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CHILD DEVELOPMENT

EMPIRICAL ARTICLE

Can 5-month-old infants consider the perspective of a novel eyeless agent? New evidence for early mentalistic reasoning

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Abstract

Is early reasoning about an agent's knowledge best characterized by a mentalistic stance, a teleological stance, or both? In this research, 5-month-old infants ($N = 64$, 50% female, 83% White) saw a novel eyeless agent consistently approach object-A as opposed to object-B. Although infants could always see both objects, a screen separated object-B from the agent. When object-B protruded above the screen, infants interpreted the agent's actions as revealing a preference for object-A over object-B. When object-B did not protrude above the screen, however, infants refrained from attributing such a preference: Consistent with mentalistic accounts, they reasoned that the agent's representation of the scene did not include object-B, and they used the agent's incomplete representation, non-egocentrically, to interpret its actions.

KEYWORDS
infancy, mentalistic accounts, perspective taking, preference task, psychological reasoning, teleological accounts

To make sense of an agent's actions in a scene, we generally consider what information is available to the agent. When this information is less complete than our own, so that the agent is ignorant about critical aspects of the scene, we adopt the agent's perspective to predict, interpret, and respond to the agent's actions. What are the infant roots of this perspective-taking ability? Are infants in the first year of life (henceforth young infants) already able to attribute to an ignorant agent a representation of a scene that differs from their own? When researchers began studying epistemic reasoning in infancy, two types of accounts were proposed that offered different answers to this question (for a recent review, see Scott et al., in press).

According to *mentalistic* accounts, young infants are capable of tracking what information is available to ignorant agents. Mentalistic accounts differ in how they describe these epistemic attributions, from simple registrations dependent on a minimal psychological-reasoning system (two-system accounts; Butterfill & Apperly, 2013; Low et al., 2016; Low & Watts, 2013) to more sophisticated mental states dependent on a psychological-reasoning system akin to that of older children and adults (one-system accounts; Baillargeon et al., 2016; Carruthers, 2013; Leslie et al., 2004; Luo & Baillargeon, 2010). Despite these differences, however, mentalistic accounts agree that young infants possess rudimentary perspective-taking skills: Under some conditions at least, infants are able to recognize that an agent's representation of a scene is less complete than their own, and they then use this incomplete representation, non-egocentrically, to reason about the agent's actions.

In contrast, *teleological* accounts argue that young infants lack any perspective-taking skills. In this view, the cognitive system responsible for reasoning about agents' actions is initially limited to processing physical variables, as opposed to mental states (Csibra et al., 2003; Gergely & Csibra, 2003). When watching an agent act in a scene, infants generate a teleological action explanation that specifies the layout of the scene, the agent's actions, and the end-state the agent achieves. This explanation, together with a core principle of rationality (and its corollaries of consistency and efficiency; Baillargeon et al., 2016; Gergely et al., 1995), is often sufficient to allow infants to predict what the agent will do next (Csibra et al., 2003; Gergely et al., 1995). Difficulties arise, however, when parts of the layout are perceptually accessible to infants but not the agent. Because infants can process only physical variables, they cannot attribute to the agent a separate representation of the layout that is less complete than their own; instead, they rely on their *own* representation of the layout to predict the agent's actions. In this sense, teleological infants' epistemic reasoning is thus non-mentalistic, reality-based, and egocentric. It should be emphasized that this form of egocentrism is different from the more pervasive form Piaget (1954) attributed to infants: Teleological infants can distinguish between themselves and other agents, and they can also distinguish between their actions and those of other agents; their egocentrism is limited to using their representation of the layout of a scene when interpreting the actions of agents in the scene. As Gergely and Csibra (2003) stated, "teleological action explanations make reference to the relevant aspects of reality as those are represented by the interpreting infant herself when observing the action unfold in its situational context" (p. 289). Teleological limitations are gradually overcome in the second year of life as physical variables become incorporated into a more advanced system that is capable of inferring mental states, including epistemic states such as ignorance.

Prior findings

Do young infants possess at least rudimentary perspective-taking skills, as suggested by mentalistic accounts, or do they lack any such skills, as suggested by teleological accounts? Over the past two decades, findings obtained with *agents with eyes* have supported mentalistic accounts: There is now considerable evidence that young infants can distinguish between their own representation of a scene and an ignorant agent's less complete representation. For example, infants aged 6–12 months understand that a human agent may be ignorant about information relevant to a scene (a) if she is absent when critical events occur (Ting et al., 2019; Tomasello & Haberl, 2003; Vouloumanos et al., 2014), (b) if she is present but facing a direction that prevents her from seeing critical objects or events (Liszkowski et al., 2007, 2008; Luo & Johnson, 2009), or (c) if she is present and facing the right direction but her view of critical objects or events is blocked by an opaque barrier (Kim & Song, 2015; Luo & Baillargeon, 2007; Luo & Johnson, 2009). Similar results have also been obtained with non-human agents with eyes (Choi & Luo, 2015; Hamlin et al., 2013; Meristo & Surian, 2013). Together, these results suggest that when reasoning about what visual information is available to agents with eyes, young infants typically apply a simple *line-of-sight heuristic*: An agent with eyes will see an object or an event if and only if it falls within a direct and uninterrupted line of sight.

Findings obtained with *eyeless agents* paint a more complex picture. In studies that have used an eyeless agent in an open scene with no barrier present, young infants typically behave as though they assume that the agent can detect all of the objects in the scene, just as they do themselves (Johnson et al., 2007, 2010; Kanakogi et al., 2013; Kuhlmeier et al., 2003; Luo, 2011; Tauzin & Gergely, 2019). Surprisingly, however, the same appears to be true in studies that have included an opaque barrier (Csibra et al., 1999; Gergely et al., 1995; Hernik & Southgate, 2012). When this barrier stands between an eyeless agent and a target, infants seem to believe that the barrier blocks the agent's *physical* access to the target (i.e., the agent must detour around the barrier to reach the target), but not the agent's *perceptual* access to the target.

To illustrate, in a series of computer-animated experiments (Csibra et al., 1999; Gergely et al., 1995), 9- and 12-month-olds were habituated to an event in which two eyeless agents, a large and a small circle, stood on either side of a much taller barrier. To start, the large circle silently expanded and contracted, the small circle did the same in its turn, and this contingent exchange was then repeated. Next, the small circle jumped over the barrier to join the large circle, and the two circles then repeated their expansion-contraction exchange. In the test events, the barrier was removed, and the small circle approached the large circle either by traveling in a straight line (new-path event) or by jumping as before (old-path event). Infants looked significantly longer at the old-path than at the new-path event, suggesting that (a) they expected the small circle to travel to the large circle via the most efficient path, in accordance with the rationality principle and its corollary of efficiency, and hence (b) they detected a violation when the small circle jumped instead. For present purposes, the key point here concerns the habituation event: Because the barrier was taller than the two circles, it remains unclear, from an adult's perspective, how the circles could detect each other's presence and take turns in their contraction-expansion exchange. How did infants make sense of what they saw? Did they simply use their own representation of the scene to interpret the circles' actions, as teleological accounts would suggest?

In another computer-animated experiment (Hernik & Southgate, 2012), 9-month-olds were familiarized to an event in which an eyeless agent, a block, entered centrally at the top of a monitor and moved toward a tall barrier that stood horizontally at the center of the scene; an inanimate object, object-A, stood in front of one side of the barrier (e.g., the left side), and the block detoured around that side and came to rest against object-A. Across trials, the width of the barrier was changed (e.g., narrow, medium, or wide), and the block always approached object-A efficiently, choosing a detour path that minimized effort. In the test events, the medium barrier was used, object-A was positioned in front of the other side of the barrier (e.g., the right side), and a new object, object-B, now occupied object-A's former position; the block entered as before and either detoured around the same side of the barrier as in the familiarization trials and came to rest against object-B (new-object event) or detoured around the other side of the barrier and came to rest against object-A (old-object event). Infants looked significantly longer at the new-object that at the old-object event, suggesting that (a) they expected the block to approach object-A in its new position, in accordance with the rationality principle and its corollary of consistency, and hence (b) they detected a violation when the block approached object-B instead. For present purposes, the key point here is that because the barrier was taller than the block, object-A, and object-B, it remains unclear, from an adult's perspective, how the block could have known, when entering the scene in the first familiarization trial or the first test trial, what objects were present on the far side of the barrier and where they were located. Did infants simply use their own representation of the scene to predict the block's actions, as teleological accounts would suggest?

Two interpretations

The results described in the preceding section are open to at least two interpretations. One (*dual-stance*) possibility is that young infants adopt different stances when reasoning about agents with eyes and agents without eyes. When observing an agent with eyes, they adopt a mentalistic stance and assume that the agent will see critical objects or events as long as these fall within a direct and unobstructed line of sight; when this condition is not met, they recognize that the agent's information about the scene will be less complete than their own, and they then use this incomplete information to predict, interpret, and respond to the agent's actions. When observing an eyeless agent, however, infants fall back on a teleological stance: They refrain from considering what information may or may not be available to the agent, and they rely on their own representation of the scene to reason about the agent's actions. In this view, the presence of eyes would thus trigger a more mentalistic, less egocentric approach to tracking agents' information about a scene. This interpretation, if true, would have implications for developmental accounts of early epistemic reasoning. For example, it might suggest that the mentalistic and teleological stances are two distinct modes of construal that both emerge early in development and are triggered by distinct contextual cues. Alternatively, it might suggest that infants begin life with a primitive teleological stance and gradually revise it as they learn (among other things) that eyes matter for determining who knows what—first for themselves, then for similar agents (e.g., parents, siblings, other humans), and eventually, through processes of abstraction and generalization, for any agent with eyes (e.g., pets, animated puppets, computer-animated shapes). For highly unfamiliar agents without discernable eyes, however, young infants would revert back to a teleological stance to interpret these agents' actions.

A second (*mentalistic-stance*) interpretation is that young infants possess a single, mentalistic stance, which they apply to agents with eyes, as we have seen, as well as to agents without eyes. In this view, the results in which eyeless agents appeared to know more than they should and approached objects that were hidden from them would need to be explained without reference to a teleological stance. For example, perhaps the infants tested by Gergely, Csibra, and colleagues (Csibra et al., 1999; Gergely et al., 1995) were unsure how to interpret the circles' contingent contraction-expansion exchanges on either side of the barrier and tended to ignore them. After they observed the small circle jump over the barrier and join the large circle in the first few habituation trials, infants could have attributed to the small circle, at the start of subsequent trials, (a) the inference that the large circle was likely to again be present on the far side of the barrier and (b) the goal of joining the large circle. These attributions would have been sufficient to support infants' test responses. As to the infants tested by Hernik and Southgate (2012), perhaps they had difficulty calculating the block's perspective as it entered the scene in each trial. The animations provided a bird's eye-view of the scene, which might have made it challenging for infants to compare the relative heights of the block and barrier. As a result, infants might have incorrectly assumed that the block was tall enough to peer over the barrier and detect what was on the far side.

Was the dual-stance or the mentalistic-stance interpretation correct? To address this question, the present research examined whether young infants might be able, under simple circumstances, to attribute to an eyeless agent a representation of the layout of a scene that was less complete than their own. We reasoned that positive evidence would cast doubt on the dual-stance interpretation, would support the mentalistic-stance interpretation, and, more generally, would demonstrate that young infants can demonstrate non-egocentric perspective taking even when reasoning about novel eyeless agents.

Experiment

We speculated that if young infants did adopt a mentalistic stance toward eyeless agents, they might apply a *line-of-perceptual-access heuristic* similar to the line-of-sight heuristic they used with agents with eyes. Specifically, they might expect an eyeless agent to be able to detect an object as long as a direct, uninterrupted line could be drawn from some portion of the agent to some portion of the object. Given such a heuristic, infants should expect, when an eyeless agent was separated from an object by an opaque barrier, that (a) the agent would be unable to detect the object, and hence would be ignorant about its presence, if no part of it protruded from the barrier (i.e., no direct, uninterrupted line could be drawn from the agent to the object), but (b) the agent would be able to detect the object if it protruded from the barrier (i.e., a direct, uninterrupted line could be drawn from the agent to the object). In line with these speculations, our research examined whether 5-month-olds would expect an eyeless agent to be ignorant about the presence of an object on the far side of a barrier unless the object protruded from the barrier.

To assess infants' expectations, we built on two prior findings from preference tasks involving agents with eyes. The first finding is that infants aged 5 months and older attribute a preference for object-A to an agent who consistently approaches object-A as opposed to object-B, and they expect the agent to continue acting on this preference when the objects' positions are switched (Ting et al., 2021; Woodward, 1998). The second finding is that this effect is eliminated if the agent cannot see object-B: If object-B is hidden from the agent by a barrier, infants refrain from attributing a preference for object-A to the agent (Kim & Song, 2015; Luo & Johnson, 2009). In line with these findings, we devised a preference task involving an eyeless agent. In the familiarization trials, the agent stood between object-A and object-B and consistently approached object-A. An opaque barrier separated object-B from the agent, and object-B was either shorter (*hidden-object* condition) or taller (*protruding-object* condition) than this barrier (object-A and object-B were always visible to infants). In the test trials, the barrier was removed, the objects' positions were switched, and the agent approached either object-A (*old-object* event) or object-B (*new-object* event). Finding that infants in the protruding-object condition looked significantly longer at the new-object than at the old-object event, whereas infants in the hidden-object condition looked equally at the events, would indicate that infants (a) attributed to the agent a preference for object-A over object-B when both objects were perceptually accessible to the agent, but (b) refrained from attributing such a preference when object-B was not perceptually accessible to the agent. This last finding, in particular, would demonstrate that infants could attribute to a novel eyeless agent a representation of a scene that was less complete than their own, supporting the mentalistic-stance interpretation.

METHOD

Design

Our experiment was adapted from that of Luo and Baillargeon (2005). Infants faced a puppet-stage apparatus and received two orientation trials, four familiarization trials, one display trial, and two test trials (Figure 1; for photos depicting the initial scene in each trial and condition, see SuppInfo.pdf). In

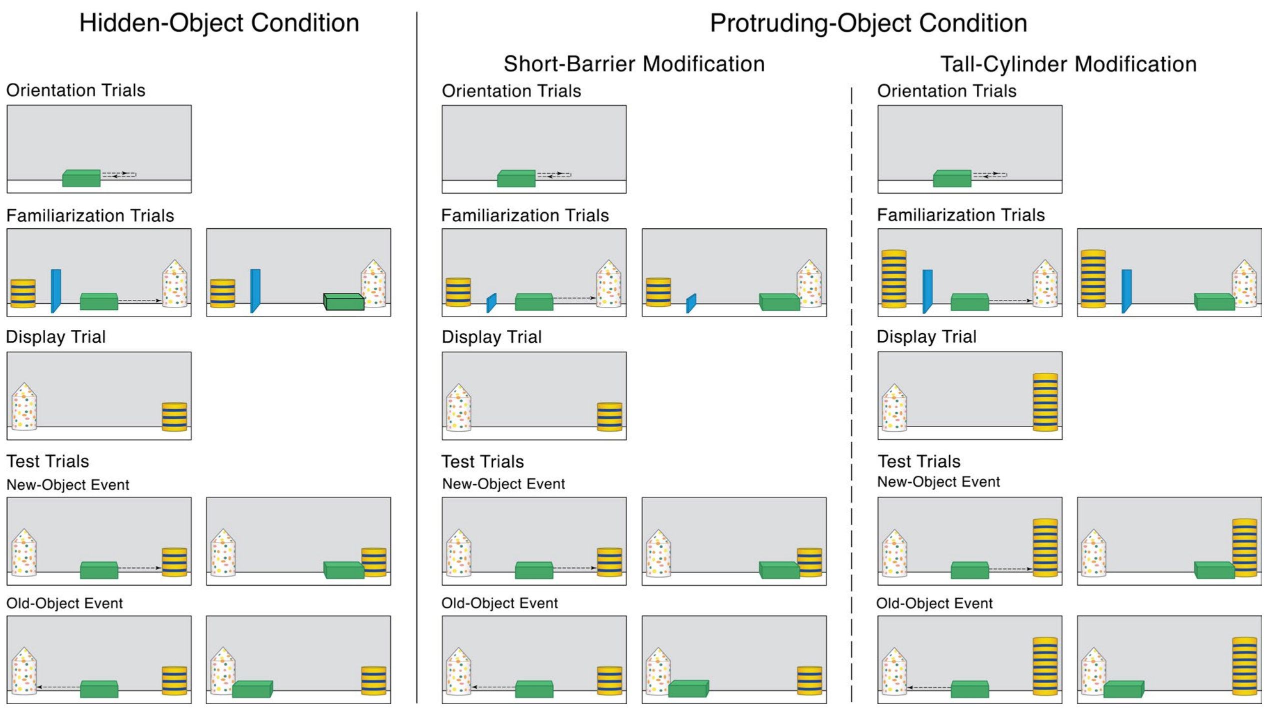

FIGURE 1 Schematic drawing of the events shown in the hidden-object condition and in the short-barrier and tall-cylinder modifications of the protruding-object condition

the *orientation* trials, a rectangular box (5.5 cm tall) moved back and forth (21 cm each way) at the center of the apparatus, starting from the left in the first trial and from the right in the second trial; each full cycle lasted 6 s, and cycles were repeated until the trial ended (see Procedure for criteria). At the beginning of each *familiarization* trial in the hidden-object condition, a striped cylinder (13.5 cm tall) and a dotted cone (23 cm tall) stood on the left and right sides of the apparatus, respectively, with the box centered between them. A tall barrier (20.5 cm tall) stood halfway between the box and the cylinder, and no part of the cylinder protruded above the barrier, relative to the box (this lateral arrangement of the cylinder and barrier made it easy for young infants to compare their heights). The familiarization trials in the protruding-object condition were similar except that the cylinder now protruded above the barrier. This was achieved in one of two ways, by modifying the height of either the barrier or the cylinder. For infants in the *short-barrier* modification, the barrier was now 6.5 cm, instead of 20.5 cm; for infants in the *tall-cylinder* modification, the cylinder was now 27.5 cm, instead of 13.5 cm. This conservative design kept the hidden-object and protruding-object conditions as similar as possible, by modifying only one stimulus at a time. In each modification, about 7 cm of the cylinder protruded above the barrier (short-barrier: 6.5 cm barrier and 13.5 cm cylinder; tall-cylinder: 20.5 cm barrier and 27.5 cylinder).

In the *display* trial, the barrier was removed, and the objects' locations were switched; this trial helped infants register these changes in advance of the test trials. Finally, in the *test* trials, the box approached either the cone (*old-object* event) or the cylinder (*new-object* event) in a 3-s pretrial and then paused until the trial ended. Test order was counterbalanced in each condition.

The dual-stance interpretation predicted that because the box was an eyeless agent, infants would adopt a teleological stance to explain its actions and, as a result, would respond *similarly* in the two conditions. In the familiarization trials, infants should bring to bear their own representation of the layout of the scene (which included the cylinder and the cone), and they should notice that the end-state of the box's actions always involved the cone as opposed to the cylinder. This teleological action explanation, together with the principle of rationality and its corollary of consistency, should be sufficient to allow infants to predict what the box would do when the layout changed in the test trials. Specifically, infants should expect the box to achieve the same end-state as before by approaching the cone in its new position, and they should detect a violation when it approached the cylinder instead. Thus, in both conditions, infants should look significantly longer at the new-object than at the old-object event.

In contrast, the mentalistic-stance interpretation predicted that infants would adopt a mentalistic stance to explain the box's actions and, as a result, would respond *differently* in the two conditions. If infants were able to apply a simple line-of-perceptual-access heuristic to determine which objects the box could detect, then infants in the protruding-object condition should attribute to the box a representation of the layout that was similar to their own and included both the cone and the cylinder. As a result, infants should interpret the box's actions in the familiarization trials as reflecting a preference for the cone over the cylinder, they should expect the box to continue acting on this preference in the test trials, in accordance with the principle of rationality and its corollary of consistency, and they should detect a violation when the box chose to approach the cylinder instead. Infants should therefore look significantly longer at the new-object than at the old-object event. In the hidden-object condition, however, infants should attribute to the box a representation of the layout that was less complete than their own and included only the cone (because no portion of the cylinder protruded above the barrier, the box should be ignorant about the cylinder's presence in the scene). As a result, infants should refrain from attributing to the box a preference for the cone (the box might be repeatedly approaching the cone simply because it believed there was no other object present in the scene). Infants should therefore have no basis for predicting whether the box would approach the cone or the cylinder in the test trials, leading them to look equally at the new-object and old-object events.

In sum, evidence that infants looked significantly longer when the box approached the cylinder as opposed to the cone in the protruding-object condition, but looked equally whether the box approached the cylinder or the cone in the hidden-object condition, would cast doubt on the dual-stance interpretation and support the mentalistic-stance interpretation.

Power analysis

Two previous experiments by Luo and colleagues used a live preference task with a 2 × 2 within-subject design contrasting responses in two conditions to new-object and old-object events. One experiment tested 5-month-olds with an eyeless agent (Luo & Baillargeon, 2005) and yielded a Condition × Event effect size (η_p^2) of 0.224. The other experiment tested 6-month-olds with a human agent (Luo & Johnson, 2009) and yielded a Condition × Event effect size of 0.158. We conducted a G*Power analysis (Faul et al., 2007) using the average of these two values (.191), with alpha set at .05 and power set at .95; as explained in the last section, support for the mentalistic-stance interpretation depended on finding significantly different looking patterns in the hidden-object and protruding-object conditions. This analysis suggested that the minimum number of infants per condition was about 29. Consistent with this estimate, we tested 32 infants per condition, for a total of 64 infants.

Participants

Participants were 64 healthy, term infants (32 female, *M* = 5 months, 10 days, range = 4.24–6.0). Half of the infants were randomly assigned to the hidden-object condition, and half to the protruding-object condition; in the latter condition, 16 infants saw the short-barrier modification, and 16 infants saw the tall-cylinder modification. Another 17 infants were excluded because they were distracted (4), fussy (3), inattentive (2), or drowsy (1); because the difference in their test looking times was over 3 *SD*s from the condition mean (2, one per condition); or because they were difficult to observe (2), produced ceiling looking times (2), or experienced parental interference (1). Infants were tested at university laboratories in two small Midwestern towns; 27 infants (12 in the hidden-object condition and 15 in the protruding-object condition) were tested in Columbia, Missouri, and 37 infants (20 in the hidden-object condition and 17 in the protruding-object condition) were tested in Urbana, Illinois. At each testing location, infants' names were obtained from a university-maintained database of parents interested in participating in child-development research. Overall, about 83% of the infants were White, 9% multiracial, 5% Black, and 3% other; 4% were Hispanic. Parents were contacted by phone calls and emails; they were offered reimbursement for their transportation expenses but were not compensated for their participation. Each infant's parent gave written informed consent, and the protocol was approved by the Institutional Review Boards at the University of Missouri at Columbia and the University of Illinois at Urbana-Champaign.

Apparatus

The apparatus consisted of a display booth (106 cm high × 101 cm wide × 47 cm deep, in each laboratory) with a large front opening; between trials, a curtain was lowered to cover this opening. The side walls were painted white and the back wall and floor were covered with pastel adhesive paper. A muslin-covered window in each side wall was used to introduce, move, or remove stimuli between trials. The box (5.5 × 18 × 15.5 cm) was green and had a hidden rod at the back that extended under the back wall and was used by a hidden experimenter to move the box; the handle fit into a linear groove that was lined with felt and had adjustable stops, to ensure that the box moved smoothly and quietly along the correct path in each trial. The two objects were 11.5 cm in diameter. The cone was white with pastel dots; its cylindrical portion was 16.5 cm tall and its cone portion was 6.5 cm tall, for a total height of 23 cm. The cylinder was yellow with blue horizontal stripes and was either 13.5 or 27.5 cm tall. The barrier was light blue, 28 cm wide, 0.5 cm thick, and either 6.5 cm or 20.5 cm tall; small supports helped keep it upright. For 7/32 infants in the hidden-object condition, the box had a V-shaped ornament on its top; the combined height of the box and ornament was still 5 cm shorter than the barrier, and comparison of the test data collected with and without the ornament revealed no significant differences.

Procedure

Each infant sat on a parent's lap, centered in front of the apparatus; parents were instructed to close their eyes during the test trials and to refrain from interacting with their infants. Two hidden observers (naïve about the infant's condition and test order) monitored the infant's looking behavior; looking times recorded by the primary observer were used for the data analyses. To assess interobserver agreement, each trial was divided into 100-ms intervals; for each interval, the computer determined whether the observers agreed on whether or not the infant was looking at the events shown in the trial. Percent agreement was calculated for each trial by dividing the number of intervals in which the observers agreed by the total number of intervals in the trial. Agreement was calculated for 59/64 infants (only one observer was present for the remaining infants) and averaged 90.34% per trial per infant.

Infants in both conditions were attentive during the 3-s pretrial at the start of each familiarization and test trial ($M = 2.26$ s, $SD = 0.93$). Trials ended when infants (a) looked away for two consecutive seconds after looking for a minimum of 3 (orientation), 2 (familiarization), or 5 (display and test) cumulative seconds or (b) reached a maximum of 60 cumulative seconds. The minimal value of 3 s in the orientation trials corresponded to a half-cycle and allowed infants to register how far the box traveled in each trial; the minimal value of 5 s in the display and test trials allowed infants to continue processing what they were seeing before the trial could end.

To reduce any positive skewness in the test data, all looking times were log-transformed in the analyses (Csibra et al., 2016); for ease of communication, raw looking times are provided in the article. Preliminary analyses of the test data revealed no interaction of condition and event with the infant's testing location, sex, or test order, all $Fs(1, 60) \leq 1.93$, $ps \geq .170$; the data were thus collapsed across the latter three factors.

The results reported below were from confirmatory analyses designed to test the predictions of the dual-stance and mentalistic-stance interpretations; all *p* values were two-tailed, and a p value <.05 was considered statistically significant.

RESULTS

Looking times during the averaged orientation trials, the averaged familiarization trials, and the display trial were analyzed by separate ANOVAs with condition (hidden-object, protruding-object) as a between-subjects factor. This effect was non-significant in all three analyses, all Fs(1, 62) ≤0.38, ps ≥ .539, suggesting that infants in the two conditions looked about equally during these trials (for descriptive statistics, see Table 1; for the raw data, see Dataset in https://mfr.osf.io/render?url=https%3A%2F%2Fosf.io%2Fpf2uy%2Fdownload).

Looking times during the test trials (Figure 2a) were analyzed by an ANOVA with condition (hidden-object, protruding-object) as a between-subjects factor and event (new-object, old-object) as a within-subject factor. The analysis yielded significant main effects of condition, $F(1, 62) = 4.91$, $p = .030$, and event, $F(1, 62) = 5.33$, $p = .024$, as well as a significant Condition × Event interaction, $F(1, 62) = 9.18$, $p = .004$, $\eta_p^2 = 0.129$. Planned comparisons revealed that infants in the protruding-object condition looked significantly longer at the new-object than at the old-object event, $F(1, 62) = 14.24$, $p = .0004$, Cohen's $d = 0.637$, with 25/32 infants showing this pattern. In contrast, infants in the hidden-object condition looked equally at the events, $F(1, 62) = 0.26$, $p = .612$, $d = -0.085$, with only 18/32 infants looking longer at the new-object event. Wilcoxon signed-ranks tests confirmed these results (protruding-object: $Z = 3.22$, $p = .001$; hidden-object: $Z = 0.28$, $p = .779$).

Another ANOVA focusing on the protruding-object condition compared the test responses obtained with the two different modifications (Figure 2b). This analysis had modification (short-barrier, tall-cylinder) as a between-subjects factor and event (new-object, old-object) as a within-subject factor. The analysis yielded only a significant main effect of event, $F(1, 30) = 12.85$, $p = .001$, $\eta_p^2 = 0.300$. Planned comparisons confirmed that infants who saw the short-barrier modification looked significantly longer at the at the new-object than at the old-object event ($F(1, 30) = 5.27$, $p = .029$, $d = 0.516$; 12/16 infants; $Z = 2.07$, $p = .038$), as did infants who saw the tall-cylinder modification ($F(1, 30) = 7.71$, $p = .009$; $d = 0.773$; 13/16 infants; $Z = 2.35$, $p = .019$).

Finally, we also conducted a Bayes factor analysis focusing on the hidden-object condition. Recall that the dual-stance interpretation predicted that infants in that condition would look differentially (experimental hypothesis) as opposed to equally (null hypothesis) at the new- and old-object events. Given the non-significant result of the hidden-object condition, as reported above, a Bayes factor analysis allowed us to assess whether this non-significant result merely failed to reject the null hypothesis or actually provided evidence for the null hypothesis. According to conventional cut-offs, a Bayes factor above 3 indicates at least moderate support for a hypothesis (Beard et al., 2016; Jarosz & Wiley, 2014). We used the Bayes factor calculator for paired t-tests developed by Rouder et al. (2009; http://pcl.missouri.edu/bayesfactor). This calculator provides an output for the Jeffreys-Zellner-Siow (JZS) prior, which combines the Jeffreys prior on variance and a Cauchy (scale 0.707) prior distribution on the standardized effect size mu_diff/sigma_diff. We obtained a Scaled JZS Bayes factor of 4.65 in favor of the null hypothesis, indicating that the data of the hidden-object condition were over four times more likely to occur under the null hypothesis than under the experimental hypothesis. This result provided additional evidence against the dual-stance interpretation and for the mentalistic-stance interpretation.

DISCUSSION

Infants in the protruding-object condition looked significantly longer at the new-object than at the old-object event, whereas infants in the hidden-object condition looked equally at the events. These results suggest that infants applied a simple line-of-perceptual-access heuristic in the familiarization trials to determine which objects the eyeless box could detect. When the cylinder did not protrude from the barrier (i.e., no direct, uninterrupted

TABLE 1 Mean looking times (in seconds) and standard deviations (in parentheses) during the averaged orientation trials, the averaged familiarization trials, the display trial, and the new-object and old-object events shown in the test trials, per condition and modification

				Test trials	
	Orientation trials	Familiarization trials	Display trial	New-object event	Old-object event
Hidden-object condition					
Overall	40.73 (16.64)	18.79 (10.33)	14.64 (10.19)	19.43 (14.78)	20.95 (15.10)
Protruding-object condition					
Overall	38.65 (16.92)	17.95 (10.19)	13.58 (10.07)	19.14 (16.44)	11.28 (8.93)
Short-barrier modification	37.44 (19.15)	16.71 (9.58)	13.28 (13.20)	19.97 (18.47)	11.58 (9.63)
Tall-cylinder modification	39.86 (14.89)	19.19 (10.93)	13.88 (5.93)	18.32 (14.69)	10.98 (8.48)

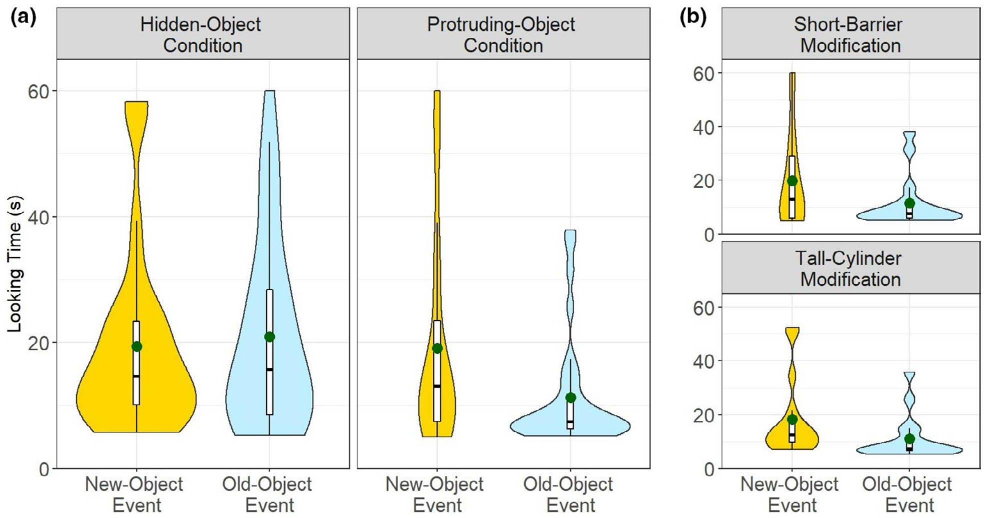

FIGURE 2 Violin plots showing infants' looking times at the new-object and old-object test events in the hidden-object and protruding-object conditions (a), and in the short-barrier and tall-cylinder modifications of the protruding-object condition (b). Dots represent means. The width of the shaded area represents the proportion of looking times observed at each value, smoothed by a kernel density estimator. Overlaid on each violin plot is a boxplot with a box ranging from the 25th to the 75th percentile, a line drawn at the median, and whiskers extending up to 1.5 times the interquartile range

line could be drawn from the box to the cylinder), infants assumed that the box could detect the cone but not the cylinder—even though both objects were visible to them. They then refrained from interpreting the box's repeated actions toward the cone as revealing a preference for that object, leaving them with no basis for predicting whether the box would approach the cone or the cylinder in the test trials. However, when the cylinder protruded from the barrier (i.e., a direct, uninterrupted line could be drawn from the box to the cylinder, either because the barrier was now shorter or because the cylinder was now taller), infants assumed that the box could detect both the cylinder and the cone. As a result, they interpreted the box's repeated actions toward the cone as reflecting a preference for that object over the cylinder, they expected the box to continue acting on this preference in the test trials, and they found it unexpected when it approached the cylinder instead.

Our research demonstrates that infants in the first half-year of life engage in perspective taking even with a novel eyeless agent: When the agent's representation of a scene is less complete than their own, they use the agent's incomplete representation, non-egocentrically, to interpret its actions. These results extend those described in the Introduction involving agents with eyes (Choi & Luo, 2015; Hamlin et al., 2013; Kim & Song, 2015; Liszkowski et al., 2007, 2008; Luo & Baillargeon, 2007; Luo & Johnson, 2009; Meristo & Surian, 2013; Ting et al., 2019, 2021; Tomasello & Haberl, 2003; Vouloumanos et al., 2014), and they provide converging evidence that early epistemic reasoning is both mentalistic and non-egocentric. Together, these results make clear that mentalistic accounts provide a more accurate characterization of early epistemic reasoning than do teleological accounts. There is some degree of confusion in the field as to how mentalistic and teleological accounts differ, and we hope that by carefully laying out the diverging predictions from each type of account for the simple epistemic-reasoning task used here, our research can help bring more clarity to discussions of these accounts.

Our results also suggest several interesting directions for future research. First, it would be useful to contrast, under similar experimental conditions, infants' use of a *line-of-sight* heuristic with non-human agents with eyes, and their use of a *line-of-perceptual-access* with identical but eyeless agents. One possible design is suggested by a report by Meristo and Surian (2013) in which 10-month-old infants were presented with computer-animated events involving geometric shapes with eyes. Infants were first familiarized with two events. In one, a fair distributor divided two items equally between two recipients, and in the other, an unfair distributor gave both items to the same recipient. In the *short-barrier* condition, a bystander stood at the back of the scene behind a short barrier and observed these distributions: Its eyes were visible over the barrier. In the *tall-barrier* condition, the barrier was slightly taller and the bystander did not observe the distributions: Only the portion of the bystander above its eyes was visible over the barrier. In the test trials, the bystander faced the two distributors and gave one of them a treat. Infants in the short-barrier condition expected the fair distributor to receive the treat, whereas infants in the tall-barrier condition held no expectation about which distributor would receive the treat. Our results suggest that if the agents in this report were replaced with eyeless agents, infants in both conditions would now expect the fair distributor to receive the treat. As long as a direct, uninterrupted line could be drawn from the eyeless bystander to the events, infants should expect the bystander to be informed about who was fair and who was unfair and to act accordingly.

A second research direction will be to explore other facets of infants' reasoning about perceptual access for eyeless agents. For example, at the heart of the line-of-perceptual-access heuristic is the assumption that eyeless agents cannot detect objects *through* barriers and other opaque surfaces (in our research, it was because infants assumed that the box could not detect the cylinder through the barrier that they considered whether the cylinder protruded from the barrier). How might infants come by such an assumption? One possibility is that it is derived from infants' own perceptual experiences. Everyday life provides infants with extensive evidence that they cannot detect objects through opaque surfaces; over time, processes of abstraction and generalization could bring infants to extend this limitation to other agents, including novel eyeless agents. Another possibility is that this assumption is a default property of the psychological-reasoning system. Over the course of evolution, the fight for survival could have led to the emergence of a broad assumption that agents generally cannot detect objects through opaque surfaces, allowing predators to approach stealthily, prey to hide, animals to cache food, and so on. Another facet of perceptual access to explore will be whether infants reason differently about eyeless agents with and without a front-back structure. It may be that when an eyeless agent has no discernable front-back structure, infants assume that the agent can detect any object around it, in a sort of globe of perceptual access, as long as a direct, uninterrupted line can be drawn from the agent to the object (this might also be true for adults, at least in some cases; for example, we might expect the Whomping Willow in the Harry Potter movies to be able to detect birds approaching it from any direction). In contrast, when an eyeless agent has a front-back structure (Deligianni et al., 2011; Johnson et al., 2008), infants may expect the agent to detect an object only if a direct, uninterrupted line can be drawn from the *front* of the agent to the object. A simple test of these speculations would be to examine whether infants expect an eyeless agent without a front-back structure to be able to detect an object that is located *behind* it (from infants' perspective), but expect an agent with a front-back structure to be unable to do so (for related findings with a human agent, see Luo & Johnson, 2009).

Third, our results have implications for the studies discussed earlier in which eyeless agents seemed aware of objects hidden from them by opaque barriers (Csibra et al., 1999; Gergely et al., 1995; Hernik & Southgate, 2012). In addition to the alternative explanations mentioned in the Introduction, another intriguing possibility is that infants might be willing to *suspend* their default assumption that agents cannot detect objects through opaque surfaces if given sufficient evidence to the contrary. Thus, upon seeing the large and small circles engage in contingent expansion-contraction exchanges despite the tall barrier between them, infants might have inferred that the two circles could somehow detect each other, through some unspecified form of perceptual access (e.g., sounds too faint to hear). From this perspective, the finding that whereas 9-month-olds succeeded at the task, 6-month-olds did not (Csibra et al., 1999) might suggest that the ability to suspend the default assumption that opaque surfaces typically block perceptual access is an ability that develops over the second half-year of life, perhaps as infants accumulate a wide range of perceptual experiences. Lacking this ability, the 6-month-old infants in the study would have been unable to make sense of the circles' contingent exchanges, and, as a result, they might have refrained from forming any expectations about the circles' actions across trials. Tentative support for this analysis comes from two experiments. In one (Csibra, 2008), 6-month-olds were first familiarized with a computer-animated event in which an eyeless agent, a short box, detoured around either side of a barrier to reach an inanimate target that protruded above the barrier. In the test trials, the barrier was removed, and infants now expected the agent to move to the target via a straight path. Thus, when these young infants were shown a physical layout conceptually similar to that of the protruding-object condition in the present research, they had no difficulty forming expectations about the agent's actions. In another experiment (Liu & Spelke, 2017), 6-month-olds succeeded at a task similar to that of Csibra et al. (1999) when the habituation event was modified so that the large circle was replaced with an inanimate target and the small circle, who now had eyes, faced this target until the barrier dropped down between them. Here again, 6-month-old infants had no difficulty forming expectations about the agent's actions when there was no ambiguity about its perceptual access to the target.

Finally, and more generally, our results provide new evidence that infants in the first year of life can flexibly process an agent's representation of a scene and block out (e.g., using some form of masking mechanism) critical information that is not available to the agent (Baillargeon et al., 2010; Luo & Baillargeon, 2010). In our task, 5-month-old infants blocked out an object that an eyeless agent could not detect. In other tasks, 5- to 12-month-olds blocked out objects that an agent with eyes could not see (Kim & Song, 2015; Luo & Baillargeon, 2007; Luo & Johnson, 2009; Ting et al., 2021). In yet other tasks, infants behaved as though they recognized that objects or agents might be hidden from *them*. For example, when an experimenter looked behind an opaque barrier with expressions of excitement, 12-month-olds peeked around the barrier to see what the experimenter could see (Moll & Tomasello, 2004); when a small circle traveling along a narrow path jumped over an area occluded by a barrier, 12-month-olds inferred that an obstacle behind the barrier must be blocking the circle's path (Csibra et al., 2003); and when an inanimate object was thrown from behind a barrier, 7- to 12-month-olds inferred that an agent behind the barrier must have thrown the object (Saxe et al., 2005, 2007). Together, these various reports demonstrate young infants' remarkable flexibility in processing representations: They can block out objects that are hidden from others as well as posit objects or agents that are hidden from them.

In sum, 5-month-old infants in the present experiment tracked what information was available to a novel eyeless agent in a scene; when they judged that the agent was ignorant about a critical aspect of the scene, they appropriately adopted the agent's perspective to interpret its actions. Our experiment used an unusually large sample for an infant-cognition experiment (with 32 infants per condition), and frequentist and Bayesian analyses of the data supported the same conclusion. Our results thus provide new and compelling support for a highly abstract, mentalistic, and non-egocentric characterization of early psychological reasoning.

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