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Inferring the Outcome of an Ongoing Novel Action at 13 Months

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Many studies have demonstrated that infants can attribute goals to observed actions, whether they are presented live by familiar agents or on a computer screen by abstract figures. However, because most, if not all, of these studies rely on the repeated action presentations typical of infant studies, it is not clear whether infants are simply recognizing the completed action as goal directed, or whether they can productively infer a not-yet-achieved outcome from an ongoing action. We investigated this question by presenting 13-month-old infants with a single animated chasing event. Infants looked longer at the outcome of this action when, given the opportunity, the chaser did not catch the chasee than when it did. Crucially, this result was dependent on whether the action could be construed as efficient with regard to this goal state. This finding suggests the ability to infer the goal of an ongoing novel action and illustrates the productivity of 1-year-olds' action understanding.

Keywords: infants, goal attribution, prediction, action understanding

For any social species, the ability to make predictions about the likely actions of other individuals is crucial. One of the primary functions of recognizing others' actions as goal directed may in fact be to facilitate predictions about the future course that an action will take, enabling one to prepare an appropriate response (Csibra & Gergely, 2007; Keil, 2006). The fundamental importance of goal attribution in action interpretation is suggested by the fact that it is shared with both nonhuman primates (Rochat, Serra, Fadiga, & Gallese, 2008; Wood, Glynn, Phillips, & Hauser, 2007) and human infants as young as 3 months of age (Sommerville, Woodward, & Needham, 2005).

However, despite the many documented studies showing that young infants and nonhuman primate species do attribute goals to the actions of others (Csibra, 2008; Gergely, Nádasdy, Csibra, & Bíró, 1995; Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Rochat et al., 2008; Southgate, Johnson, & Csibra, 2008; Wood et al., 2007; Woodward, 1998), it is unclear whether either species can use its abilities inferentially to hypothesize the likely end state (i.e., the goal) that observed actions were implemented to achieve. Most studies that have explored infants' understanding of actions as goal directed involve repeatedly presenting infants with a complete action–goal event structure and assessing infants' reactions to the same goal outcome under changed environmental constraints. For example, in one paradigm, infants are repeatedly shown an agent choosing one of two possible goal objects, and then in test trials the location of the two goal objects is changed. In this situation, infants look longer when the agent alters its choice of goal, suggesting that they had encoded the relationship between the agent and a particular goal (Woodward, 1998). Infants' performance on this paradigm supports the view of theorists who advocate a criterion for goal attribution that includes factors such as repeated action on the same object (Baron-Cohen, 1994; Premack, 1990).

Another way in which goal attribution may be achieved is through an evaluation of the efficiency of an action with respect to its outcome (Gergely & Csibra, 2003). If an observed action is justified by environmental constraints, then the action, the outcome, and the environmental constraints produce a well-formed teleological schema, and the outcome is attributed as the agent's goal. Many studies support the existence of such a schema for evaluating the actions of others. In a typical paradigm of this type, infants repeatedly watch an agent whose actions toward a goal object are efficient given the environmental constraints. However, when the environmental constraints change, infants expect the agent to alter its action pathway so that it continues to represent the most efficient means to the goal (Csibra, 2008; Gergely et al., 1995; Kamewari et al., 2005; Southgate, Johnson, & Csibra, 2008).

Csibra and Gergely (2007) proposed that the teleological schema can also be used productively to infer an agent's goal from an ongoing action. Given the particular environmental constraints of the agent, infants could infer the goal of an action by hypothesizing an outcome that would be justified by the ongoing action. Two studies have gone some way toward testing this hypothesis. In a study by Csibra, Bíró, Koós, and Gergely (2003), which was replicated and extended by Wagner and Carey (2005), 12-month-old infants appeared able to employ the efficiency principle as a criterion not only to evaluate a means–end behavior as well formed (and goal directed) but also to infer an as-yet-unseen end state. Infants were habituated to an event in which a large ball

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chased a small ball, but when the small ball passed through a gap in a barrier, the large ball had to detour around the barrier. After infants had been habituated, they were shown two event outcomes, in which the large ball either caught up with the small ball and stopped next to it or traveled past the small ball and stopped somewhere else. Infants looked longer at the event in which the large ball passed by the small ball, suggesting that this outcome was incompatible with their expectations that this was a chasing event in which the large ball's goal was to catch the small one. Both articles interpreted the results in this paradigm as evidence that 12-month-old infants can use the efficiency principle to represent future end states of actions that they have not yet seen happen. However, the repeated presentation of the action and the outcome on test events leave open the possibility of an alternative interpretation. Infants may have inferred the unseen outcome before they saw it the first time, or, alternatively, they may have used the first one or two outcome presentations to evaluate whether the outcome constituted a well-formed teleological representation. In the second case, infants need not have evoked a hypothesis about the likely end state of the observed action before they saw this end state. The feasibility of infants learning from one outcome event is not unlikely considering the results of a recent study on infants' abilities to predict the goal of a human hand placing objects in a container (Falck-Ytter, Gredebäck, & von Hofsten, 2006). In this study, 12-month-old infants demonstrated their predictive capacities by making anticipatory eye movements to the container before the hand had reached it but only from the second action of a trial. On the first action, infants' eye movements did not lead the hand trajectory, suggesting that they quickly learned what to expect.

The current study addressed the question of whether infants can really infer unseen goal states, by measuring looking time to the outcome of an action that is presented only once. Four groups of 13-month-old[1] infants watched an event in which two balls moved around an environment. Half the infants saw events in which the actions of one of the balls could be construed as efficient (with respect to the environmental constraints) if its goal was to chase and catch the other ball (efficient action). The other infants watched the balls making the same movements, but because they were set in a different environment, their actions could not be interpreted as justifiably related to the goal of chasing the other ball (nonefficient action). We hypothesized that infants would attempt to interpret the observed action by positing a likely goal state that would be efficiently brought about by this action. Thus, when they observe movements that are justified by the environmental constraints, infants may interpret the action as "chasing" and infer that the likely outcome of the action will involve one ball catching the other ball, and may find a different outcome unexpected. However, when the movements of the balls are not justified by any environmental constraints, they would not permit infants to interpret the event as chasing, and the infants would not form the expectation that one ball will catch the other ball. We tested infants' expectations by presenting half of them in both conditions with an outcome that would be congruent with interpreting the actions as goal-directed chasing (together outcome), whereas the other half saw an outcome incongruent with this goal (apart outcome).

Method

Participants

Thirty-two infants participated in the study (17 girls, 15 boys; mean age = 12.9 months, range = 12.0–13.3 months). Infants were recruited from the Greater London area and volunteered by their parents for participation in the study. The majority of infants were Caucasian and middle class. An additional six infants were tested but excluded from final analyses because of caregiver interference (three), or the infant did not meet the criterion for inclusion (three; see below). Eight infants were assigned to each of four conditions: efficient action–together outcome (mean age = 12.85), efficient action–apart outcome (mean age = 12.83), nonefficient action–together outcome (mean age = 12.85), nonefficient action–apart outcome (mean age = 12.93).

Stimuli

Animations of two colored balls moving around a three-dimensional green environment were created with Maxon Cinema 4D. Two familiarization events were included, designed to introduce infants to the scene and the actors, in order to avoid ceiling looking time on the single test event. These familiarization events showed first the red ball (Familiarization Trial 1) and then the blue ball (Familiarization Trial 2) entering the screen and navigating the environment for 22 s and then leaving the scene. The two balls were never shown together during familiarization. Infants in the efficient action conditions saw familiarization events in an environment in which barriers were present, whereas infants in the nonefficient action conditions saw the same movement patterns but with no barriers present (see Figure 1). The single test event was a movie in which the smaller red ball entered the top left screen, closely followed by the larger blue ball. In the efficient action condition, the event depicted a chasing event, in which the blue ball followed the red ball, but whereas, due to its smaller size, the red ball could pass through the gaps in the barriers, the blue ball had to detour around the barriers in order to continue pursuing the red ball. After 20 s of this chasing action, the smaller red ball came to a halt against a barrier that it could not pass through. At this point, the larger blue ball either came to rest against the red ball (together outcome) or came to rest at another point next to the barrier (apart outcome). These event outcomes remained visible until the infant had looked away for 2 continuous seconds. Infants in the nonefficient action conditions saw the same test movements of the balls, but because there were no barriers present in the scene, these movements could not be construed as an efficient chasing action. As in the efficient action condition, half the infants in the nonefficient action condition received the together outcome and half viewed the apart outcome. (Each of the videos is available online at http://www.cbcd.bbk.ac.uk/people/scientificstaff/vicky/chasingmovies).

Procedure

Infants were seated on the caregiver's lap at a distance of approximately 100 cm from a 50 × 67-cm plasma screen in a

[1] We chose this age because earlier studies suggested that younger infants might not be able to interpret a chasing action as goal directed unless they see its outcome (Csibra et al., 2003).

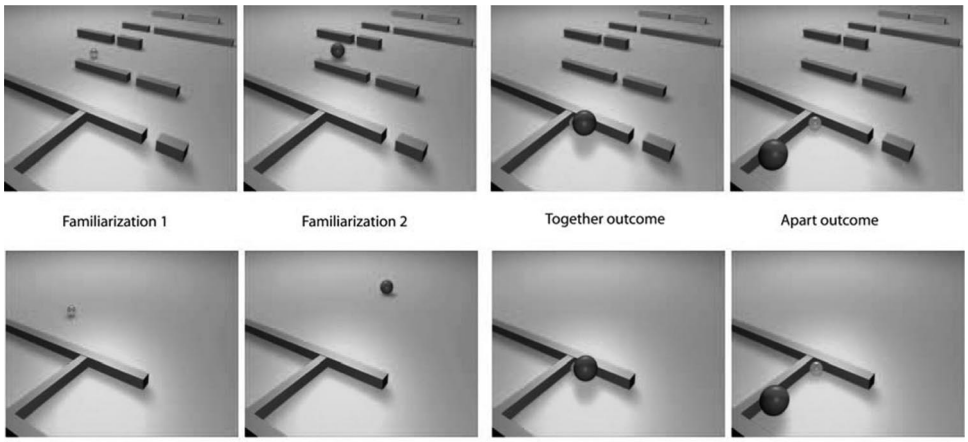

Figure 1. Frames from the events seen by infants viewing the efficient action event (top row) and the nonefficient action event (bottom row).

darkened room. Infants saw two familiarization trials and a single test trial according to the condition to which they were assigned. No looking times were analyzed during familiarization events. The caregivers were instructed to close their eyes during the presentation of the events. A lullaby tune played continuously throughout the experiment from speakers located behind the plasma screen. A cartoon briefly appeared before the onset of the two familiarization trials and the test trial, which served to attract the infants' attention toward the screen. A bell behind the screen was occasionally rung to get the infants' attention if they became distracted but was never rung during the outcome period in which we measured looking times. The infants' looking behavior was recorded by a remote-control infrared video camera and mixed together with the stimuli the infant was viewing, for offline coding. When the infant was looking at the screen, the experimenter started the presentation of the movies. The stimuli were controlled by a custom-built computer program.

Data Analysis

Looking time in the test trial was calculated from the point at which the larger blue ball came to rest until the infant had looked away for 2 consecutive seconds. To be included in analysis, infants had to view at least 6 s of the test movie and also the entire last 1 s before the balls came to rest. Infants in all four groups looked for an equal amount of time at the test movies before the balls came to rest (efficient–apart, 18.5 s; efficient–together, 19.3 s; nonefficient–apart, 17.7 s; nonefficient–together, 19.1 s; all ps $>$ .2). The looking times to the event outcomes of every infant were measured offline by two researchers: The first author and a research assistant who was blind to the experimental hypothesis. The two measurements correlated at a high level (r = .992). The analyses were based on the measurements of the first author.

Results

Each infant's looking time to the test trial outcome is presented in Figure 2. A univariate analysis of variance was carried out with looking time as the dependent measure and action (efficient vs. nonefficient) and outcome (together vs. apart) as between-subjects factors. This analysis of variance yielded no main effects but revealed a significant interaction between action and outcome, $F(1, 28) = 4.98$, $p = .03$, $\eta_p^2 = .15$. Follow-up independent-samples t tests revealed that infants in the efficient action–apart outcome group looked significantly longer at the outcome (M = 14.9 s, SD = 6.2 s) than infants in the efficient action–together outcome group (M = 8.37 s, SD = 5.2 s), $t(14) = 2.25$, $p = .04$, $\eta_p^2 = .49$ (two-tailed). This suggests that, having seen an efficient chasing action, infants found the apart outcome more unexpected than the together outcome. In contrast, there was no difference between the looking times of infants in the nonefficient action–apart outcome group (M = 10.1 s, SD = 5.8 s) and the nonefficient action–together outcome group (M = 12.6 s, SD = 5.5 s), $t(14) = 0.89$, $p = .39$ (two-tailed). These results demonstrate that only infants who viewed the efficient action sequence were able to infer the likely outcome of this event. No other comparisons reached significance (ps $> .05$).

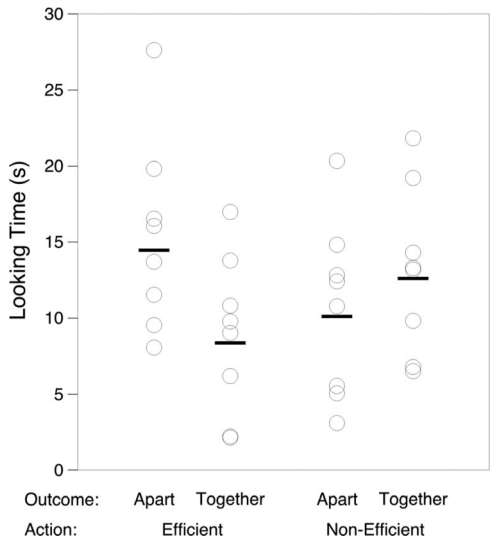

Figure 2. Individual looking times at the event outcome for each of the four groups of infants. Black bars represent the mean of each group.

Nonparametric statistics confirmed that these results were not driven by outliers. For infants viewing the efficient action event, seven (of eight) infants in the apart outcome group looked longer than the median looking time of the together outcome group, whereas only one (of eight) infant in the together outcome group looked longer than the median looking time of the apart outcome group (Fisher's exact, $p = .01$, two-tailed; see Figure 2). The same comparisons for infants viewing the nonefficient actions did not reveal any difference ($p = .6$, two-tailed). Furthermore, none of the individual looking times was more than two standard deviations from the mean of their group.

Discussion

How were infants in this study able to infer the likely outcome of the events in the efficient action condition but not in the nonefficient action condition? Unlike in previous studies exploring infants' abilities to predict action outcomes (Csibra et al., 2003; Falck-Ytter et al., 2006; Wagner & Carey, 2005), infants in the current study viewed the outcome only once, at the point where looking time was measured, and so had no prior opportunity to acquire knowledge about the end. In fact, the only difference between the events in the two action sequences was that the movement of the agents was necessitated by the physical constraints in the efficient action condition. We propose that when infants see these events, they attempt to come up with a likely goal for the agents by hypothesizing what goal would justify their actions. Infants watching the efficient action movie were able to reconcile the blue ball's actions with the goal of catching the red ball or coming into contact with it. Note that the ability to form hypotheses, and predict such outcomes, must require some prior experience with such an outcome. However, even if infants watching the nonefficient action movie generated the same goal hypothesis, they were unable to reconcile the observed action pattern with this goal state, as the blue ball's behavior did not constitute an efficient means to this end (the blue ball did not approach the red one when it could have but made unnecessary detours that increased its distance from the red one).

Note that a mere sensitivity to the spatiotemporal contingencies between the two agents (Bassili, 1976) is not sufficient here to enable infants to attribute a likely goal to them. The spatiotemporal contingencies in the two action movies were identical, and on this basis infants in both groups should have attributed the same goal. Sensitivity to the spatiotemporal contingences may suggest an interaction between the two agents, but it does not allow the infant to attribute a specific future goal to them. Although adults might describe the behavior of the agents in the nonefficient action movie as resembling that of "playing" or "teasing," it is unlikely that infants would have the necessary background knowledge to generate such a hypothesis. In any case, such an interpretation of the nonefficient action event would not generate expectations about the end state that the outcomes we presented could be matched with.

Although many other studies have demonstrated infants' abilities to attribute goals to agents (Gergely et al., 1995; Woodward, 1998) and have shown that infants use the efficiency principle to achieve this (Bíró & Leslie, 2007; Csibra, 2008; Kamewari et al., 2005; Sodian, Schoeppner, & Metz, 2004; Southgate et al., 2008), the present study is the first to clearly show that infants can use the efficiency criterion to infer future goal states. Two previous studies that had attempted to demonstrate this left open the question of whether infants might, in fact, have gained knowledge of the end state of the event from the first action or two actions of the looped presentation (Csibra et al., 2003; Wagner & Carey, 2005). As the current study presented infants with a single event, and the event outcome was shown to them only once, we can be confident that infants did make a prediction as to the likely event outcome and appealed to the principle of efficient action to validate this hypothesis. Of course, one may still argue that looking-time measures are always ambiguous as to whether they reflect real predictions (of action outcomes, in our case) or simply "postdictions" that detect a mismatch between an event and its antecedent only a posteriori (Hood, Carey, & Prasada, 2000). In principle, the infants in this study could have evaluated the goal efficiency of the action only when they observed its outcome. However, such a feat would require infants to keep the uninterpreted motion patterns of both objects in their memory and, having seen the action outcome, recall this information. Such memory traces should be sufficiently detailed for allowing the assessment of the efficiency of the actions in relation to the outcome that is revealed at the end. It seems unlikely that infants would keep such detailed, uninterpreted information in their mind and then be able to evaluate the efficiency of such memorized behaviors. It is more plausible to assume that such evaluation took place during action observation and was based on a hypothesized end state (i.e., on a goal that was inferred before the conclusion of the action).

Because goal attribution in the current study was based on a single (though extended) action, our result suggests that although goal understanding may be facilitated by repeated observations of an agent acting toward a certain end, such experience is not, as some have suggested (Baron-Cohen, 1994; Premack, 1990), a prerequisite for goal attribution in infancy. The present study investigated a single age group and does not allow us to draw conclusions about the development of goal prediction in infants. We chose to conduct this study with 1-year-olds because earlier studies suggested that younger infants might not be able to infer unseen goals for animated actions (Csibra et al., 2003). However, we do not think that the achievement of predictive goal attribution need be a special step, or a late achievement, in the development of action understanding. Although the ability to recognize an action as goal directed does not depend on experience with that particular action (e.g., Gergely et al., 1995; Southgate et al., 2008), the ability to infer a hypothesized goal state for an ongoing action must require some experience of that goal. Thus, although younger infants may not possess the necessary experience to hypothesize catching as a goal for the actions we presented here, they may be able to productively attribute an unseen goal to a more familiar action (e.g., Daum, Prinz, & Aschersleben, 2008), even without repeated presentations. It may also be the case that younger infants would succeed in inferring the unseen goal of the current chasing actions because, unlike in Csibra et al. (2003), the displays presented here were three-dimensional, an aspect that appears to facilitate goal attribution in younger infants (Csibra, 2008). Nevertheless, our finding demonstrates not only that this ability is present by 13 months of age but also that it is governed by an abstract understanding of how behaviors and outcomes are related to each other.

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