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REPORT

The attribution of attention: 9-month-olds′ interpretation of gaze as goal-directed action

Susan C. Johnson,[1] Su-Jeong Ok[1] and Yuyan Luo[2]

1. Department of Psychology, Stanford University, USA
2. Department of Psychology, University of Missouri – Columbia, USA

Abstract

The current study distinguishes between attributions of goal-directed perception (i.e. attention) and non-goal-directed perception to examine 9-month-olds' interpretation of others' head and eye turns. In a looking time task, 9-month-olds encoded the relationship between an actor's head and eye turns and a target object if the head and eye turns were embedded in a sequence of multiple, variable actions with equifinal outcomes, but not otherwise. This evidence supports the claim that infants of this age may attribute perception, at least goal-directed perception, to others and undermines arguments that gaze-following at this age consists only of uninterpreted reflexes. The evidence also suggests alternative interpretations of the typical errors infants make in standard gaze-following procedures. Implications for infants' understanding of perception and attention in both human and non-human agents are discussed.

Introduction

The ability to construe ourselves and others as mentalistic agents with intentional states such as beliefs, desires and perceptions is central to human nature. Recent advances in infant cognition have brought the developmental roots of this important ability into the arena of empirical debate. Two types of mental state attributions have received the most scrutiny as possible foundational constructs – the attribution of goals and the attribution of perception. This paper uses the work on goal-attribution to distinguish between attributions of perception and attributions of attention and begin to clarify the patterns of successes and failures in infants' ability to attribute either.

A consensus is building on the ability of infants to attribute goals to others. In a variety of studies, infants have encoded the target objects of both familiar and unfamiliar agents performing simple actions (Csibra, Gergely, Biro, Koos & Brockbank, 1999; Gergely, Nadasdy, Csibra & Biro, 1995; Luo & Baillargeon, 2005; Shimizu & Johnson, 2004; Woodward, 1998). In a pivotal study based on a visual habituation method, Woodward (1998) showed that infants can encode the goals of a human grasp. She showed infants a human hand repeatedly reaching for and grasping one of two objects on a stage, until the infants were habituated and no longer attended to the event. The positions of the objects were then switched and the hand reached either for the original target object, now in a new location, or the other, previously ignored object, now in the old location. Infants as young as 5 months recovered interest and looked longer at reaches to the new object in the old position, than reaches to the old object in the new position, even though overall the new object event was more perceptually similar to the habituation event. Woodward reasoned that infants must have encoded the original habituation event in terms of the relationship between the actor's hand and its target (i.e. its goal.) Two control conditions showed that the effect was selective; infants failed to differentiate between test events when the 'grasper' was an inanimate pincer performing the same actions or when the human actor simply laid the back of her hand across the target object.

More recent work has addressed the puzzle of how infants decide whether any given, otherwise ambiguous action is goal-directed. Several possibilities have been offered. Woodward and colleagues have suggested that

Address for correspondence: Susan Johnson, Department of Psychology, Jordan Hall, Bldg 420, Stanford University, Stanford, CA 94305, USA; e-mail: scj@psych.stanford.edu

first person introspection and experience are important (Sommerville, Woodward & Needham, 2005). In support of this, they showed that 3-month-olds who were artificially provided with the opportunity to 'grasp' objects via sticky mittens were more apt to encode the target of others' grasps than were infants who had not been given this experience.

Others have speculated that observable characteristics of the actions themselves can elicit goal-attributions, particularly the presence of an effect and/or an equifinal outcome arrived at through variable means (Gergely *et al.*, 1995; Heider, 1958; Leslie, 1994; Premack & Premack, 1994). Indeed, in two different studies, infants treated actions with the back of a human hand as goal-directed if they had previously seen the action lead to an effect (Biro & Leslie, 2004; Kiraly, Jovanovic, Prinz, Aschersleben & Gergely, 2003). In one case the hand pushed the target object to a new position and in the other Velcro was positioned on both the hand and object such that the object could be lifted into the air by contact with the back of the hand. After seeing these demonstrations, infants treated simple contact with a target by the back of a hand as goal-directed, unlike in the original Woodward study. Biro and Leslie showed the same effect with an inanimate rod used to pick up a target object. They also demonstrated the power of equifinal variation on infants' interpretations. In a preliminary study, infants who saw the inanimate rod repeatedly approach and pick up the target, each time from a slightly different direction, seemed more likely to treat the rod as goal-directed than infants who did not.

The work on infants' attributions of perception has produced no similar consensus. The majority of studies have focused on infants' ability to follow the gaze of another, under the assumption that if attributions of perception are made, they will be in the form of attributions of vision via the eyes. Unsurprisingly, the conditions under which infants are found to follow the gaze of another are unlike those found in adults. Thus the debate centers around how to interpret the pattern of successes and failures that infants produce. On the one hand, infants' ability to follow adults' gaze is quite precocious if the procedures are sufficiently streamlined (D'Entremont, Hains & Muir, 1997). If schematic stimuli and an attentional cuing method are used, the attentional focus of extremely young, even newborn, infants can be appropriately redirected by another's eye movements (Farroni, Massaccesi, Pividori, Simion & Johnson, 2004; Hood, Willen & Driver, 1998).

On the other hand, when older infants are presented with different configurations of eye and head movements, they make a variety of errors. Until about 12 months, infants typically follow head movements rather than eye movements, even if the eyes are closed or occluded; or if the eyes move without any accompanying head movement, infants will often not follow at all (Brooks & Meltzoff, 2002, 2003; Corkum & Moore, 1998).

Similarly, a variety of studies have shown that the environment influences infants' performance as well. For instance, infants are reluctant to follow another's gaze toward empty space (Flom, Deak, Phill & Pick, 2004) and they will often fixate on the wrong target if more than one candidate target is present (Butterworth & Jarrett, 1991).

Two studies have set aside the gaze-following/attentional-cueing methods in favor of the visual habituation methods used in goal-attribution studies (Phillips, Wellman & Spelke, 2002; Woodward, 2003). In both studies, infants failed to encode the relationship between an actor's looking behavior and a specific target before the age of 12 months. In the study by Woodward, 7- and 9-month-olds successfully followed the gaze of the actor to one of two target objects during test, but nonetheless showed no preference for the new-target event. This is in direct contrast to the willingness of similarly aged infants to encode the relationship between manual behaviors such as grasping and a target.

Why do infants treat these two behaviors (manual versus looking behaviors), and seemingly these two mental states (goals versus perception), differently? One possibility is that the relationship between each mental state and relevant, observable behavior is not equally transparent. As Woodward points out, grasping involves direct physical contact; gaze does not. Grasping often has a direct physical consequence; gaze never does. In addition, grasping can be objectively observed in the self whereas gaze cannot. On this view, young infants may be able to follow the gaze of others due to, perhaps, an uninterpreted reflexive ability, but it takes much longer for infants to construct a mentalistic interpretation of gaze (Corkum & Moore, 1998; Woodward, 2003).

We would add one additional difference. Sometimes looking behaviors simply have no target. Whereas grasping is almost always a deliberative, object-directed action, eye and head movements happen for both deliberative and non-deliberative, as well as object-directed and non-object-directed reasons. People turn to look at things, but they also turn away from things; people stretch, fidget, and allow their eyes to drift absent-mindedly. The distinction between goal-directed and non-goal-directed head and eye movements may be particularly important, conceptually mapping onto the distinction between attention, i.e. goal-directed perception, and non-goal-directed perception. This characteristic of eye and head movements could make it more difficult in general to learn the relationship between orientation and perception, but also more difficult to decide whether any particular movement of the head or eyes has a target. Thus infants may have a mentalistic interpretation of gaze in general, follow head and eye turns regularly, but still fail to encode the target of head and eye turns in cases where the presence of attention is in question.

The distinction between attention and non-goal-directed perception may make it more difficult, not only for infants learning the relationship between gaze and perception, but also for researchers designing methods to test that learning. Can we make it easier for infants to recognize goal-directed head and eye turns? Would the same action characteristics that lead infants to treat unfamiliar manual actions as goal-directed also lead them to treat otherwise ambiguous shifts in head and eye orientation as goal-directed? If so, we could tentatively conclude that infants attribute attention, if not perception more generally, to others.

The current study is a first attempt to examine infants' understanding of gaze and orientation in this light. Infants saw either (1) a single head and eye turn ending in a single fixation on the side of a target object, as in Woodward (2003), or (2) a head and eye turn toward the target that included three distinct fixations on separate surfaces of the object (side, top, and front), before a final fixation on the target's side. We predicted that infants would encode the relationship between the actor and target only in the condition with multiple, variable fixations.

Method

Participants

Twenty full-term infants from a large metropolitan area participated. Parents were contacted through mailings and phone calls. Infants were assigned to either the Single Fixation condition (n = 10; mean age = 273 days, range 244 to 295; six female, four male), or Multiple Fixations condition (n = 10; mean age = 264 days, range 248 to 276; five female, five male). Eight additional infants were excluded from the final sample because they did not complete the procedure (five), experimenter error (two), or interference from a sibling (one).

Materials

The targets

A football decorated with yellow stripes and a red box decorated with blue dots were used, both 14 cm wide by 23 cm high.

The stage

The infant was seated on the parent's lap approximately 45 cm in front of a stage. The stage had a 56 cm wide by 54 cm high front opening behind which a black curtain could be lowered between trials. The floor of the stage was white. The sides were gray boards with a granite-like pattern. The box and football were positioned on the stage, one on each side. An actor sat at the back of the stage in front of a black curtain with only her face and upper body visible. Her head was equidistant between the two objects, at approximately the same level. A hidden assistant stood behind the stage to operate the curtain.

The camera and observers

A video camera mounted above the actor's head allowed two observers to watch the infant's face on TV monitors in an adjacent room. The observers judged when the infant looked away from the display. The primary observer was always naïve. Neither observer could see the stage, the objects or the actor. A computer with specialized software recorded the infant's looking times.

Procedure

Infants in both conditions saw four familiarization trials followed by four test trials. The test trials in each case were identical. Only the familiarization trials differed.

Each trial began when the curtain rose to reveal the actor seated between the two objects with her eyes fixated on the center of the stage floor. The infant's face appeared on the monitors and the observers began recording. After the infant oriented to and fixated on the display for 2 cumulative seconds, as signaled by a soft beep from the computer, the event began. The duration of the event in each condition was preset by the computer; 1 second for the Single Fixation condition and 7 seconds for the Multiple Fixations condition. A continuously beating metronome allowed the actor to time her motions to fit the appropriate interval. When the computer calculated that the infant had looked away from the display for 2 consecutive seconds or looked at the display for 30 cumulative seconds, it signaled the end of the trial with another beep. The assistant then lowered the curtain. Throughout the experiment, the actor avoided eye contact with the infant and kept a neutral face. All timing calculations made by the computer were based on the judgments of the naïve primary observer.

Figure 1 *Illustration of the familiarization and test events in the Single Fixation condition (top left), the Multiple Fixations condition (top right) and the test events (bottom).*

Single Fixation condition – familiarization event

The actor in the Single Fixation condition turned her head and eyes to look at the target and then remained fixated on it for the remainder of the trial (see Figure 1). The entire event lasted approximately 1 second and included only one action and one fixation. The infant's looking behavior was recorded from the moment the actor stopped moving as approximated by the preset computer-timed interval.

Multiple Fixations condition – familiarization event

The Multiple Fixations event was based on the hypothesis that repeated behaviors with equifinal variability cue goal-directedness. Therefore the actor began the trial fixated on the stage floor at midline, turned once toward the object and then seemed to 'scrutinize' it with a sequence of distinct fixations on the object before coming to rest in the standard orientation toward the object (see Figure 1). The fixation sequence was as follows: The actor first turned her head to look at the side of the object, then moved upward to look at the top of the object, then forward to look at the front of the object, finally moving back to the original position to look at the side of the object. The actor performed the required head and body movements by moving forwards and backwards or up and down, without actually moving directly towards the target. This ensured that the actual distance between the actor and target object was never shorter in the Multiple Fixations condition than in the Single Fixation condition. The entire sequence lasted approximately 7 seconds. The infant's looking behavior was recorded from the moment the actor stopped moving as approximated by the preset computer-timed interval.

Test events

Before the test phase began, the locations of the two objects were switched and infants were presented with two types of test trials in counterbalanced orders (new-old-new-old vs. old-new-old-new). In the old-goal event, the actor looked at the same target object as in familiarization – now in a new location. In the new-goal event, she looked at the other target object, now in the familiar location. Half of the infants saw the new-goal and half saw the old-goal event first. Each test trial ended when the infants (1) looked away for 2 consecutive seconds after having looked for at least 5 cumulative seconds, or (2) looked for 60 cumulative seconds.

Observer reliability

Sixteen of the 20 infants were coded by two observers. Looking time was divided into increments of 100 ms by the computer. The average percentage of increments in which the two coders' judgments agreed was 92%.

Results

Familiarization data

Infants' mean looking times during familiarization were calculated. Infants continued to look at the display for 17.9 seconds (SD = 5.6) after the actor in the Single Fixation condition fixated on the target. Infants in the Multiple Fixations condition continued to look for 13.7 seconds (SD = 5.9) after the actor stopped moving. A one-way analysis of variance (ANOVA) on infants' average looking times revealed no reliable difference, though infants may have had a slight tendency to continue to look at the display in the Single Fixation condition after the actor stopped moving, $F(1, 18) = 2.72$, $p = .12$.

Looking time analysis

We predicted that infants in the Multiple Fixations condition would look longer at the new-goal test events than the old-goal test events, but that infants in the Single Fixation condition would fail to distinguish between them, as in Woodward (2003). We also expected that an overall analysis would reveal an interaction between the two conditions and two test events, rather than a main effect of either. An average looking time score for each test event was first calculated for each infant. The scores were entered into both parametric and non-parametric analyses of infants' overall looking preferences. Mean looking times are depicted in Figure 2.

Preliminary ANOVAs revealed no main effects of test order or sex, nor interactions with condition. Therefore these variables were eliminated from further analyses. A 2 × 2 ANOVA with condition (Single vs. Multiple Fixations) and test event (new-goal vs. old-goal) revealed no main effect of either variable. As predicted, however, it did reveal a significant interaction ($F(1, 18) = 5.45$, $p = .031$, $\eta^2 = .59$).

Also as predicted, infants in the Single Fixation condition failed to distinguish between the two test events ($M_{new} = 15.0$, $SD_{new} = 9.5$; $M_{old} = 16.8$, $SD_{old} = 8.6$), $F(1, 9) = 0.47$, n.s. Most importantly, however, infants in the Multiple Fixations condition looked reliably longer at the new-goal events than the old-goal events ($M_{new} = 19.0$, $SD_{new} = 10.7$; $M_{old} = 11.4$, $SD_{old} = 3.9$), $F(1, 9) = 6.11$, $p = .036$, $\eta^2 = .59$).

The same pattern of results was seen in the non-parametric analyses. Only three of the 10 infants in the Single Fixation condition looked longer at the new-goal events than the old-goal events. However, nine of the 10 infants in the Multiple Fixations condition did so. This yielded a significant interaction between condition and test event by Fisher's exact test, $p = .020$. Within the two conditions, Wilcoxon signed ranks tests revealed an effect of test event only in the Multiple Fixations condition, $z = -2.19$, $p = .028$.

An additional analysis of looking behavior

The primary analyses reported above compared the amount of time infants spent looking at the entire display in each test trial. A further question arises. To what extent is infants' success in the Multiple Fixations condition due to a novelty effect of the target items, rather than the actor–target goal relationship? That is, if a reflexive or otherwise uninterpreted attentional mechanism leads infants to follow the gaze of the actor, the infant may become familiarized with the target object without encoding the goal relationship between it and the actor. The actor's switch to a new target in the test trials might then elicit longer looking, not because infants recognize that the goal relationship has changed, but because they find themselves now attending to a novel object. In the original design of Woodward's (1998) goal-directed grasping studies, this alternative was ruled out by showing that an inanimate pincer directed the infants' attention to the targets just as effectively as the hand, yet yielded no 'goal' effect. Nonetheless, this alternative has not been ruled out in the case of gaze.

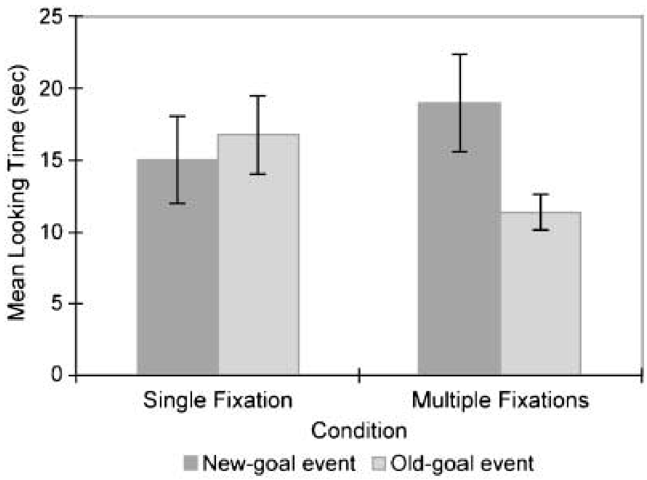

Figure 2 *Mean looking time per trial in the new-goal and old-goal test events by condition. Error bars represent standard errors.*

Therefore the videotapes were recoded for how long each infant looked at each object during test trials. A second coder coded 25% of the tapes. Both coders were blind to condition and event type. Agreement was 97%. The results are shown in Figure 3. The data from the Single Fixation condition are shown for completeness only, as the alternative hypothesis addresses only the data in the Multiple Fixations condition.

The alternative hypothesis suggests that the significant difference in looking times between the new-goal and old-goal events in the Multiple Fixations condition may be due to the novelty of the new object in the new-goal events. At minimum, therefore, a significant difference in looking times should exist in the Multiple Fixations condition between the new object in the new-goal events ($M_{nong} = 3.3$ seconds, $SD_{nong} = 3.1$) and the old object

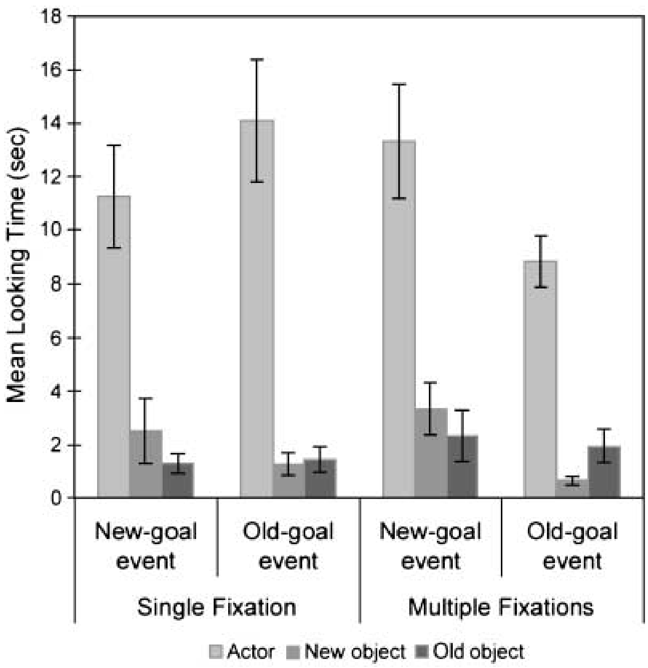

Figure 3 *Mean looking time per trial at each part of the display by condition and test event. Error bars represent standard errors.*

in the old-goal event (M_{ooog} = 1.9 seconds, SD_{ooog} = 2.0). A two-tailed, paired *t*-test revealed no such effect, p = .31. A two-tailed, paired comparison of the summed looks to either object in the new-goal (M_{sumng} = 5.7 seconds, SD_{sumng} = 5.10) vs. old-goal events (M_{sumog} = 2.6 seconds, SD_{sumog} = 2.1) also yielded no reliable difference, p = .13.

If the difference in infants' overall looking rates to the new-goal and old-goal events was not due to the novelty of the new target object, what was it based on? The time infants spent looking at the actor in each test trial was estimated by subtracting the looks to each target object from the overall looking time. Infants in the Multiple Fixations condition looked at the actor for 13.3 seconds (SD = 6.8) during the new-goal events, but only 8.8 seconds (SD = 3.0) during the old-goal events. A two-tailed, paired comparison of these two means revealed a reliable difference, $t(1, 9) = 2.62$, $p = .028$. Apparently, the difference in looking times to the new-goal and old-goal events in the Variable condition is due largely to infants' relative scrutiny of the actor in each event. Furthermore, it bears noting that the actor's final stance (looking left versus looking right) in the new-goal event was identical to her final stance in familiarization, while her final position in the old-goal event was different and therefore more novel.

Discussion

Nine-month-old infants encoded the relationship between an actor's head and eye turns and a target object. They did so when the head and eye turns were embedded in a sequence of variable actions with equifinal outcomes, but not otherwise. This conclusion is bolstered by the finding that infants' preferential looking to the events in which the actor looked to a new target object seemed to be driven by their scrutiny of the actor, rather than a novelty effect of the target object. This is the first piece of evidence that infants of this age may attribute perception, at least goal-directed perception, to others. Many questions arise from this finding.

What information in the Multiple Fixations action sequences did infants use? This condition contained a variety of enriched information relative to the Single Fixations condition. Not only did it contain information about common outcomes across actions, it also contained repetitions of the overall goal and persisted for a longer time. Further research is needed to determine the relative contribution of each of these (and any other) cues. Infants' failure to encode the relationship between an actor and the target of the actor's gaze in both the current Single Fixation condition and previous work (Woodward, 2003) may have been due to the lack of one or all of these sources of information. Regardless, the current data suggest that 9-month-olds are not altogether unable to encode the relationship between a looker and the target of looking, as previously argued (Woodward, 2003).

How *should* we interpret 9-month-olds' failure to encode the goal of simple head and eye turns that they nonetheless follow (Woodward, 2003)? The possibility suggested here rests on the distinction between perception and attention. Unlike manual actions such as grasping, the goal-directed nature of any particular head and/or eye movement is often ambiguous. Sometimes people turn their head and eyes toward a potential target in order to see it, but sometimes they do so for incidental reasons – they may be turning away from something else or absent-mindedly drifting. Learning to differentiate the different sorts of turns (attentive versus non-attentive) may be difficult for infants. They may initially follow a gaze in an attempt to interpret the behavior, but in the face of uncertainty, fall short of attributing attention to it. It may take until infants are closer to 12 months of age, with an additional 3 months of experience, before they can reliably recognize simple head turns performed in experimental isolation as goal-directed.

More general implications

Infants make a variety of other 'mistakes' in their productive gaze-following behaviors as well, sometimes following when an adult would not, or not following when an adult would. As previously mentioned, until about 12 months, infants typically follow head movements rather than eye movements, even if the eyes are closed or occluded; or if the eyes move without any head movement, infants will often not follow at all (Brooks & Meltzoff, 2002, 2003; Corkum & Moore, 1998). In addition, infants are reluctant to follow another's gaze toward empty space (Flom *et al*., 2004) and they will often fixate on the wrong target if more than one candidate target is present (Butterworth & Jarrett, 1991).

These failures could be taken to suggest that infants (1) do not attribute vision to the viewer, and (2) therefore do not attribute either perception or attention to the viewer. However, while the first point may be correct, the second need not follow. Both historical and developmental evidence includes cases in which an organism's ability to perceive its world was recognized before the modality of that perceptual ability was identified. In the history of science, the electromagnetic sensors of platypi is one such example. Early observers of the platypus recognized that its feeding behavior underwater in opaque mud was perceptually guided, but the identity of the responsible sense organ remained a mystery until recently (Burrell, 1927; Pettigrew, Manger & Fine, 1998). The sonar of bats is another example.

Developmentally, recent work by Johnson and Ma (2005) suggests that scientists are not the only ones capable of recognizing an organism's ability to perceive in the absence of an identified perceptual organ/system; 5-year-olds can do it too. Five-year-olds shown videotapes of a novel, featureless animate agent interacting with an adult, explained the novel agent's behavior as perceptually guided, while simultaneously acknowledging that they did not know how the perception was accomplished – explicitly denying that it had eyes, ears, or the ability to touch.

Finally, Johnson and colleagues have shown that even infants may do this. In several studies infants were given the opportunity to observe a novel, faceless agent interact with an adult or even with the infants themselves. When the agent then shifted its 'attention' to another object in the room, infants followed its directional orientation as though following its gaze, despite the absence of any recognizable perceptual organs (Johnson, 2003, under review; Johnson, Slaughter & Carey, 1998). In one recent study, infants used the specific geometric relationship between the agent's behavior and its environment to infer the location of its perceptual organs. When the geometric relationship changed, infants' inferences about the location of the agent's perceptual organs changed (Johnson, under review).

Given these historical and developmental arguments, as well as the results of the current study, the 'mistakes' of younger infants in gaze-following situations may be better understood as reasonable behaviors based on the attribution of a relatively underspecified perceptual/attentional ability to human and non-human agents alike. Further work is required to understand more fully the form such an attribution might take.

This raises one important caveat about the current study. In principle, goals and perceptions are thought to have complementary directional influences. Agents act on the world via goals, but the world acts on agents via perception. In practice, it may be that one attribution is never detected without the other. Nonetheless, without this distinction, evidence for the two mental states is in danger of collapsing on each other. The current study documents 9-month-old infants' ability to treat head and eye turns as goal-directed. While this may well reflect an attribution of attention/perception by the infants, additional research is needed to document for certain that infants recognize the perceptual aspect of the goal-directed behavior; that is, that the state of the world affects the agent. One preliminary piece of evidence comes from new studies by Luo and Johnson (in preparation). Six-month-olds first saw an actor turn to gaze at and grasp one of two potential targets. In test the actor turned and grasped either the new or old target object. Predictably, infants looked longer at trials in which the actor grasped the new object, but only in conditions in which there was an unobstructed line of 'perceptual access' between the actor's head (the presumed locus of the perceptual organs) and both targets in familiarization. That is, the infants acted as though the state of the world affected the agent.

In summary, 9-month-olds successfully encoded the relationship between an actor and the target of her head and eye turns if the turns displayed obvious goal-directedness. By distinguishing between directed perception (i.e. attention) and non-directed perception, this and future studies may further clarify patterns of success and failure in infants' ability to follow and reason about others' gaze.

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