, p=.029 (two-tailed).

One possible interpretation is that 4-month-olds did not follow gaze because there was some task demand that exceeded their immature capabilities (e.g., motor control), or the novelty of the test context was overwhelming to them. Preliminary analyses of data from infants' 5-month sessions (when they were more mature and more familiar with the setting) do not support this possibility: at 5 months infants averaged only 7% target looks on gaze trials (SD=11%), and 13% (13%) on gaze+point trials, barely improved from 4 months.

A related possible concern is whether younger infants could even detect or discriminate R's gaze shifts. However, by 5 months of age infants can detect fairly small gaze shifts by adults (Symons, Hains, & Muir, 1998). Thus, it is very unlikely that infants at 4-5 months did not detect gaze cues.

Finally, it is possible that the videos rewards were not in fact rewarding to 4-month-olds. Unfortunately, we have no means to test the reward value of the videos for individual infants. Despite this limitation, the study arguably offers the strongest evidence concerning infants' ability to follow gaze cues *per se*, even when such a response is reinforced. The results, along with other available evidence, strongly support the view that gaze-following emerges after 6 months, and develops slowly from 9 to 36 months (Butterworth & Jarrett, 1991; Deák et al, 2000; Doherty et al, 2009), likely due to protracted learning processes working on variable, complex input (see Jasso et al, 2012; Nagai, Hosoda, Morita, & Asada, 2003; Triesch et al, 2006).

Where Do Infants Follow Gaze?

What evidence is available concerning the nature of these learning processes? To address this, we should consider how the social and physical context of interactions affects infants' gaze-following. Here I briefly consider several reported contextual effects that hint at these processes. However, contextual effects on infants' cue-following remain largely unknown, so this represents just a first step.

One factor shown to matter is the location of targets relative to the infant. Butterworth and Cochran (1980) showed that infants follow gaze to targets within their visual field (i.e., in front of them) earlier than targets outside their visual field (i.e., peripheral or behind them). Deák et al (2000; Flom et al, 2004) showed that this difference holds true for pointing gestures, suggesting a more general property of infant cued spatial attention. Deák et al (2000), however, showed that the effect is partly due to a confound; namely, the size of the adult's head turn when infant and adult face each other. Although this contributes to the effect, the rest of the effect has not been explained. One possibility is that as infants get better at maintaining representations of an adult's head- and eye-direction when they have turned away from the adult, they become better able to reconcile the represented head/eye direction with the locations of distal objects (see Doherty et al, 2009; Jasso et al, 2012).

Another contextual factor that seems to affect gaze-following is clutter, or the concentration of visual distractors (Wass, 2014). Preliminary evidence suggests that infants are less responsive to gaze cues in more cluttered environments: Deák, Walden, Kaiser and Lewis (2008) found that 15-22-month-olds, who are old enough to follow gaze in 'stark' laboratory settings, did not do so in a laboratory context seeded with additional distracting objects.

If this tentative finding is confirmed as a general effect, it will suggest that even after infants learn to follow gaze, it remains a low-salience cue. Consistent with this, Deák et al (2008) further found that infants in the cluttered environment were much more likely to follow combined gaze+point or gaze+verbalization cues. It seems that adults' gaze shifts alone do not effectively recruit and re-direct infants' attention, in normative environments (i.e., with some clutter). Perhaps infants eventually learn that gaze is a high-frequency but low-validity source of information for predicting other people's actions.

Here I have discussed only two contextual factors, but certainly others probably affect infants' cue-following. Also, even these two factors are not well understood. For example, research on 'clutter' has not distinguished whether incidental objects are relevant to the infant (e.g., toys) or not, or tested the effects of different kinds of distractors (e.g., animate vs. inanimate). Moreover, dynamic events as well as static objects compete for infants' attention. It is likely that many kinds of elements in different environments can modulate infants' response to adults' gaze and other cues. Other factors such as the novelty of an environment, and 'background' factors like ambient noise and brightness, might also affect infants' responsiveness to gaze cues.

Underlying these speculations is a general question: are contextual effects specific to infants' social cue-following responses, or do they follow general properties of the infant's cognitive system, such as perceptual interference, perceptual salience, attentional 'spotlight', and capacity limits? Wu and Kirkham (2010), for example, found that gaze cues (i.e., a pictorial face) recruit infants' attention differently than other directional cues. Although it is unknown when this difference generalizes to naturalistic contexts, addressing that would likely tell us something about the specific and general processes that underlie infants' everyday social cue-following and social learning.

Implications

Although some theorists have posited that infants have an innate or 'core' gaze-following capacity (e.g. Baron-Cohen, 1995; Kinzler & Spelke, 2007), and others have focused on the possibility that gaze-following emerges within the first few weeks or months, a review of all currently available evidence fails to support the view that infants younger than 6 months can reliably follow gaze. Younger infants are, however, sensitive to moving, high-contrast objects, and will scan in the direction of motion (i.e., motion-cued scanning, or MoCS). This behavior is strongly evolutionarily conserved, and does not require specialized knowledge of species-specific social cues. My claim is *not* that all gaze-following rests on MoCS, but that all published findings purporting to show early gaze-following can be more parsimoniously explained by MoCS. Certainly more complex social cue-following skills eventually emerge, but these might require patterned input that is constrained by early, species-general sensorimotor capacities like MoCS.

Other age-related changes also suggest that gaze-following arises from gradual learning processes. For example, infants respond more robustly when gaze-cues are accompanied by pointing cues; they respond first to head turns and only much later to eye-direction *per se*; they respond more to large head turns than small ones. All of these effects are consistent with general perceptual-motor learning processes (Jasso et al, 2012; Paulus, 2011).

Infants eventually incorporate even more varied social information in deciding when and how to respond to social prompts or opportunities. Toddlers' burgeoning awareness of mental states will influence their responses to adults' behavioral cues. So far, no theories offer an explanation for how this awareness becomes integrated with earlier-emerging capacities such as gaze-following. However, in order to generate a valid, testable theory of this development, it is crucial to start with a clear and accurate characterization of how the earliest cue-following behaviors emerge. If these skills emerge much like other perceptual-motor skills, and are subject to similar contextual factors, then gaze-following might be distinguished less by its origins than by its fate, as it eventually serves vital roles in communication and social cognition (Tomasello, 1999).

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