Received: 24 October 2022 | Revised: 21 September 2023 | Accepted: 26 September 2023

DOI: 10.1111/desc.13453

Developmental Science WILEY

RESEARCH ARTICLE

Infants rationally infer the goals of other people's reaches in the absence of first-person experience with reaching actions

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Funding information
NSF Graduate Research Fellowship, Grant/Award Number: F32HD103363; Defense Advanced Research Projects Agency, Grant/Award Number: CW3013552; Siegel Foundation; National Science Foundation, Grant/Award Number: CCF-1231216; Social Sciences and Humanities Research Council of Canada, Grant/Award Number: 752-2020-0474

Abstract

Does knowledge of other people's minds grow from concrete experience to abstract concepts? Cognitive scientists have hypothesized that infants' first-person experience, acting on their own goals, leads them to understand others' actions and goals. Indeed, classic developmental research suggests that before infants reach for objects, they do not see others' reaches as goal-directed. In five experiments ($N = 117$), we test an alternative hypothesis: Young infants view reaching as undertaken for a purpose but are open-minded about the specific goals that reaching actions are aimed to achieve. We first show that 3-month-old infants, who cannot reach for objects, lack the expectation that observed acts of reaching will be directed to objects rather than to places. Infants at the same age learned rapidly, however, that a specific agent's reaching action was directed either to an object or to a place, after seeing the agent reach for the same object regardless of where it was, or to the same place regardless of what was there. In a further experiment, 3-month-old infants did not demonstrate such inferences when they observed an actor engaging in passive movements. Thus, before infants have learned to reach and manipulate objects themselves, they infer that reaching actions are goal-directed, and they are open to learning that the goal of an action is either an object or a place.

KEYWORDS
action understanding, cognitive development, goal attribution, infancy, online testing, open materials and data

Highlights

- In the present experiments, 3-month-old prereaching infants learned to attribute either object goals or place goals to other people's reaching actions.
- Prereaching infants view agents' actions as goal-directed, but do not expect these acts to be directed to specific objects, rather than to specific places.
- Prereaching infants are open-minded about the specific goal states that reaching actions aim to achieve.

1 | INFANTS RATIONALLY INFER THE GOALS OF OTHER PEOPLE'S REACHES IN THE ABSENCE OF FIRST-PERSON EXPERIENCE WITH REACHING ACTIONS

To communicate and cooperate, we must discern the goals underlying others' actions (Gweon, 2021; Jara-Ettinger et al., 2016; Tomasello et al., 2005). In observing people's actions, adults often can infer their goals. When we observe an act of reaching and grasping an object, for example, we infer that the actor's goal is to act on the object; when we observe an act of walking, we infer that the actor's goal is to arrive at some place. Knowledge of the diverse actions that agents can perform, and the diverse goals that they seek to achieve, supports our understanding of people's minds and behavior. Here, we explore the foundations of goal attribution through studies of human infants' understanding of acts of reaching that they cannot yet perform.

1.1 | Infants' understanding of reaching

Psychologists have probed early capacities for goal attribution by presenting infants with a person who reaches for one of two objects (e.g., a bear on the left over a ball on the right). To test whether infants encode that object as the person's goal, researchers measure infants' attention to subsequent reaching after a change in the objects' locations. In classic research, Woodward (1998) found that 6- and 9-month-old infants looked longer when the person reached to the same place for a different object than when she reached to a different place for the original object. Because infants look longer when they detect significant changes in the environment, these findings provided evidence that by 6 months of age, infants view another person's reaches as directed to particular objects rather than to particular places (Biro & Leslie, 2007; Feiman et al., 2015; Luo & Johnson, 2009).

How does this ability arise? For centuries, many scholars have argued that knowledge grows from sensorimotor experience and slowly builds to abstract concepts (Gutas, 2012; Hume, 2003; Locke, 1847). From first-person experience reaching for and manipulating objects, infants may learn the goal structure of others' reaching actions: that other people's reaching is motivated by goals to act on specific objects. Research on 3-month-old infants, who cannot reach for and grasp objects by themselves, has provided evidence that is consistent with this hypothesis. When tested in Woodward's paradigm, 3-month-old infants looked equally following reaches to a different object in the original location and to the original object in a different location (Gerson & Woodward, 2014a, 2014b; Sommerville et al., 2005). After gaining experience reaching, either with age or with first-person action training (via velcro-covered "sticky mittens"), however, infants expected people to reach for the original object. Thus, an understanding of others' goals may arise from first-person action experience (Fogassi et al., 2005; Gallese & Goldman, 1998; Tomasello et al., 2005; von Hofsten, 2004; Woodward, 2009b). Through reaching experience, the authors reasoned, infants use their own experienced goals, focused on specific objects, to guide their inferences about others who face those objects.

1.2 | Re-evaluating prereaching infants' capacities for action understanding

The view that infants learn about other people's goals from their own experienced actions encounters at least two difficulties. The first is conceptual: This view begs the question of how infants come to understand their own goals, if all they experience are sensations of light, sound, and movement (Saxe et al., 2004). The second difficulty is raised by research on action understanding. Many experiments have demonstrated that infants understand the goals of actions that they have never performed, including jumping over a barrier (Csibra, 2003; Gergely et al., 1995), climbing a hill (Hamlin et al., 2007, 2010; Tan & Hamlin, 2022), or reaching over a barrier for an object that stands behind it (Skerry et al., 2013) (see also, Southgate & Begus, 2013). Presented with agents engaging in these actions, infants view the actions as goal-directed, even though months or years will pass before they become capable of performing them.

In studies by Liu et al. (2019), for example, 3-month-old infants observed a person who repeatedly reached over a barrier to contact a ball. In some experiments, the ball changed colors and produced sounds upon contact, as though the person's actions had caused those changes. In a further experiment, the person's hand stopped short of the ball, which lit up and produced sound spontaneously. Next, the barrier was removed, and the person reached for the ball either directly or on the original, now inefficient trajectory. Here, the infants—who had no first-person experience with reaching—expected the person to reach directly only if her action caused changes in the ball. These findings provide evidence that prereaching infants expect actions to be goal-directed and efficient when causal information highlights the goal structure of the reaching action.

These findings also suggest an alternative interpretation for the sticky mittens effect. By using Velcro mittens to interact with objects, infants may learn that contacting an object causes a change in the object: It moves together with the mitten. Consistent with this interpretation, 3-month-old infants who have contacted objects with sticky mittens only look longer to reaches to a different object in Woodward's paradigm when they view an actor who contacts an object while wearing such mittens (Woodward, 2009b). It is possible that prereaching infants will infer that reaching is object-directed, within Woodward's paradigm, if the reaching action causes a change in the object, as in Liu et al. (2019).

Even if reaching has effects on objects, there may be a further reason that prereaching infants have not expected people to continue acting on the same object when the locations of two objects are exchanged: Prereaching infants may not have strong priors that reaching is directed at objects. Instead, prereaching infants may initially be open-minded about what others' goals could be: to act on a specific object based on its form and function, to act on an object based on

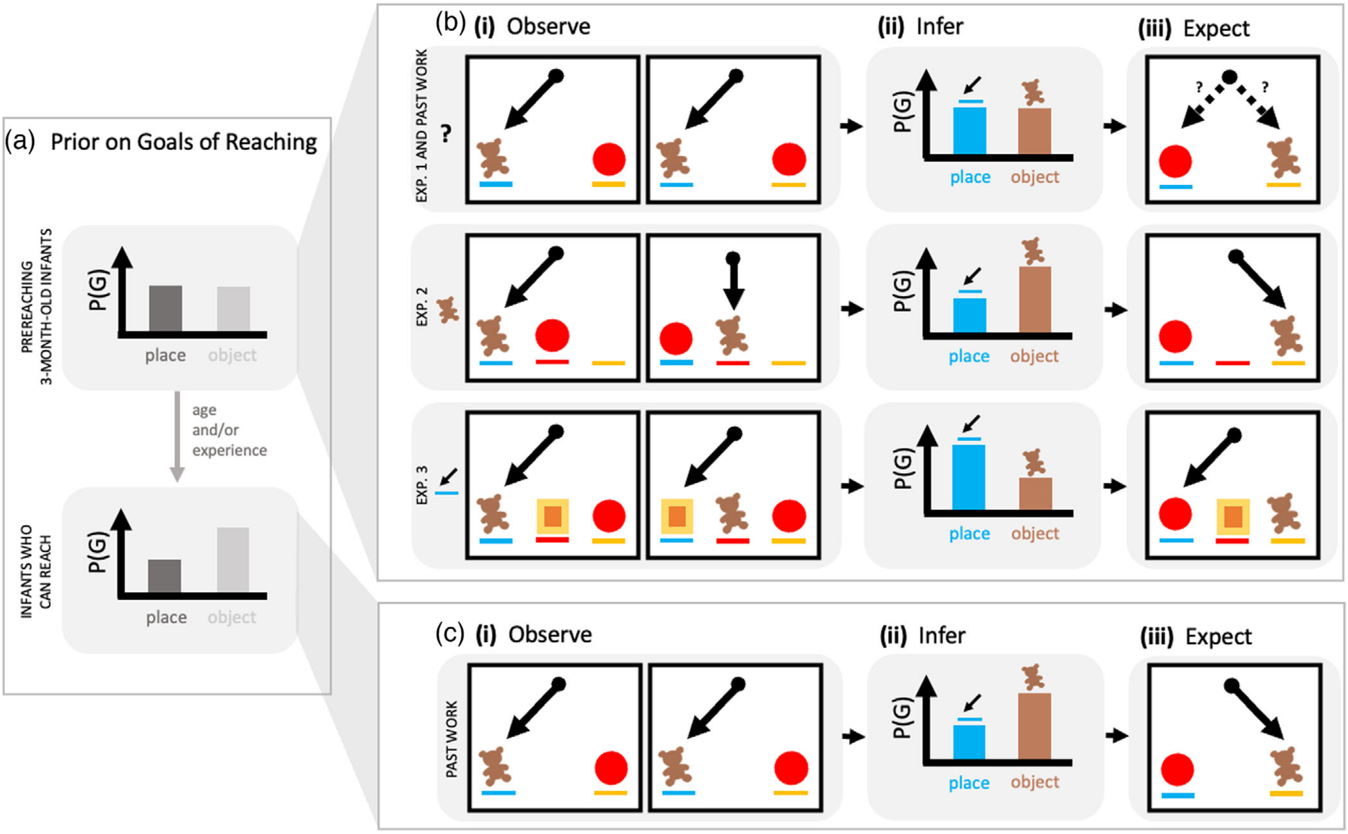

FIGURE 1 Prereaching and reaching infants' possible prior beliefs about the goals of reaching, and the inferences that these beliefs would support when observing others' reaches. (a) Whereas older infants may expect reaching to be directed at objects, prereaching infants may be open-minded about the goals of reaching. (b and c) When observing a person's reaching (i), prereaching infants may infer the relative probability that the person acted with respect to object versus place goals (ii), supporting expectations of future actions (iii). Under this framework, both before and after reaching experience, infants understand people's actions with respect to their goals, but it is their prior beliefs, over what kinds of goals people are likely to have as they act, that drive the differences in their goal inferences (top vs. bottom rows).

its location, or to follow a particular trajectory to a particular location, with no object goal.

In Woodward's paradigm, the actor's action during familiarization is consistent not only with an object goal but with a place goal or a movement goal (Figure 1), because the actor repeatedly reaches not only to the same object but along the same trajectory to the same place. Research shows that older infants expect that particular, distinctive objects, such as a ball rather than a bear, are the most likely goals of reaching actions (Woodward, 1998), whereas specific places, such as the top rather than the bottom of a hill, are the most likely goals of locomotor actions (Hamlin et al., 2007), and specific movements, such as a regular rather than an irregular pattern, are the most likely goals of dancing actions (Schachner & Carey, 2013). Younger infants, however, may find specific objects, places, and movements to be equally plausible goals of any action. As infants observe different actions under conditions that distinguish these possible goals, they may learn that particular kinds of actions, like reaching or walking, typically are directed to specific objects and places, respectively. Developmental scientists have described the ability to incorporate new evidence, together with one's prior beliefs and knowledge, as rational learning (Gopnik & Wellman, 2012; Xu & Kushnir, 2013; see also, Nichols et al., 2016; Perfors et al., 2011; Xu, 2019). Are prereaching infants rational learners of others' goals?

1.3 | Research overview

The present experiments used the causal manipulation of Liu et al. (2019) to examine prereaching infants' abilities to infer the goals of others' reaching actions. We first asked whether 3-month-old infants expect reaches to be directed to objects with specific forms and functions, rather than to objects in specific places, when they observe an agent reaching for objects that light up and change color on contact with her hand. To preview our conclusions, we find no evidence that 3-month-old infants have this expectation. Accordingly, the next four experiments tested the hypothesis that infants infer the specific goals of an individual actor who intentionally reaches for one of two objects based on the evidence that they observe. If prereaching infants are rational learners of others' goals, and they lack strong priors as to whether object, place, or movement goals are most likely to guide others' reaches, then they may attribute any of these goals to an actor when given evidence that distinguishes these goals from one another.

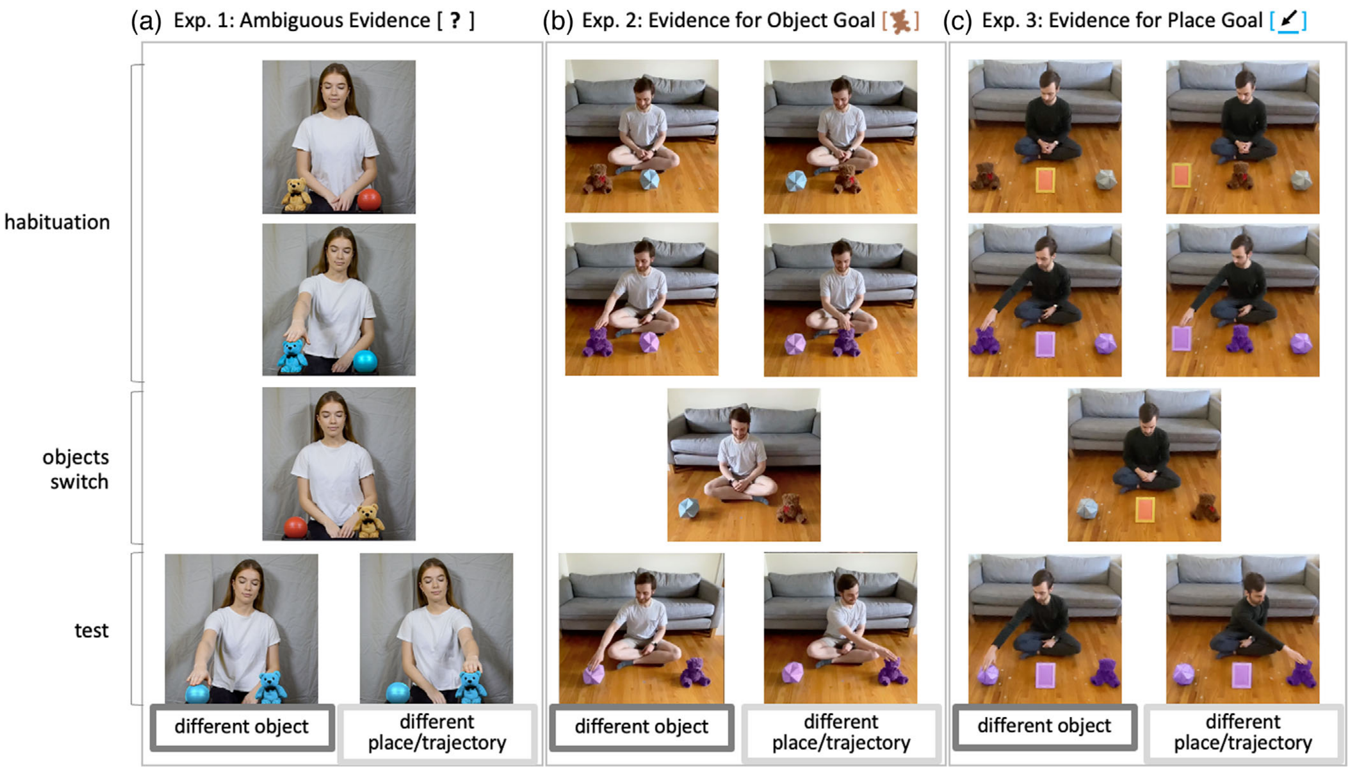

FIGURE 2 Design of Experiments 1–3. During habituation, a person reaches to (a) the same object in the same place, (b) the same object in two different places, or (c) the same place for two different objects. At test, the objects appear in new places, and the person either reaches to a different object or a different place, relative to habituation.

2 | EXPERIMENT 1: AMBIGUOUS EVIDENCE

In Experiment 1, 3-month-old infants were habituated to videotaped events of an actor who repeatedly reached for and contacted one of two objects, always in the same two locations, by moving on the same trajectory (Figure 2a). This paradigm was like Woodward's paradigm, except that both objects changed color and a sound played when the actor contacted the object, indicating that the action caused a change in the object (following Liu et al., 2019), and highlighting the goal structure of the action. Then the objects switched places, and infants' looking time was recorded as the actor alternately reached for each object over six test trials. If 3-month-old infants view reaching actions that cause changes in an object as directed to that specific object, independently of its location, then they should look longer at the test actions on the other object. In contrast, if infants either do not see acts of reaching as goal-directed, or rationally infer that a reaching action can be based either on what an object is or on where it is (Figure 1), then they should look equally at the two test actions.

2.1 | Method

For all experiments, the method and analysis plans were preregistered on the Open Science Framework (OSF) at https://osf.io/ervm3/. Stimuli, data, and code are available on the OSF.

2.1.1 | Participants

All participants were tested with their caregivers' informed consent. All study protocols were approved by the Harvard University Committee on the Use of Human Subjects. Participants received $5 USD and a certificate of participation; in-person participants also received a small prize (e.g., a stuffed animal).

In Experiment 1, twenty 3-month-old infants contributed data (mean age = 3.47 months; range = 3;2-3;29; 8 girls, 12 boys). Three more participants began the experiment but were excluded due to fussiness (n = 1) or experimenter error (n = 2). Experimenters who were naïve to the events seen by participants determined exclusions using preregistered criteria.

Participants were recruited through phone calls or emails to caregivers listed in the laboratory's database of families who had expressed interest in participating (e.g., by responding to mailings or signing up online). In Experiment 1, all participants came from the greater Boston area. About 60% of participants' caregivers completed demographics questionnaires: 42% of these participants were White, 25% were Asian, 17% were Hispanic/Latino, and 17% were multiracial.

Sample size justification

Our sample size was based on a simulated power analysis over pilot data (n = 6), collected with Experiment 1′s methods (see SI).

2.1.2 | Displays

As in Woodward's original experiments, infants were presented with two objects—a bear and a ball—and an actor who reached for one of the objects. The actor's face and upper body were visible behind the center of the stage and appeared in video recordings. Infants received 6 to 14 habituation trials, followed by 6 test trials. In each trial, the actor reached for and touched an object. Upon contact, both objects changed color (to blue) and a bell sounded for 2.1 s, as though the actor's actions had caused these changes in the selected object. Then, the actor retracted their hand (at the 6 s mark), and the objects returned to their original colors as the sound stopped.

Throughout habituation and test, both objects changed color when the actor touched just one object, lest longer looking at a reach to a different object at test be attributable to a novel color change in the other reached-for object. Because 3-month-old infants only see an actor as causing such state changes if their hand physically contacts the object (Liu et al., 2019), infants likely inferred, on each trial, that the object or place that was contacted by the actor was her goal.

Habituation

On each habituation trial, the actor faced two different objects (a brown teddy bear and a red ball) and always reached for one object (the original object) (Figure 2a). Across trials, the object that the actor reached for was always in the same place and the actor's hand always followed the same trajectory to that object (either left or right of the actor). These trials were designed to familiarize infants to reaches that were aimed at a specific object in a specific place.

Test

After habituation, the same two objects exchanged places, relative to habituation. A single familiarization trial depicted the new arrangement of objects, with no reaching. Then, on alternating test trials, the actor reached for the original object in a new location and for the new object in the original location, relative to habituation. We coded infants' looking times, following the actor's reaching, as a measure of infants' expectations for the actor's actions.

2.1.3 | Procedure

Data collection for Experiment 1 was completed before the COVID-19 pandemic in the laboratory. Infants sat in a car seat before a 60 by 40-in. screen, where we projected the movies at the rate of 24 frames per second. Caregivers were seated behind their infants and were instructed not to speak or direct their infants' attention. Within each experiment, the same movie was used for trials that involved the same kind of action (e.g., the actor reaching for the ball on the left). The movies were only played once per trial.

The infants saw the habituation trials until they met the habituation criterion: either the completion of 12 trials or the completion of three consecutive trials in which looking was no more than half as long as on

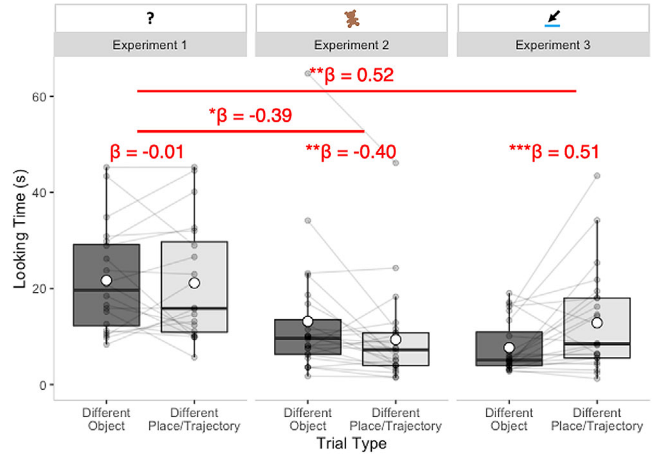

FIGURE 3 Infants' looking to reaches to different objects and places in Experiments 1–3. White circles indicate means, pairs of connected dots indicate data from a single infant, horizontal lines within boxes indicate medians, boxes indicate interquartile ranges, beta coefficients (ß) indicate standardized effect sizes, and asterisks indicate significant differences, corrected for multiple comparisons (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; two-tailed). Looking times were higher in person (Experiment 1) than over video calls (Experiments 2–3) (see SI).

the first three trials (as in Liu et al., 2019; see SI for analyses on habituation data). Then the infants saw the familiarization trial depicting the new arrangement of objects. Lastly, the infants saw the test trials. For all experiments, see SI for counterbalancing.

In all trials, after the actor reached for an object, a bell sounded, and the experimenter (naïve to all events) coded looking time using the program PyHab (Kominsky, 2019) until the end of the trial, when infants either had looked away for 2 consecutive seconds or 45 seconds had elapsed. The experimenter, who could only see the infant's face over video and was naïve to the experimental condition, coded from behind a curtain in the testing room. PyHab served to code looking, controlled the stimulus presentation, and tracked when infants reached the criterion of habituation.

2.2 | Results

All reported *p*-values are two-tailed. The infants looked equally on test trials presenting reaches to a different object ($\text{mean}_{\text{different-object}}$ = 22.00 s; SD = 13.60 s) and a different place ($\text{mean}_{\text{different-place/trajectory}}$ = 22.02 s; SD = 13.87 s) ($\beta = -0.03$, 95% CI of β [−0.35, 0.30], $b = -0.01$, $t[18] = -0.15$, $p = 0.875$; Figure 3). See SI for full model details.

2.3 | Discussion

Despite cues to causal action that support prereaching infants' understanding of action efficiency and goals, the infants did not expect the actor to reach for the original object at test. We next sought to determine whether this and previous null findings are due to a failure to (i) appreciate that reaching is goal-directed, or (ii) determine whether the actor aimed to act on a specific object or a specific place.

3 | EXPERIMENT 2: EVIDENCE FOR AN OBJECT GOAL

Experiment 2 tested whether infants can, with clear evidence, infer that the goal of another person's reaching is a specific object. In Experiment 2, an actor reached for one of two objects that appeared in two alternating places in habituation trials (Figure 2b). At test, the reached-for object appeared at a third place where the actor had never reached, whereas the other object appeared at one of the reached-for places. If 3-month-old infants can represent a specific object as the goal of the actor's reaching action when the actor reaches to the same object, over variation in its location, then the infants may expect reaches for the same object at the new location (Figure 1).

3.1 | Methods

The methods of Experiment 2 were the same as those of Experiment 1, except as follows. Due to the pandemic, we conducted Experiments 2–5 using Zoom video conferencing software. Infants were tested in their homes. Because we were unable to access the original set-up and objects during this phase of the pandemic, we presented new video-recorded events in which an actor sat on the floor of an apartment and reached for a different brown bear and a blue ball. Because the ball was blue, instead of having the objects' colors change to blue as in Experiment 1, the colors changed to purple in Experiment 2.

3.1.1 | Participants

Twenty-four 3-month-old infants contributed data (mean age = 3.42 months; range = 3;00-4;00; 9 girls, 15 boys). Two more participants began the experiment but were excluded due to fussiness. No caregivers reported issues with stimulus presentation that would hinder infants' understanding of the actions.

In Experiment 2, a third of the participants came from the greater Boston area (n = 8). The remaining participants were recruited via ChildrenHelpingScience.org.

Sample size justification
Our sample size was based on a simulated power analysis over pilot data (n = 18), collected with Experiment 2′s methods (see SI).

3.1.2 | Displays

Displays were like those for Experiment 1, except as follows. First, the two objects appeared in three rather than in two places across the experiment: on the left, in the center, and on the right side of the display. Second, because the pandemic precluded filming in Experiment 1′s set-up, the actor sat on the floor of a room, and reached for one of the objects on the room's floor. On the habituation trials (Figure 2b), the actor always reached for the same object, as in Experiment 1, as it alternately appeared on one of the sides of the room and in the middle of the room, over the series of habituation trials, while the other object stood untouched. Thus, relative to Experiment 1, the habituation sequence of Experiment 2 provided evidence that the actor reached to different places for a single object.

On the test trials, the object for which the actor had reached now appeared in a new place, on the side of the room toward which the actor had never reached, and the other object occupied the place on the side of the room where the actor had reached on half the trials. As in Experiment 1, on alternating test trials, the actor reached to a different object or to the same object in a different place, relative to the actor's reaching on the habituation trials.

3.1.3 | Procedure

As data collection took place over video calls, the footage of infants was recorded using Zoom. The frame rate of stimuli was 60 frames per second. In Experiment 2, the infants sat on their caregivers' laps and viewed movies on laptop screens (n = 22) or desktop screens (n = 2) with the computer's webcam focused on the infant's face. Differences in screen size did not influence infant habituation rates or looking times at test in Experiments 2–5 (see SI). In Experiments 2–5, the caregivers were asked to look away during test trials and were instructed to sit quietly and not influence their infants. The caregivers received instructions for setting up their computers (e.g., hiding the videos of themselves and the experimenters). They were asked to report any disruptions to the stimulus presentation.

Habituation trials were presented to each infant until they met the habituation criterion: either the completion of 14 trials or the completion of three consecutive trials in which looking was no more than half as long as on the first three trials. Then the infants saw the familiarization trial depicting the new arrangement of objects. Lastly, the infants saw the test trials.

In the habituation and test trials of Experiments 2–5, after the actor reached for an object, a bell sounded, and the experimenter (naïve to all events) coded looking time using the program jHab (Casstevens, 2007) until the end of the trial, when infants had looked away for 2 consecutive seconds or 120 s had elapsed. We increased the maximum number of habituation trials and the maximum duration of infant-controlled trials, after Experiment 1, to better match the methods of previous experiments using Woodward's paradigm, especially those of Sommerville et al. (2005) (see SI for evidence that this change did not impact findings). We did not use PyHab because the use of Zoom caused delays in PyHab during piloting.

To ensure that the experimenter remained naïve to events throughout the experiment, we used a separate monitor (occluded to the experimenter) to present all the events (Figure S1). A separate researcher renamed the stimulus files, such that the names did not provide information about the counterbalanced variables.

3.2 | Results

Infants looked longer on the test trials in which the actor reached for a different object ($\text{mean}_{\text{different-object}}$ = 13.21 s; *SD* = 16.16 s) than on the trials in which the actor reached to the same object in a different place ($\text{mean}_{\text{different-place/trajectory}}$ = 9.52 s; *SD* = 15.25 s) ($\beta = -0.39$, 95% CI of β [−0.66, −0.13], $b = -0.41$, $t[22] = -2.926$, $p = 0.007$; Figure 3). This finding differed significantly from the null findings of Experiment 1 ($\beta = -0.39$, 95% of β [−0.78, −0.01], $b = -0.40$, $t[63] = -2.00$, $p = 0.049$).

3.3 | Discussion

Experiment 2 provides evidence that prereaching infants can infer, given evidence, that reaches are directed to specific objects. These findings stand in contrast to the null findings of Experiment 1 and of classic research on prereaching infants' capacities for goal attribution. Moreover, they raise a question: Are infants predisposed to infer that an act of reaching is guided by the goal of obtaining a specific object, or would they infer, with equal readiness, that the goal of a particular agent's reaching is to arrive at a specific place? Experiment 3 addressed this question, further testing the possibility that 3-month-old infants are open-minded about others' goals. If the prereaching infants in Experiment 1 did not demonstrate sensitivity to object goals because of a conflicting place goal, then infants should learn to attribute a place goal to a person whose reaches are directed to a specific location.

4 | EXPERIMENT 3: EVIDENCE FOR A PLACE GOAL

In Experiment 3, an actor faced three objects. On alternating habituation trials, he reached to the same place, along the same trajectory, for two different objects (Figure 2c). At test, these two objects now appeared at the other locations, and the third object, which he had never touched, appeared at the original location. If infants can rationally infer that a place is the goal of someone's reaches, then they may expect reaches directed to original location, now occupied by the never-reached-for object (Figure 1).

4.1 | Method

4.1.1 | Participants

Twenty-four 3-month-old infants contributed data to this experiment (mean age = 3.49 months; range = 3;00-3;30; 11 girls, 13 boys). Two more participants began the experiment but were excluded due to fussiness ($n = 1$) or falling asleep ($n = 1$).

In Experiment 3, half of the participants were recruited from our lab database of children who were based in the greater Boston area at the time of their birth ($n = 12$). The remaining participants were recruited via ChildrenHelpingScience.org.

Sample size justification
Our sample size was based on simulated power analyses over pilot data ($n = 12$) and over Experiment 2′s data, with the latter analysis based on the assumption that infants' capacities for inferring object goals and place goals would be similar (see SI).

4.1.2 | Displays

Displays were like those of Experiment 2, except as follows. For Experiment 3′s habituation trials (Figure 2c), the actor faced three objects (a bear, a ball, and a yellow picture frame), and he always reached to objects at one of the side locations (either left or right), following the same trajectory. On alternating trials, two of the three objects appeared at that location. Thus, Experiment 3 aimed to provide infants with evidence that the actor reached for the objects because of where they were.

In the test trials, the third object, which the actor had never reached for, appeared in the original location where the actor had reached during familiarization (on one side of the room), and the two objects that he had previously reached for appeared in the middle and on the opposite side of the room. On alternating test trials, the actor reached to the new place and to the same place for a different object, relative to his reaching in habituation.

4.1.3 | Procedure

Data collection for Experiment 3 took place over Zoom video calls, following the same protocols as in Experiment 2. In Experiment 3, the infants sat in their caregivers' laps and viewed movies on laptop screens ($n = 23$) or a tablet screen ($n = 1$). The habituation criterion and the coding procedures were the same as in Experiment 2.

4.2 | Results

Infants looked longer on the test trials in which the actor reached to a different place ($\text{mean}_{\text{different-place/trajectory}}$ = 13.23 s; *SD* = 13.48 s) than on the test trials in which he reached to the same place as in habituation but for a different object ($\text{mean}_{\text{different-object}}$ = 7.33 s; *SD* = 6.91 s) ($\beta = 0.53$, 95% CI of β [0.22, 0.85], $b = 0.51$, $t[22] = 3.29$, $p = 0.003$; Figure 3). This finding differed significantly from that of Experiment 1 ($\beta = 0.52$, 95% of β [0.14, 0.91], $b = 0.53$, $t[65] = 2.65$, $p = 0.010$). This finding provides evidence that infants inferred, from the actor's actions during familiarization, that the actor's goal was to arrive at a particular place.

4.3 | Discussion

Experiment 3 provides evidence that 3-month-old infants can infer that the goal of an actor's reach is a specific place, rather than a specific object, when the variability in the events provides evidence for this goal. Taken together with the contrasting findings of Experiments 1 and 2, this finding provides evidence that prereaching infants rationally attribute either object goals (as in Experiment 2) or place goals (as in Experiment 3) to agents when the agents' actions support them. In contrast, when an agent reaches to a single place for a single object, infants are open-minded as to whether the agent aims to arrive at a particular object or a particular place (as in Experiment 1).

We recognize, however, that there were methodological differences between Experiment 1 and Experiments 2 and 3, due to the shift to online research: The latter two experiments presented a different actor and objects, in a different setting, due to physical distancing guidelines and building closures. In an effort to elicit comparable levels of attention to the events in Experiments 2 and 3, which were presented on smaller screens in more variable home environments, the latter studies also used a modified habituation protocol. Did infants form goal inferences in Experiments 2 and 3, but not in Experiment 1, because of these differences? Our supplementary analyses (see SI) suggested that the changes to the habituation procedure did not impact the present findings. Nevertheless, we conducted Experiment 4, in part, to test the effects of these procedural differences between Experiment 1 and its successors.

Experiment 4 was conducted for two further reasons. First, it tested an alternative interpretation of infants' performance in Experiment 3. Because the actor remained in one place and reached to one location throughout the habituation sequence, all his reaches to that location followed the same trajectory. Thus, infants' behavior in this experiment may have been based on an analysis of the movement that the actor made rather than the goal that the movement achieved. Adults infer movement goals, rather than place goals, given unambiguous evidence (Schachner & Carey, 2013). In Experiment 4, we therefore asked whether infants can attribute a place goal to an actor over changes in the trajectory by which the actor arrives at his goal.

Second, Experiment 4 tested an alternative interpretation of the null findings of Experiment 1. In Experiment 1, the actor reached with two hands in alternation during the test trials, approaching the two objects with whichever hand was on the same side as the object. In Woodward's classic experiments, in contrast, actors reached with one hand throughout each study, and this procedure was followed, as well, in Experiments 2 and 3. Do younger infants struggle to infer goals when an actor uses two hands rather than one hand to act on objects? To address this question, Experiment 4, presented infants with an actor who reached with both hands in alternation at test, as in Experiment 1. As in Experiment 3, however, he reached for two different objects at a single place.

5 | EXPERIMENT 4: FURTHER EVIDENCE FOR A PLACE GOAL

Experiment 4 adapted the methods of Experiment 3 and investigated 3-month-old infants' abilities to attribute a place goal to an actor who reaches for objects in a particular place by moving on a novel trajectory. On each habituation trial, the actor reached consistently to a single place, along a single trajectory (Figure 4a). Across the habituation trials, he sat on one side of the room (e.g., the left) and reached for the object in front of him, using the hand on that side (in this example, the left) and moving the hand directly forward to contact the object. At test, the actor appeared in the center of the room, and he either reached to the same place for a different object or to a different place (on the other side of the room), using the hand that was nearer to the object on each side, as in Experiment 1. Both test events therefore presented the actor moving along novel trajectories and switching hands. If 3-month-old infants attribute a place goal, independent of trajectory, to an actor who reaches for two different objects in a particular place, then they may expect the actor to reach to the same place as in habituation. If 3-month-old infants do not attribute place goals under these conditions, or if they do not have strong expectations when an actor reaches with different hands on different trials, then they may look equally to the two test events.

5.1 | Methods

5.1.1 | Participants

Twenty-four 3-month-old infants contributed data to this experiment. One infant began the experiment but was excluded due to fussiness. In Experiment 4, a quarter of the participants were part of our lab database of children who were based in the greater Boston area at the time of their birth ($n = 6$). The remaining participants were recruited via ChildrenHelpingScience.org. About 66% of participants' caregivers completed demographics questionnaires: 69% of these participants were White, 13% were Asian, 6% were Black, 6% were Hispanic/Latino, and 6% were multiracial.

To maximize efficiency in recruitment, whenever possible, the same infants participated in Experiments 4 and 5. We randomized the order in which the infants participated in each experiment, and we scheduled these experiments in two separate sessions on different days. Of the 24 infants, 21 also participated in Experiment 5. Eleven of these infants participated in Experiment 4 first, and 10 participated in Experiment 5 first. The infant who was excluded due to fussiness had participated in Experiment 5 first. In both Experiments 4 and 5, the pattern of findings did not differ depending on whether an infant had already participated in the other experiment first (see SI).

Sample size justification

Our sample size was based on simulated power analyses over pilot data ($n = 5$) and over Experiment 3's data, with the latter analysis based

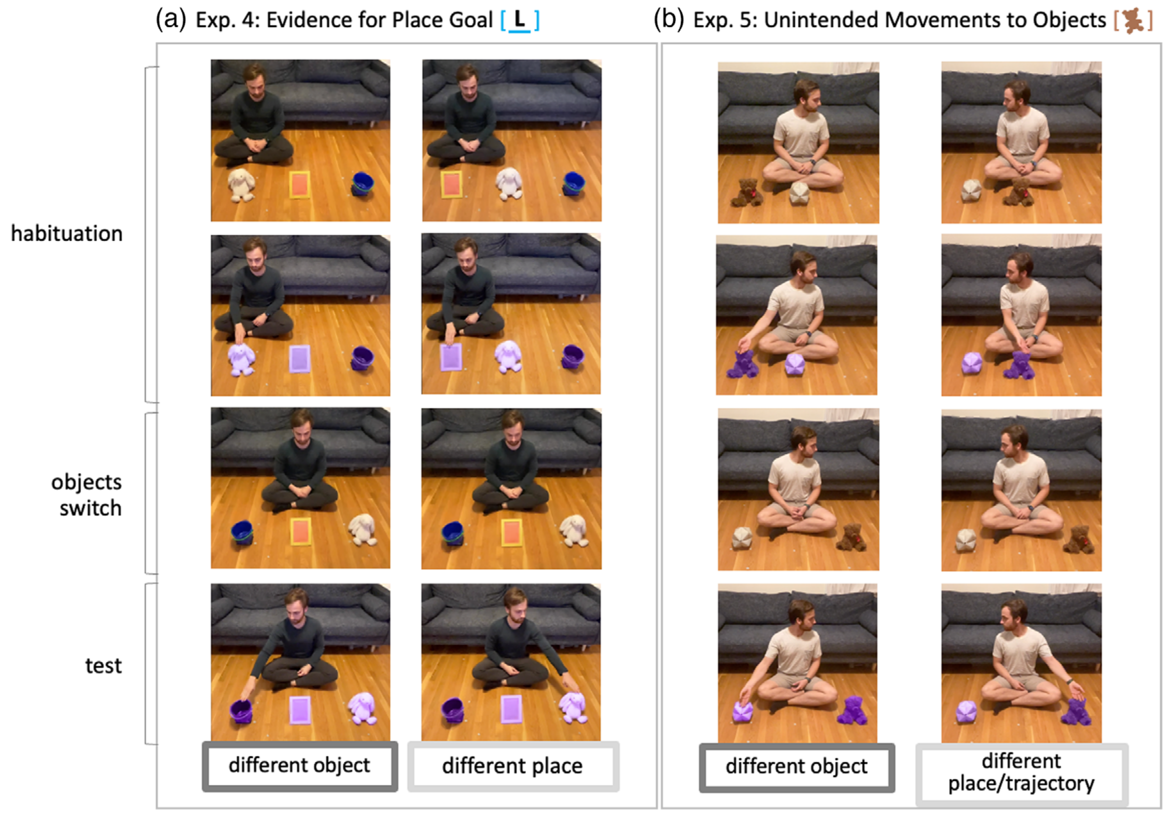

FIGURE 4 Design of Experiments 4 and 5. During habituation, a person's hand (a) reached to the same place for two different objects or (b) passively fell on the same object in the same place. The objects changed color upon contact, as in Experiments 1 to 3. At test, the objects appeared in new places, and the person alternately contacted a different object or an object at a different place, relative to habituation. In Experiment 5, both test events involved moving along different trajectories.

on the assumption that infants' capacities for inferring place goals in Experiments 3 and 4 would be comparable (see SI).

5.1.2 | Displays

Displays were like those of Experiment 3, except as follows. First, the actor sat on one of the two sides of the room during the habituation sequence, rather than in the center. During the familiarization trial and at test, in contrast, the actor sat at the center of the room. At test, he reached, in alternation, for the objects on the two sides of the room, using the hand on the same side of the room as the object for which he was reaching, and moving the hand on a diagonal trajectory rather than directly forward. All the test trials therefore presented acts of reaching with each hand. Moreover, the test trials presented reaches to familiar and novel places on novel trajectories. The experiment therefore dissociated the effects of changes in the place to which the actor reached from changes in the path over which the actor moved.

Because the same infants participated in Experiments 4 and 5, we used a different set of objects in each experiment. In this experiment, the objects were a picture frame (as in Experiment 3), a stuffed rabbit, and a toy bucket. In Experiment 5, by contrast, (see below) the actor acted on the paper ball and teddy bear from Experiments 1–3. Because the same actor appeared in both experiments, the change in objects minimized the chance that participants' expectations in the first experiments would generalize to the second experiment (see SI).

5.1.3 | Procedure

Except as noted in the "Displays" section, the procedure was like that of Experiment 3. All the infants in Experiment 4 viewed the movies on laptop screens.

5.2 | Results

Because the same actor reached to the same places in Experiments 4 and 5, we analyzed whether place information in one experiment influenced infants' looking in the next experiment. Across experiments, we found no such influence (see SI).

In Experiment 4, infants looked longer during the test trials in which the actor reached to a different place ($mean_{different\text{-}place}$ = 14.99 s; SD = 19.48 s) than those in which the actor reached to the same place as in habituation but for a different object ($mean_{different\text{-}object}$ = 9.25 s; SD = 8.58 s) (β = 0.35, 95% CI of β [0.04, 0.66], b = 0.34, $t[22]$ = 2.23, p = 0.036; Figure 5a). This effect was no weaker than that of Experiment 3 (β = −0.19, 95% of β [−0.61, 0.23], b = −0.18, $t[44]$ = 2.50,

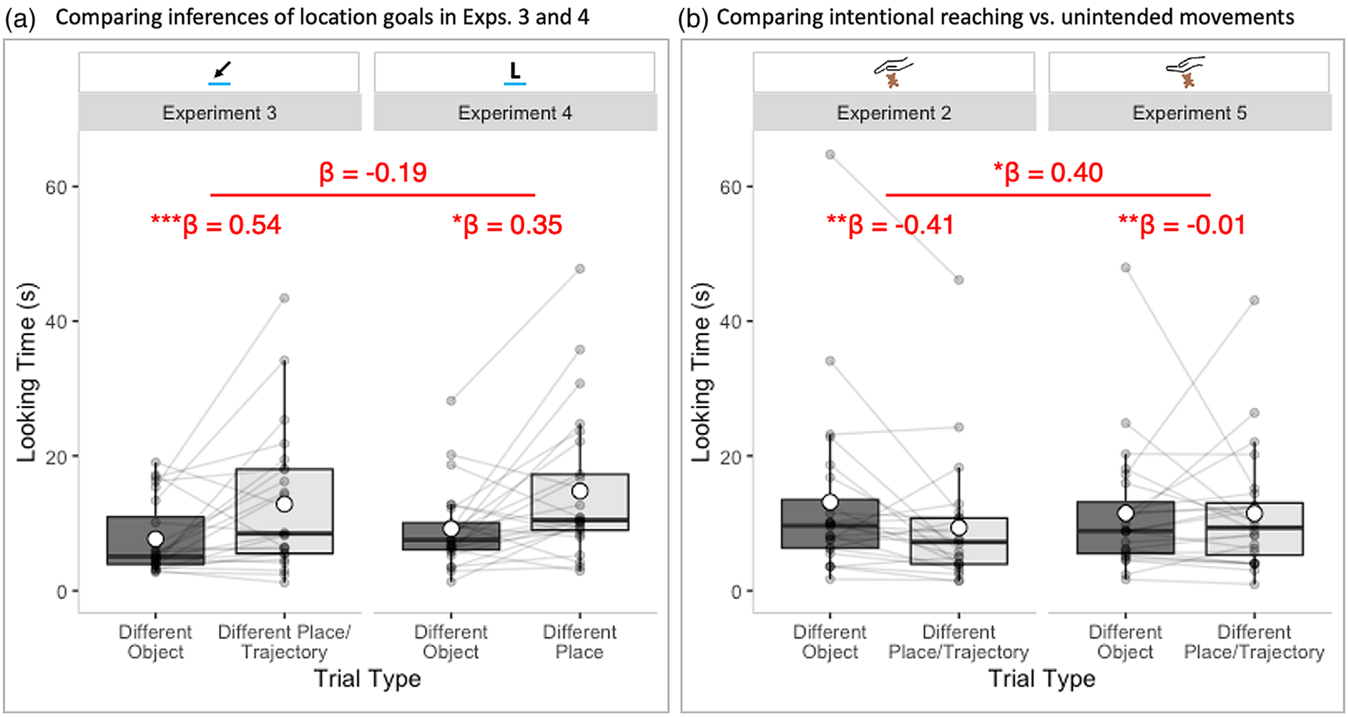

FIGURE 5 Experiment 4, together with Experiment 3, probed the specificity of place goal inferences (a), whereas Experiment 5, together with Experiment 2, probed the specificity of goal inferences across the full series of studies (b). (a) Infants' looking to actions involving actions towards different places versus different objects in Experiments 3 and 4. (b) Infants' looking to events involving actions versus passive movements in Experiments 2 and 5; these experiments presented the same objects and places but contrasted controlled, perceptually guided actions with passive, unseen movements. White circles indicate means, pairs of connected dots indicate data from a single infant, horizontal lines within boxes indicate medians, boxes indicate interquartile ranges, beta coefficients (ß) indicate standardized effect sizes, and asterisks indicate significant differences, corrected for multiple comparisons (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; two-tailed).

$p = 0.386$), despite the changes, at test, in the reaching trajectories and the reaching hands.

5.3 | Discussion

Experiment 4′s findings provide evidence that 3-month-old infants attribute a place goal to an actor, independent of the trajectory that the actor follows in arriving at that place, when the actor reaches to one place for two different objects. These findings provide further evidence that 3-month-old infants can form inferences, from their observations of others' actions, about the diverse goals that guide those actions. They also provide evidence that goal attribution is robust over a change in the hand used to reach an object. Thus, 3-month-old infants who view reaching actions are attuned to the goals of the actor, rather than the trajectories over which the actor moves or the hands that the actor employs.

One may question, however, whether these experiments provide evidence for 3-month-old infants' goal understanding. Do infants of this age see others' acts of reaching as goal-directed? At least one alternative explanation remains. Infants may have attended only to the moment of contact between the actor's hand and a particular object (Experiment 2), or an object at a particular place (Experiments 3 and 4), with no notion of goals. Although Woodward (1998) tested for, and ruled out, this alternative interpretation of her findings in older infants, to our knowledge, few past studies on 3-month-old infants' goal understanding, using Woodward's paradigm, have used such controls (cf. Choi et al., 2018). Selective encoding of the moments of contact between the hand and the object is especially plausible in the present experiments, because the objects lit up and emitted a sound when the actor's hand contacted them. Infants may have attended to the particular object (Experiment 2) or the particular place (Experiments 3 and 4) at which an object changed color on contact because they were focused on the causes of the state change in the objects, rather than the goals of the actor.

To address these concerns, we returned to the key manipulation used in Woodward's (1999) original experiments and conducted a final experiment. Following Woodward (1999), we presented infants with events based on those of Experiment 2, but with two changes: first, instead of reaching for an object, the actor's hand passively fell on the objects. Second, instead of looking at the object to which his hand moved, the actor looked away throughout the study. If the infants in Experiments 2 only attended to the moments of contact between a hand and an object, then the infants in Experiment 5 also should look longer when the hand contacted a new object. In contrast, if the infants in Experiment 2 attributed an object goal to the agent, then the findings Experiment 5 should differ, because the experiment presented passive movements rather than goal-directed actions.

6 | EXPERIMENT 5: PASSIVE MOVEMENTS TO OBJECTS

Experiment 5 adapted the methods of Experiment 2 to probe the nature of 3-month-old infants' sensitivity to action goals. In this experiment, infants saw an actor contact one of two objects that appeared in two alternating places during the habituation sequence, as in Experiment 2 (Figure 4b). There were two ways, however, in which the actor's actions differed from the intentional actions of Experiment 2: differences that distinguish these actions, for adults and older infants, from the actions that we perceive as reflecting object goals.

First, the actor's hand fell passively on the object, with the back of the hand making contact with the object. It is likely that infants are familiar with passive arm movements, because people regularly allow their arms to fall after reaching for high objects, to swing passively as they walk, or to come to rest on the arms of a chair as they sit. Except in unusual circumstances, however, people rarely contact objects with the backs of their hands when they intend to act on the objects, and 5- and 9-month-old infants do not attribute an object goal to a person who has acted in this manner (Woodward, 1999).

Second, the actor did not look at the object while his hand moved toward it. In the previous experiments, by contrast, the actor looked at each object both before reaching for it and during the reaching action. At 3 months of age, infants are sensitive to an actor's perceptual access to an object or event, and in the absence of this access, they do not represent an actor's action as goal-directed (Choi et al., 2018; Hamlin et al., 2013; Woo & Spelke, 2022). For example, when an actor directly reaches for one object, but has not seen that another object is present, 6-month-old infants do not expect the actor to continue reaching to the same object when the two objects both later become accessible and visible to the actor (Luo & Johnson, 2009; cf. Hernik & Southgate, 2012).

At test, the previously contacted object appeared at a third place that the actor's hand had never contacted, and the object underwent the same state changes as in the previous experiments. If the 3-month-old infants in Experiment 2 had attended only to the moment of contact between the actor's hand and the object, then the infants in Experiment 5 should look longer when the actor's hand contacted a different object at test. In contrast, if 3-month-old infants' differential looking at test in Experiments 2 reflected genuine goal understanding, then the infants in the present experiment might not look differently at the test events, because a passive movement toward an unattended object is not a goal-directed action.

6.1 | Methods

6.1.1 | Participants

Twenty-four 3-month-old infants contributed data to this experiment. No participants met the exclusion criteria. In Experiment 5, 20.8% of the participants were part of our lab database of children who were based in the greater Boston area at the time of their birth ($n = 5$). The remaining participants were recruited via ChildrenHelpingScience.org. About 75% of participants' caregivers completed demographics questionnaires: 61% of these participants were White, 16% were Asian, 11% were Black, 6% were Hispanic/Latino, and 6% were multiracial.

Sample size justification

We piloted 5 participants using a similar design, except that the actor's outfit differed. (We refilmed the stimuli so that the outfit was identical to that of Experiment 2.) In the pilot experiment, infants did not appear to look differently to the test trials. Given the lack of a strong trend, we used the data from Experiment 2 to conduct a simulated power analysis to determine an appropriate sample size. We found that with 24 infants, there would be 82% power to detect an effect of the same size as in Experiment 2.

6.1.2 | Displays

Displays were like those of Experiment 2, except as follows. First, the actor did not contact the object with the palm of his hand. Rather, the back of his hand contacted the object. Second, the actor did not engage in a controlled reaching movement with its characteristic patterns of acceleration and deceleration; instead, the actor's arm fell passively, with the character acceleration due to gravity. Third, the actor never looked at the objects; throughout each trial, his head was turned away from the object that he contacted. Importantly, both objects changed color when the actor contacted an object, as in Experiment 2.

6.1.3 | Procedure

In Experiment 4, all infants sat in their caregivers' laps and viewed movies. The procedure was identical to that of Experiment 2. All of Experiment 5′s infants viewed the movies on laptop screens.

6.2 | Results

Infants looked equally on the test trials presenting actions that ended in contact with a different object ($\text{mean}_{\text{different-object}} = 11.43$ s, $SD = 13.50$ s) and those that ended in contact with the same object in a different place ($\text{mean}_{\text{different-place/trajectory}} = 11.60$ s, $SD = 14.95$ s) ($\beta = -0.02$, 95% of β [-0.26, 0.22], $b = -0.01$, $t[23] = -0.16$, $p = 0.870$) (Figure 5b). This null finding differed significantly from the findings of Experiment 2, in which the actor intentionally reached for the same object over changes in its location ($\beta = 0.40$, 95% of β [0.04, 0.75], $b = 0.38$, $t[45] = 2.17$, $p = 0.034$). The pattern of findings did not differ depending on whether an infant had participated in Experiment 4 before or after the present study (see SI). Moreover, this pattern could not be explained by differential attention to the objects in Experiments 2 and 5 when the actor contacted those objects while looking at the objects versus while looking away (see SI). Thus, infants inferred that the goal of the actor was a specific object when he executed palmar reaches for that object while looking in its direction, but not when his hand fell passively on that object while looking elsewhere.

6.3 | Discussion

Experiments 2 and 5 together provide evidence that if an actor looks at an object, executes controlled reaching movements toward a single object at two locations, and contacts the object with the palm of his hand, 3-month-old infants view this event as a goal-directed action with the object as its goal. In contrast, if the actor looks away from the object, engages in a passive movement, and contacts the object with the back of his hand, the infants do not view the movement as a goal-directed action with the object as its goal. These findings provide evidence that 3-month-old infants rationally attributed object goals to the agent in Experiment 2; they did not attend only to the causal relation between the hand and the state change in the objects.

One possible interpretation is that 3-month-old infants are sensitive to the intentionality of agents' actions (Woodward, 1999). This experiment does not reveal, however, whether infants' goal attribution depended on all the features of intentional, object-directed actions that distinguished Experiments 2 and 5, because these features were not varied independently. Further research will be needed to determine whether gaze direction, controlled action, and palmar contact each serve to specify intentional, object-directed actions in prereaching infants (see Hernik & Southgate, 2012). The present methods may be useful for this purpose.

7 | GENERAL DISCUSSION

Our findings indicate that prereaching infants can exploit variation in an agent's actions to infer the agent's goals. Three-month-old infants' learning is rational and efficient: They learn to attribute both object goals and place goals to an actor within a single experimental session, after viewing no more than 14 acts of reaching. Moreover, 3-month-old infants do not make these inferences when viewing passive movements; like their 6-month-old counterparts (Woodward, 1999), they attribute object goals to people who reach for objects in a controlled and effective manner while looking at them, but not to people whose arms fall passively on objects while they are looking away. Together, the findings provide evidence that young infants possess an abstract concept that actions are goal-directed, before they learn the more specific goal states that actors aim to achieve when they engage in specific kinds of actions: in this case, reaching.

The findings raise questions concerning the scope of infants' learning. First, do prereaching infants who view people reaching to the same objects at variable places, following variable trajectories, learn that reaching is generally directed to objects? Young infants sometimes learn narrowly: Infants who are trained using sticky mittens form expectations concerning an agent's future object-directed reaching only when the person reaches for the same objects that the infants themselves reached for during training, wearing similar mittens (Gerson & Woodward, 2014a). Likewise, infants who are trained using sticky mittens demonstrate enhanced causal perception, but only when the objects are the same as those in training (Rakison & Krogh, 2012). Sometimes, however, prereaching infants learn broadly: When given information that actions cause changes in objects, 3-month-old infants who receive no action training demonstrate a generalized understanding that actions that they have never performed tend to be efficient (Liu et al., 2019; see also, Skerry et al., 2013). Future research could examine the generalizability of infants' learning after observing variation in an agent's actions, as in Experiments 2–4. Future research may further examine how the goal representations that infants formed in Experiments 2–4 compare to the representations that infants form over development, or to the representations that 3-month-old infants form following sticky mittens training.

Second, what is the breadth of the goals that prereaching infants can entertain? In the present studies, infants represented either object goals or place goals (Experiments 2–3), independent of the movement trajectories that the agent followed (Experiment 4), provided that the movements were actively controlled (Experiments 2 and 5). Future research could examine prereaching infants' abilities to represent other kinds of goals, including trajectory goals independent of location (Schachner & Carey, 2013), or social goals directed at other agents (see Hamlin et al., 2010; Woo et al., 2023).

In sum, we submit that prereaching infants are not ignorant but open-minded about the goals underlying others' actions. They understand that people act to realize their goals before they appreciate the kinds of actions that people engage in and the kinds of goals those actions typically achieve. Children likely learn that reaching is typically directed to objects, just as they likely learn that locomotion is typically directed to places. Given that humans' and animals' actions sometimes depend on what objects are (e.g., grasping rocks to use as weapons) as well as where objects are (e.g., traveling to forage for food), an initial open-mindedness to the potential goals of actions may be adaptive. Older infants likely have learned that particular objects are the most frequent goals of others' reaching actions, but they likely continue to rationally infer others' goals in relation to the evidence that they observe. We look forward to research that tests these predictions, examining both the phylogenetic and the ontogenetic origins of goal attributions for the diverse kinds of actions that humans and other animals perform. In humans (and, perhaps, other animals as well), an early-emerging, abstract concept of *goal* appears to direct infants' rapid learning about other people's actions and minds.

ACKNOWLEDGMENTS

We thank: the families who participated; Tomer Ullman, Fiery Cushman, and the Cambridge Writing Group for feedback; Bill Pepe, Cristina Sarmiento, Mia Taylor, Andrea Ventura, Manasa Ganesh Kumar, Gabriel Chisholm, Maria Castro Roldán, and Melyssa Almeida for research assistance; Michael Gajda and Laura Mullertz for acting in stimuli; Hyowon Gweon for sharing online testing protocols; and ChildrenHelpingScience.com for supporting participant recruitment.

This work was supported by National Science Foundation STC award CCF-1231216, by Siegel Foundation Award S4881, by Defense

Advanced Research Projects Agency award CW3013552, by an NSF Graduate Research Fellowship (F32HD103363) (S.L.), and by a Social Sciences and Humanities Research Council Doctoral Fellowship (752-2020-0474) (B.W.).

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All experiments were formally preregistered. All deidentified data are hosted on the Open Science Framework at https://osf.io/ervm3/.

ETHICS STATEMENT

All study protocols were approved by the Harvard University Committee on the Use of Human Subjects.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Woo, B. M., Liu, S., & Spelke, E. S. (2023). Infants rationally infer the goals of other people's reaches in the absence of first-person experience with reaching actions. *Developmental Science*, e13453. https://doi.org/10.1111/desc.13453