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DO 8-MONTH-OLD INFANTS CONSIDER SITUATIONAL CONSTRAINTS WHEN INTERPRETING OTHERS' GAZE
AS GOAL-DIRECTED ACTION?

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Abstract

Some actions of agents are ambiguous in terms of goal-directedness to young infants. If given reasons why an agent performed these ambiguous actions, would infants then be able to perceive the actions as goal-directed? Prior results show that infants younger than 12 months cannot encode the relationship between a human agent's looking behavior and the target of her gaze as goal-directed. In the present experiments, 8-month-olds responded in ways suggesting that they interpreted an agent's action of looking at object-A as opposed to object-B as evidence for her goal directed towards object-A, if her looking action was rational given certain situational constraints: a barrier separated her from the objects or her hands were occupied. Therefore, the infants seem to consider situational constraints when attributing goals to agents' otherwise ambiguous actions; they seem to realize that within such constraints, these actions are efficient ways for agents to achieve goals.

An important question in early development concerns how infants come to construe agents' actions in psychological terms (e.g., Gergely & Csibra, 2003; Leslie, 1995; Onishi & Baillargeon, 2005; Premack & Premack, 1995). One issue central to this question, among others, deals with infants' understanding of agents' goals. From an early age, infants act in ways suggesting that they realize that agents' actions are guided by their goals (e.g., Behne, Carpenter, Call, & Tomasello, 2005; Csibra, Gergely, Bíró, Koós, & Brockbank, 1999; Gergely, Nádasdy, Csibra, & Bíró, 1995; Guajardo & Woodward, 2004; Luo & Baillargeon, 2005a; Sommerville & Woodward, 2005; Song & Baillargeon, 2007; Southgate, Johnson, & Csibra, 2008; Woodward, 1998). However, how infants come to identify agents' goal-directed actions remains debatable. Some researchers propose that infants should first identify the goals underlying agents' actions that are familiar to them, especially those they themselves can produce, and should gradually become more flexible with experience (e.g., Carpenter, Nagell, & Tomasello, 1998; Meltzoff, 1995, 1999, 2005; Sommerville, Woodward, & Needham, 2005; Tomasello, 1999; Tomasello, Carpenter, Call, Behne, & Moll, 2005; Woodward, 2005; Woodward, Sommerville, & Guajardo, 2001). Others suggest that specific behavioral cues embedded in agents' actions enable infants to perceive these actions, whether familiar or not, as goal-directed (e.g., Bíró, Csibra, & Gergely, 2007; Bíró & Leslie, 2007; Csibra, Bíró, Koós, & Gergely, 2003; Csibra & Gergely, 2007; Johnson, Ok, & Luo, 2007; Jovanovic, Király, Elsner, Gergely, Prinz, & Aschersleben, 2007; Király, Jovanovic, Prinz, Aschersleben, & Gergely, 2003). The present experiments took a different approach to this question by examining whether constraints in the situation in which agents perform their actions enable infants to encode agents' goals. Positive evidence would contribute to our knowledge about what information facilitates infants' goal-related understanding of agents' actions.

Beginning in the first year of life, infants attempt to make sense of agents' actions in terms of possible goals (e.g., Behne et al., 2005; Csibra, 2008; Csibra et al., 1999; Daum, Prinz, & Aschersleben, 2008; Gergely et al., 1995; Hamlin, Hallinan, & Woodward, 2008; Johnson, Shimizu, & Ok, 2007; Luo & Baillargeon, 2005a; Phillips & Wellman, 2005; Sommerville & Woodward, 2005; Song & Baillargeon, 2007; Southgate et al., 2008; Woodward, 1998; Woodward & Sommerville, 2000). A goal is defined as a particular outcome that an agent wants to achieve. In a groundbreaking study, Woodward (1998) found that infants as young as 5 to 6 months of age encoded the goal object of a human agent's repeated grasping. Infants were first habituated to an event in which they saw the human

agent's arm and hand reach for and grasp object-A, as opposed to object-B. Following habituation, the objects' positions were reversed. During test, infants saw the agent's arm and hand reach for and grasp object-A in its new location (old-goal event) or object-B in the position previously occupied by object-A (new-goal event). The infants looked reliably longer at the new-goal than at the old-goal event. These and control results supported the conclusions that infants interpreted the agent's actions during habituation as directed toward the goal of approaching object-A, and that they expected the agent to continue acting on this goal during test and hence responded with increased attention when the agent grasped object-B in the new-goal event. This finding has been replicated in different laboratories using various tasks (e.g., Luo & Baillargeon, 2005a, 2007; Luo & Johnson, 2009; Shimizu & Johnson, 2004; Sodian & Thoermer, 2004; Song, Baillargeon, & Fisher, 2005b).

Recent research has greatly advanced our knowledge about infants' intentional understanding. Infants not only act as if they interpret agents' actions in terms of goals, they also construe agents' goal-directed actions as stemming from particular dispositions (a tendency or state that helps us interpret and predict an agent's goal-directed behavior), for example, a color preference (Luo & Beck, in press), a preference for one object over another (e.g., Luo & Baillargeon, 2005a; Repacholi, 1998; Repacholi & Gopnik, 1997; Song et al., 2005b), a positive inclination towards one agent as opposed to another (e.g., Hamlin, Wynn, & Bloom, 2007; Kuhlmeier, Wynn, & Bloom, 2003; Premack & Premack, 1997), or a predilection to engage in a certain activity (e.g., Song & Baillargeon, 2007; Song, Baillargeon, & Fisher, 2005a). More recent research also supports the hypothesis that infants consider an agent's representation of the setting in which the agent's actions take place (which may be specified by the agent's perceptions, emotions, and beliefs) to interpret the agent's actions in terms of goals and dispositions, even when the agent's representation deviates from reality (e.g., Barna & Legerstee, 2005; Luo & Baillargeon, 2007; Luo & Beck, in press; Luo & Johnson, 2009; Onishi & Baillargeon, 2005; Phillips, Wellman, & Spelke, 2002; Repacholi, 1998; Sodian, Thoermer, & Metz, 2007; Song & Baillargeon, 2008; Song, Onishi, Baillargeon, & Fisher, 2008; Southgate, Senju, & Csibra, 2007; Surian, Caldi, & Sperber, 2007).

Nevertheless, it remains unclear how infants determine that agents' actions are goal-directed. Sommerville, Woodward and their colleagues suggest that experience, especially infants' first-hand experience with actions, plays a crucial role (e.g., Sommerville et al., 2005; Woodward, 2005; Woodward et al., 2001). This claim comes from two

sources of evidence. First, due to young infants' limited experience, certain familiar actions are clearly goal-directed, while others are not (Woodward et al., 2001). For instance, while 5- and 6-month-olds' responses are consistent with their interpreting an agent's act of grasping an object as goal-directed, as described above (Woodward, 1998), 6-month-olds' performance suggests that they fail to encode the less common action of a human agent's contacting an object with the back of her hand as goal-directed (Woodward, 1999). Second, with development, infants' own abilities to perform actions help them identify these actions in others as goal-directed (Woodward et al., 2001). For example, 12- but not 9-month-olds seem to perceive a person's pointing and touching one of two objects with her index finger as goal-directed (Woodward & Guajardo, 2002), presumably because infants' abilities to produce and to understand pointing gestures emerge between 9 and 12 months of age (e.g., Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Butterworth, Franco, McKenzie, Graupner, & Todd, 2002; Liskowski, Carpenter, Henning, Striano, & Tomasello, 2004; Liskowski, Carpenter, & Tomasello, 2007; Tomasello, Carpenter, & Liskowski, 2007). Similarly, 12- but not 7- and 9-month-olds respond in ways suggesting that they interpret a person's act of looking at one of two objects as guided by her goal directed towards that object (Woodward, 2003), presumably because older infants are more experienced with encoding the relationship between one's looking behavior and the target of her gaze, as infants' gaze-following abilities improve between 9 and 12 months (e.g., Butterworth & Jarrett, 1991; Corkum & Moore, 1998; D'Entremont, Hains, & Muir, 1997).

The importance of first-hand experience gains further support from a study with 3-month-old infants, showing that experience acquired in a laboratory also facilitates infants' goal-related interpretation of others' actions (Sommerville et al., 2005). The 3-month-olds, who typically cannot grasp an object (Needham, Barrett, & Peterman, 2002), acted in ways suggesting that they encoded a human agent's grasping one of two objects as goal-directed in a habituation looking-time task similar to that of Woodward (1998), if they first participated in an action task in which they gained "grasping" experience by wearing Velcro mittens to manipulate objects. These positive results were not obtained, however, when the infants participated in the looking-time task before the action task or in the looking-time task alone.

Therefore, in terms of intentional understanding of others' actions, infants may start with familiar actions of agents, e.g., those that they themselves can produce. With development and experience, their repertoire of agents'

goal-directed actions gradually increases to include those that are initially unfamiliar and hence ambiguous to them. Recently, however, some researchers have found that providing disambiguating information about agents' novel actions can enable young infants to encode the goals underlying these actions.

At least two kinds of behavioral cues embedded in agents' actions seem to help infants encode goals. The first is the presence of an effect or outcome brought by agents' actions. After watching an agent touch an object with the back of her hand and move the object – the agent's novel action therefore produces an effect – 6-month-olds acted as if they interpreted this action as goal-directed (Hofer, Hauf, & Aschersleben, 2007; Hofer, Hohenberger, Hauf, Aschersleben, 2008; Jovanovic et al., 2007; Király et al., 2003). The second is equifinal variations in agents' actions to achieve a goal. For instance, 6-month-olds respond as if they interpret an agent's poking at one of two objects as goal-directed if the agent pokes at the object from different angles (Bíró & Leslie, 2007). Johnson et al. (2007) found that when shown an actor visually inspecting an object with three distinct fixations rather than one fixation, 9-month-olds acted in ways suggesting that they detected the agent's goal directed toward the particular object that guided her looking behavior.

What other information, besides behavioral cues, could help infants identify agents' otherwise ambiguous actions as goal-directed? In the studies described above, the agents' actions of touching an object with the back of her hand, poking or looking at an object, are somewhat modified, either to produce an outcome of the action, or to create equifinal variations. These modifications served to help infants recognize that the agents performed these novel actions to achieve goals. What if the agent's actions remained the same, but some constraints in the situation in which the agent's actions occurred enabled infants to perceive these actions as goal-directed? The present research sought to address this question.

Prior findings from imitation tasks have shown that in the second year of life, infants respond as if they can choose one goal-directed action over another based on how efficient or rational they are within given situations (e.g., Carpenter, Call, & Tomasello, 2005; Gergely, Bekkering, & Király, 2002; Schwier, van Maanen, Carpenter, & Tomasello, 2006; Zmyj, Daum, & Aschersleben, 2009; for similar results with non-human primates, see Buttelmann, Carpenter, Call, & Tomasello, 2007; Wood, Glynn, Phillips, & Hauser, 2007). For example, Gergely and his colleagues (2002) found that when presented with a human agent who used her head, rather than her hands, to

touch and turn on a light box, 14-month-old infants “creatively” imitated the agent’s actions: after seeing that the agent’s hands were occupied because she felt cold and had to hold onto a blanket, they used their hands to touch the light box, whereas infants more faithfully copied the agent’s action and used their head to touch the light box when the agent’s hands were free. Therefore, when given a reason for why the agent had to use her head to turn on the light box, infants themselves chose a more efficient way, i.e., to use their hands, to achieve the same goal.

Infants thus act as though they evaluate the efficiency of goal-directed actions with regards to “situational constraints” (e.g., Csibra et al., 2003; for a discussion on efficiency and goal-directedness of actions, see Southgate et al., 2008). Would they also recognize that some actions of agents could be goal-directed because of situational constraints? The present experiments addressed this question by focusing on an agent’s action of looking at objects. Researchers have pointed out that looking behavior may be difficult to interpret as goal-directed for at least the following reasons. First, unlike an agent’s action of reaching for and grasping her goal object, there is no physical link between an agent’s looking behavior and the object of her gaze: the agent’s gaze does not directly contact the object, and the gaze does not create an effect on the object (Woodward, 2003). Second, an agent’s looking behavior may be less likely to be goal-directed than object-directed actions such as grasping, as people may look around without a target, or look at an object absent-mindedly (Johnson et al., 2007). Woodward (2003) found that for 12-month-olds to identify an agent’s gaze as goal-directed, the repetition of the same behavior was sufficient; infants saw the agent repeatedly look at one of two objects. This was insufficient for 7- and 9-month-olds. However, Johnson and her colleagues (2007) reported that additional behavioral information, i.e., the cue of equifinality – the agent looked at her target object three times from different angles – as well as the repetition of the same looking acts enabled 9-month-old infants to recognize that the agent intended to look at the particular object. Therefore, younger infants are able to detect the goal underlying an agent’s gaze in more supportive conditions.

The present research explored whether situational constraints would disambiguate an agent’s looking behavior in terms of goal-directedness. Eight-month-old infants’ responses were examined in two situations in which the agent looked at the target of her gaze in situations which constrained her actions: a barrier separated her from the object (Experiment 1), or her hands were occupied (Experiment 2). Positive evidence that infants responded as if they perceived the agent’s gaze at the target object as goal-directed in these situations would indicate that situational

constraints, in addition to experience and behavioral information, facilitate infants' intentional understanding of others' behavior.

Experiment 1

The 8-month-old infants in Experiment 1 were randomly assigned to one of two conditions, a small- or a large-window condition (see Fig. 1). In the small-window condition, the infants first received familiarization trials in which a female human agent, who sat between and behind two distinct objects on an apparatus floor, a football and a box, turned to look at the football; she then paused until the trial ended. The back of the apparatus was completely covered except for a small rectangular window that allowed the agent to look at the objects; the infants could only see the agent's upper face including her eyes and nose. Following familiarization, the positions of the football and the box were reversed. The infants then received test trials in which the agent turned to look at the football in its new position (old-goal event), or the box in the position formerly occupied by the football (new-goal event). The large-window condition was identical to the small-window condition except that the window extended to the apparatus floor, so that the infants could see the agent's face and upper body.

The large-window condition was essentially similar to that of Woodward (2003). The infants should respond as if they find the agent's looking at the football during familiarization ambiguous in terms of goal-directedness, as did the 7- and 9-month-olds in Woodward (2003), and hence have no prediction about which object the agent should look at during test. The infants in the large-window condition should therefore look about equally at the new- and old-goal events.

The question of interest was how the infants in the small-window condition would respond. If the infants failed to encode the agent's looking at the football as opposed to the box during familiarization as goal-directed, then they should respond like those of the large-window condition and look about equally at the new- and old-goal events. However, if the infants would consider situational constraints to make inferences about agents' actions, then different results should be obtained. The infants might recognize that during familiarization, the agent could only look to indicate her goal because of the back as a barrier, and therefore attribute to her a goal directed towards the football, since she repeatedly looked at the football rather than the box. They should expect the agent to keep looking at the football during test, and respond with prolonged looking when she looked at the box instead in the new-goal event.

The infants in the small-window condition should therefore look reliably longer at the new-goal than at the old-goal event.

Method

Participants

Participants were 20 healthy, full-term infants, 7 male and 13 female (age range: 7 months, 7 days to 9 months, 9 days, $M = 8$ months, 3 days); 10 infants, 5 male and 5 female, were randomly assigned to the small-window condition ($M = 8$ months, 0 day) and 10 to the large-window condition ($M = 8$ months, 6 days). Another 8 infants were tested but their data were not included, because they were distracted (3), or because of fussiness (1), activeness (1), observer error (1), procedural problems (1), or the infant's average difference in test looking times that was more than 2 SDs from the mean of the condition (1).

The infants' names in this and in the following experiment were obtained from birth announcements in the local newspaper. Parents were contacted by letters and follow-up phone calls; they were offered reimbursement for their transportation expenses, but were not otherwise compensated for their participation.

Apparatus/stimuli

The apparatus consisted of a wooden display box (107 cm high x 104 cm wide x 64 cm deep) mounted 76 cm above the room floor. The infant sat on a parent's lap and faced an opening (56 cm high x 102 wide) in the front of the apparatus. Between trials, a curtain consisting of a muslin-covered frame (61 cm high x 104 cm wide) was lowered in front of the opening. The side walls of the apparatus were painted white, and the floor was covered with beige marble-patterned contact paper. The back wall of the apparatus was made of a white foam core board. A rectangular window was created in the midsection of the back wall. In the small-window condition, the window was 10 cm high and 35.5 cm wide, and its lower edge was 25.5 cm above the apparatus floor; in the large-window condition, the window extended to the apparatus floor, 35.5 cm high and 35.5 cm wide. The edges of the windows were framed with blue tape, 1 cm wide. A human agent, wearing a brown shirt, sat centered on the apparatus and behind the window throughout the experiment.

A football and a box were used. The plastic football, 20.5 cm high and 12 cm in diameter at its widest point, was half red and half purple. Its red half faced the right side wall of the apparatus during familiarization and the left

side wall during test. The football was kept in a white cardboard base so that it stood upright. The cardboard box was 19 cm high, 11 cm wide, and 15.5 cm deep; it was covered with patterned contact paper decorated with drawings of yellow sunflowers and bugs.

The infants were tested in a brightly lit room. Two 23-W fluorescent light bulbs were attached to the front wall of the apparatus to provide additional light. Two wooden frames, each 183 cm high, 69 cm wide, and covered with white cloth, stood at an angle on either side of the apparatus; these frames served to isolate the infants from the test room.

Events

In the following descriptions, the numbers in parentheses indicate the number of seconds taken to perform the actions described. The events are described from the infant's perspective. To help the agent adhere to the events' scripts, a metronome beat softly once per second. A video camcorder mounted behind and above the parent holding the infant projected an image of the events onto a TV screen in a different part of the test room; a supervisor monitored the events to confirm that they followed the prescribed scripts.

At the start of each trial, the agent sat behind the apparatus, looking at a neutral mark in the center of the apparatus floor through the window in the back wall. After turning to look at an object, the agent kept her eyes focused on the object. Thus, the agent did not make eye contact with the infant during the experiment.

Small-window condition.

Familiarization event. Each familiarization trial consisted of a 1-s pre-trial followed by a main-trial. At the start of the pre-trial, the football stood in the right corner of the apparatus, 33 cm from the midpoint of the window, 6 cm from the side wall, and 6 cm from the back wall. The box stood in the left corner of the apparatus, 34 cm from the midpoint of the window, 6 cm from the side wall, and 6 cm from the back wall. The agent sat with her forehead against the back wall; her upper face was visible to the infants through the small window. During the pre-trial, the agent turned her head about 45 degrees to the right to look at the football (1 s); she then paused, with her eyes focused on the football. In the main-trial, the infants watched this paused scene until the trial ended (see below). When this occurred, an experimenter hidden behind the apparatus lowered the curtain in front of the apparatus.

Test events.

New-goal event. The new-goal event was identical to the familiarization event except that the positions of the box and the football were reversed; each object was still of approximately equal distance from the midpoint of the window. The agent turned her head about 45 degrees to the right to look at the box during the pre-trial (1 s); she then paused, with her eyes fixated on the box. During the main-trial, the infants watched this paused scene until the trial ended (see below).

Old-goal event. The old-goal event was similar to the new-goal event except that the agent turned to look at the football (1 s).

Large-window condition. The familiarization and test events shown in the large-window condition were similar to those in the small-window condition, except that the window in the back wall extended to the apparatus floor so that the agent's face and upper body were visible to the infants, her hands hidden beneath the floor.

Procedure

During the experiment, the infant sat on a parent's lap in front of the apparatus; the infant's head was approximately 40 cm from the front edge of the apparatus. Parents were instructed not to interact with their infant during the experiment; they were also asked to close their eyes during test.

Two observers monitored the infant's looking behavior by viewing the infant through peepholes in large cloth-covered frames on either side of the apparatus. The observers could not see the events from their viewpoints and they did not know the condition the infant was in and the order in which the test events were presented. Each observer held a button linked to a computer and pressed the button when the infant looked at the event. The primary (more experienced) observer's looking times were used to determine the endings of the trials (see below). Each trial was divided into 100-ms intervals, and the computer determined in each interval whether the two observers agreed on the direction of the infant's gaze. Agreement was calculated for each main-trial on the basis of the number of intervals in which the computer registered agreement out of the total number of intervals in the trial. Interobserver agreement was measured for 30 of the 40 infants in Experiments 1 and 2 and averaged 94% per trial per infant.

All infants first received four familiarization trials appropriate for their condition in which the agent turned to look at the football (pre-trial), paused until the trial ended (main-trial). Examination of the infants' mean looking times during the 1-s pre-trial at the start of each familiarization trial suggested that the infants were highly attentive (small-

window condition: $\underline{M} = 1.0$; large-window condition: $\underline{M} = 1.0$). Each familiarization main-trial ended when the infant (1) looked away for 2 consecutive seconds after having looked for at least 2 cumulative seconds, or (2) looked for 30 cumulative seconds.

All infants then saw the new- and old-goal events appropriate for their condition on four alternating test trials. Half of the infants saw the new-goal event first; and half saw the old-goal event first. The infants were again highly attentive during the 1-s pre-trial at the start of each test trial (small-window condition: $\underline{M} = 1.0$; large-window condition: $\underline{M} = 1.0$). Each test main-trial ended when the infant (1) looked away for 2 consecutive seconds after having looked for at least 5 cumulative seconds, or (2) looked for 60 cumulative seconds.

Preliminary analyses of the test data revealed no significant interactions involving sex with condition and/or event, all \underline{F} s (1, 12) < 0.25; the data were therefore collapsed across sex in subsequent analyses.

Results

Familiarization trials

The infants' looking times during the main-trial portion of the four familiarization trials were averaged and analyzed by means of a single-factor analysis of variance (ANOVA) with condition (small- or large-window) as a between-subjects factor. The main effect of condition was not significant, $\underline{F}(1, 18) = 0.09$, suggesting that the infants in the two conditions tended to look equally during the familiarization phase (small-window condition: $\underline{M} = 18.6$, $\underline{SD} = 6.5$; large-window condition: $\underline{M} = 17.8$, $\underline{SD} = 6.4$).

Test trials

The infants' looking times during the main-trial portion of the four test trials (see Fig. 2) were averaged and analyzed by means of a 2 x 2 x 2 three-way ANOVA with condition (small- or large-window) and order (new- or old-goal event first) as between-subjects factor and event (new- or old-goal) as a within-subject factor. The analysis yielded a significant main effect of condition, $\underline{F}(1, 16) = 12.42$, $\underline{p} < .005$, as the infants in the small-window condition looked reliably longer during the test phase than did those in the large-window condition. A significant main effect of event was also found, $\underline{F}(1, 16) = 11.98$, $\underline{p} < .005$, indicating that the infants looked reliably longer at the new-goal than at the old-goal test event across conditions. Critically, this analysis yielded a significant interaction between

condition and event, $F(1, 16) = 23.03$, $p < .00025$. There was also an interaction between order and event, $F(1, 16) = 26.28$, $p = .0001$, and a significant condition x order x event interaction, $F(1, 16) = 6.58$, $p < .025$. Therefore, separate two-way ANOVAs with order as the between-subjects factor and event as the within-subject factor were performed in the two conditions.

In the small-window condition, the two-way ANOVA yielded a significant main effect of event, $F(1, 8) = 26.59$, $p < .001$, Cohen's $d = 0.9$, indicating that the infants looked reliably longer at the new-goal ($M = 21.7$, $SD = 10.7$) than at the old-goal ($M = 13.0$, $SD = 2.3$) event during the test trials. The analysis also revealed a significant order x event interaction, $F(1, 8) = 23.05$, $p < .0025$.¹

The two-way ANOVA for the large-window condition revealed that the main effect of event was not significant, $F(1, 8) = 1.25$, $p > .25$, Cohen's $d = -0.3$, suggesting that the infants looked about equally at the two events during the test trials (new-goal event: $M = 12.3$, $SD = 3.7$; old-goal event: $M = 13.7$, $SD = 4.6$). The analysis also revealed a marginally significant order x event interaction, $F(1, 8) = 4.58$, $p < .07$.²

Inspection of the individual infants' looking times revealed that 8 of the 10 infants in the small-window condition looked longer at the new- than at the old-goal event, Wilcoxon signed-ranks $T = 6$, $p < .05$, whereas only 3 of the 10 infants in the large-window condition did so, $T = 18$, $p > .35$.

Discussion

The infants in the small-window condition looked reliably longer at the new-goal than at the old-goal event. Their responses were consistent with the conclusion that they (1) interpreted the agent's action of looking at the football as opposed to the box during familiarization as goal-directed, (2) expected the agent to continue acting on her goal and keep looking at the football during test, and hence (3) responded with heightened interest when she looked at the box in the new-goal event. These results suggest that 8-month-olds are sensitive to situational constraints when they engage in goal-related reasoning about agents' actions: given that a barrier separates an agent from the objects, infants act as if they realize that the agent's looking behavior can indicate her target object.

The infants in the large-window condition, however, looked about equally at the two events, consistent with the hypothesis that they might still find the agent's looking at the football rather than the box during familiarization ambiguous in terms of goal-directedness, and therefore formed no expectation as to which of the two objects the agent should look at during test.

However, there is an alternative explanation for the results of Experiment 1. Perhaps negative results were obtained in the large-window but not in the small-window condition because some aspects of the stimuli, events, or procedure in the large-window condition were more overwhelming or confusing to the infants than those in the small-window condition. For example, being able to see more of the agent in the large-window than in the small-window condition might have distracted the infants during familiarization and thus affected their encoding of the agent's looking behavior. These alternatives were rendered less likely because the infants' looking during familiarization did not differ in the two conditions. Nevertheless, Experiment 2 was conducted to rule out alternative explanations and to provide further evidence supporting the conclusion that young infants would consider situational constraints in order to perceive the goal underlying an agent's act of looking.

Experiment 2

In Experiment 2, 8-month-old infants were assigned to one of two conditions, a hands-occupied or a hands-free condition and tested with a procedure similar to that of Experiment 1 (see Fig. 3). The hands-occupied condition was similar to the large-window condition of Experiment 1 except that throughout the experiment, the infants could see that with both hands, the agent held onto a sippy cup that was placed on the apparatus floor in front of her. The hands-free condition was similar to the hands-occupied condition except that the agent did not hold the cup; she laid her hands on the apparatus floor, one on each side of the cup.

If infants in the large-window condition of Experiment 1 looked equally at the new-goal and old-goal events because they were confused by some aspects of the apparatus and procedure, infants in Experiment 2 might find both the hands-occupied and hands-free conditions confusing or overwhelming. For example, the infants in the two conditions might be distracted by the agent sitting behind the large window and/or the sippy cup on the apparatus

floor. Therefore, infants in both conditions of Experiment 2 should behave like those in the large-window condition of Experiment 1 and look about equally at the new- and old-goal events.

In contrast, if the infants' looking responses in Experiment 1 were consistent with their having recognized that the agent's action of looking was goal-directed in the small-window but not in the large-window condition, a different pattern of results should be found in Experiment 2. In the hands-occupied condition, the infants might recognize that the agent looked at the object because her hands were occupied with the sippy cup. They would thus interpret her looking actions during familiarization as goal-directed and expect the agent to continue looking at the football during test. Therefore, the infants should find the new-goal event inconsistent with their expectation because the agent changed her goal to look at the box and hence look reliably longer at the new- than at the old-goal event, as did those in the small-window condition of Experiment 1. Conversely, the infants in the hands-free condition should reason that the agent's gaze at the football during familiarization was insufficient to suggest that she had a goal directed towards it, as those in the large-window condition of Experiment 1. They should have no expectation as to what the agent would do during test and therefore look about equally at the new- and old-goal events.

Experiment 2 would thus confirm and extend the results of Experiment 1. In the small-window condition of Experiment 1, the constraint that made the agent look at the football was the back wall of the apparatus serving as a barrier between the agent and the objects. In the hands-occupied condition of Experiment 2, the constraint was imposed by the agent herself: her hands were already busy holding the cup. Finding positive results in both the small-window and hands-occupied conditions would thus support the conclusion that infants can consider situational constraints to attribute goals to agents' otherwise ambiguous actions.

Method

Participants

Participants were 20 healthy, full-term infants, 9 male and 11 female (age range: 7 months, 3 days to 8 months, 21 days, $M = 7$ months, 24 days); 10 infants, 4 male and 6 female, were randomly assigned to the hands-occupied condition ($M = 7$ months, 24 days) and 10 to the hands-free condition ($M = 7$ months, 24 days). Another 5 infants were tested but their data were not included, because they were distracted (2), active (1), the infant looked for

the maximum time allowed (60 s) on all four test trials (1), or because of an average difference in test looking times that was more than 2 SDs from the mean (1).

Apparatus, stimuli, events, and procedure

The apparatus, stimuli, events, and procedure used in Experiment 2 were similar to those of the large-window condition of Experiment 1, except that a sippy cup was added. The blue and green plastic cup was 10.5 cm high and 6.5 cm in diameter. It had a spout, 2 cm high, on a closed top and two handles, one on each side. The cup was placed on the apparatus floor, centered on the large window, and in front of the agent. In the hands-occupied condition, the agent held the cup by the handles with both hands throughout the experiment. In the hands-free condition, the agent's hands were flat on the apparatus floor, palms down, one on each side of the cup and 7.5 cm from it.

As in Experiment 1, the infants received four familiarization trials followed by four test trials alternating between the new-goal and old-goal events appropriate for their condition. The infants were highly attentive during the 1-s pre-trials at the start of the familiarization and test trials (all M's = 1.0). The criteria to end the familiarization and test main-trials were identical to those used in Experiment 1, respectively.

Preliminary analyses of the test data revealed no interactions involving sex with condition and/or event, $F(1, 12) < 2.72$, $ps > .12$; the data were therefore collapsed across sex in subsequent analyses.

Results

Familiarization trials

The infants' looking times during the main-trial portion of the four familiarization trials were averaged and analyzed in the same manner as the familiarization data of Experiment 1. The main effect of condition was not significant, $F(1, 18) = 0.06$, suggesting that the infants in the two conditions tended to look equally during the familiarization phase (hands-occupied condition: M = 20.2, SD = 5.5; hands-free condition: M = 19.6, SD = 4.6).

Test trials

The infants' looking times during the main-trial portion of the four test trials (see Fig. 2) were averaged and analyzed in the same manner as the test data of Experiment 1. The analysis yielded a significant main effect of

event, $F(1, 16) = 4.46$, $p = .05$, indicating that the infants looked reliably longer at the new- than at the old-goal event across conditions. Critically, the analysis also revealed a significant condition \times event interaction, $F(1, 16) = 5.95$, $p < .05$. The order \times event interaction was marginally significant, $F(1, 16) = 4.13$, $p < .06$. The main effect of condition, $F(1, 16) = 2.93$, $p > .10$, and the interaction among condition, order, and event, $F(1, 16) = 1.01$, $p > .30$, were not significant.

As in Experiment 1, separate two-way ANOVAs with order as the between-subjects factor and event as the within-subject factor were performed in the two conditions. In the hands-occupied condition, the two-way ANOVA yielded a significant main effect of event, $F(1, 8) = 8.05$, $p < .025$, Cohen's $d = 0.8$, indicating that the infants looked reliably longer at the new-goal ($M = 18.6$, $SD = 7.4$) than at the old-goal ($M = 14.0$, $SD = 4.3$) event during the test trials. No other effect was significant.

The two-way ANOVA for the hands-free condition revealed that the main effect of event was not significant, $F(1, 8) = 0.08$, $d = -0.1$, suggesting that the infants looked about equally at the two events during the test trials (new-goal event: $M = 12.0$, $SD = 5.4$; old-goal event: $M = 12.4$, $SD = 5.2$).

Inspection of the individual infants' looking times revealed that 8 of the 10 infants in the hands-occupied condition looked longer at the new-goal than at the old-goal event, $T = 6$, $p < .05$, whereas only 5 of the 10 infants in the hands-free condition did so, $T = 26$, n.s..

Discussion

The infants in the hands-occupied condition looked reliably longer at the new-goal than at the old-goal event. Their responses supported the conclusion that the infants (1) realized that the agent's actions of looking at the football rather than the box during familiarization revealed her goal directed towards the football, (2) expected the agent to act in a manner consistent with her goal during test, and (3) responded with increased attention when she looked at the box in the new-goal event. These results thus extended those of the small-window condition of Experiment 1 by showing that in a situation in which an agent looked at an object because her hands are occupied, infants seemed to take this into consideration when deciding that the object is the recipient of the agent's intent.

To the infants in the hands-free condition, in contrast, the agent's gaze at the football during familiarization was still ambiguous in terms of goal-directedness. Therefore, they had no prediction of what the agent should do during test and reacted as if they accepted that the agent could look at either the football or the box. These results confirmed those of the large-window condition of Experiment 1.

The results of Experiment 2 thus ruled out low-level explanations of the Experiment 1 data. Had the infants in Experiment 1 found the large-window but not the small-window condition confusing, those in the two conditions of Experiment 2 should also have been confused and should have looked about equally at the two events during test.

General Discussion

The results of the present experiments indicate that, when watching an agent look at object-A but not object-B, 8-month-old infants respond as if they realize that the agent has a goal of looking at object-A, when it is clear that her looking action is rational within given situational constraints: a barrier separates her and the object, or her hands are occupied. Infants therefore expect the agent to continue looking at object-A even when the positions of object-A and object-B are reversed, and respond with increased attention when the agent looks at object-B instead. In contrast, when it is unclear why the agent looks at the object, infants' responses do not suggest that they encode the relationship between the agent's looking behavior and the target of her gaze. As a result, they form no prediction as to which of the two objects, object-A or object-B, that the agent should look at when the two objects are in reversed positions.³ Therefore, at least by 8 months of age, infants act as though they can make sense of others' actions with regards to situational constraints.

However, a caveat of the present research is that the experimental design was not fully balanced: whether the infants saw the new- or old-goal event first during test was counterbalanced, but which object was the goal or which side it was on during familiarization was not. Thus, the current design does not eliminate the possibility that infants had a priori preference for the box (new-goal event), which was demonstrated in the test phase of the small-window and the hands-occupied conditions and inhibited in the large-window and the hands-free conditions; therefore, the present results should be taken with caution. However, in each experiment presented here, one condition served as the control for the other condition and Experiment 2 served as the control for Experiment 1. For example, the two conditions in Experiment 2 were highly similar except for the position of the agent's hands. If infants

preferred when the actor looked at the box and/or its location during test, this preference should have affected the results in both the hands-free and the hands-occupied conditions. Thus, if there was a preference for the box, it is not so overwhelming as to always determine infant looking times. At a minimum, these experiments demonstrate that infants' looking behavior was influenced by the different situational constraints across conditions, a claim supported by the reliable condition by event interactions in each experiment.

It was possible that the situations used in the small-window condition of Experiment 1 and in the hands-occupied condition of Experiment 2 might have induced different action analyses in infants. In the former, it seemed clear that the agent could do nothing but look. Thus, through looking, she could indicate her goal object. In the latter, the agent had other options: she could have put down the sippy cup to grasp the object, which would have made her looking action unnecessary; yet she chose not to do so. In fact, the infants seemed to treat both situations as providing an explanation for why the agent would look but not grasp the object, consistent with findings with non-human primates. Built on Gergely et al. (2002), Wood and his colleagues (2007) found evidence that non-human primates act as if they interpret a person's rational actions, within given situational constraints, as goal-directed. In their "hand-occupied" condition, the person used his elbow to touch one of two food containers because his hand was holding an object. In the "hand-empty" condition, the person still used his elbow but his hand was free. The subjects chose the food container he touched reliably more often in the hand-occupied condition than in the hand-empty condition, consistent with the conclusion that they interpreted his action in the hand-occupied condition as directed towards the goal of indicating food source. The results for the hand-occupied condition were also found when the person's other hand was hidden behind his back, even though he could have used the hidden hand to grasp the container, which would have made his unfamiliar elbow touch less rational. However, the non-human primates' responses were consistent with the hypothesis that the person had to use his elbow to achieve his goal simply because his hand was at this moment unavailable. Therefore, they acted as if they considered the "current and immediate constraints" (p. 1405) to interpret others' actions, rather than imagine what could have happened. The results from the small-window and the hands-occupied conditions are consistent with the infants having a similar interpretation, that they interpreted the agent's looking as goal-directed because it was the rational action given the situational constraints present for the agent.

On the other hand, the results of the large-window condition of Experiment 1 and the hands-free condition of Experiment 2 supported the hypothesis that these were ambiguous situations to infants younger than 12 months. The agent's simple looking action was unfamiliar and unclear in terms of goal-directedness (Woodward, 2003). It did not seem to matter whether the agent's hands were visible (hands-free condition) or not (large-window condition). In both conditions, there was no reason why the agent looked, and infants' responses were consistent with their having failed to interpret her looking as goal-directed. The present hands-free condition is similar to that used with non-human primates described above (Wood et al., 2007): the subjects responded as though they were uncertain about why the person used his elbow to touch a container and hence failed to interpret this unusual action as goal-directed. However, the original hands-free condition of Gergely et al. (2002) posed a different task to infants. There was no doubt that the agent's goal was to turn on the light box. Infants were left with two means to reenact the goal, either to use their own hands or to faithfully copy the agent's action and use the head. When there was no apparent reason why the agent used her head, infants' actions were consistent with their having inferred that there was something special about the head action and hence did so themselves (Gergely et al., 2002; see also Meltzoff, 1988). This comparison leads to an interesting prediction. When the ambiguity of looking action is no longer a problem to infants, e.g., when 12-month-olds succeed in a situation essentially similar to the large-window condition, as in Woodward (2003), they should also succeed in the hands-free condition because the fact that the agent looks at an object instead of using her hands to touch it may indicate that there is something special about looking.

The preceding analyses give rise to at least three related questions. First, how would infants make predictions about the agent's actions when the situations changed? For example, in the small-window condition, after detecting the agent's goal as to look at the football during familiarization, what expectations would the infants hold if during test, the window was made larger so that the agent could potentially grasp the object? Similarly, in the hands-occupied condition, what would infants expect the agent to do if during test, her hands were no longer holding the sippy cup? Would infants expect her to look at her goal object or to use her hand to grasp the object? This is relevant to the second issue, namely, how infants determine whether an action is rational or not. According to Csibra, Gergely, Southgate, and their colleagues (e.g., Gergely & Csibra, 2003; Gergely et al., 1995; Southgate et al., 2008), the rationality of actions is largely equivalent to the efficiency of actions. To evaluate whether an action is an efficient

means to an end, assuming that the end state stays the same, one considers factors such as number of steps in the action, the length of the action path, and how long the action takes (e.g., Southgate et al., 2008). In this sense, the act of looking at an object and the act of grasping an object with one's hand may be more or less similar in terms of efficiency – both involve simple, one-step actions. To some extent, looking may be more efficient than grasping, given that looking usually takes less time. To return to the first question, when the situations change to render both looking and grasping possible, infants may still expect the agent to look instead of grasp because it's efficient. This leads to the third question: does an agent achieve different goals when she looks at an object and when she grasps an object? Assuming that the agent looks at her goal object to obtain information about it, when she contacts the object, she presumably obtains more information, both visual (after all, she is also looking at it) and tactile. If so, will this make the grasping action more efficient than looking? Will infants in turn expect agents to grasp objects whenever they can? Could this speak to why infants' responses are consistent with their interpretation of others' grasping as goal-directed before looking? There is evidence for infants' sensitivity to relative efficiency of goal-directed actions (e.g., Carpenter et al., 2005; Gergely et al., 2002; Schwier et al., 2006; Southgate et al., 2008; Zmyi et al., 2009). Future research needs to examine whether and how infants act as if they consider the "richness" of goals, i.e., how much information a goal affords, to evaluate goal-directed actions.

Theoretical implications

Where do infants' expectations about agents and their goal-directed actions come from? There is an intense debate on the nature and development of early intentional reasoning. According to some researchers, experiences with human agents play a very important role in infants' ability to understand others' intentional actions: as infants become more accomplished in producing intentional actions, they are able to understand similar actions in others, in part due to innate abilities to pair their own actions and intentional states with those of others (e.g., Carpenter et al., 1998; Meltzoff, 1995, 1999, 2005; Sommerville et al., 2005; Tomasello, 1999; Tomasello et al., 2005; Woodward, 2005; Woodward et al., 2001). Other researchers have suggested that infants are born with an abstract computational system that guides from the beginning their interpretation of agents' intentional actions (e.g., Baron-Cohen, 1995; Gergely & Csibra, 2003; Gergely et al., 1995; Johnson, 2003; Leslie, 1994, 1995; Luo & Baillargeon, 2005a; Onishi & Baillargeon, 2005; Premack, 1990; Premack & Premack, 1995). Two related issues, among others,

are central to the differences between these two approaches: one concerns non-human agents and the other concerns how infants come to identify agents' goal-directed actions.

The experience-based approach predicts that infants should initially be limited to reasoning about human agents, and that infants should first identify the goals that underlie familiar actions of human agents, especially those they themselves can produce, and should gradually become more flexible with experience. In contrast, the system-based approach predicts that young infants should be able to reason about actions of any individual they identify as an agent, whether human or non-human.

Among different accounts favoring the system-based approach, Csibra, Gergely, and their colleagues argue that infants' interpretation of agents' goal-directed actions is derived from the working of an action representation system, a "teleological stance," which consists of three elements: the action, the goal, and the situational constraints on the action, and that the system evaluates the three elements and encodes an action as goal-directed if it appears as an efficient or rational means toward the goal within the situational constraints (e.g., Csibra et al., 2003; Csibra & Gergely, 2007; Gergely & Csibra, 2003; Gergely et al., 1995). They propose that infants use behavioral cues to identify the goal-directedness of agents' actions, such as the equifinal variations of agents' actions to achieve a goal, and the presence of a change or an outcome brought by the agent's actions (Csibra et al., 2003).

Results of Sommerville, Woodward, and their colleagues (e.g., Sommerville et al., 2005; Woodward, 2005; Woodward et al., 2001), as described in the Introduction, document the importance of experience in infants' recognition of agents' goal-directed actions, supporting the experience-based approach. The results of Bíró, Johnson, Jovanovic, Király, and their colleagues (e.g., Bíró & Leslie, 2007; Johnson, Ok et al., 2007; Jovanovic et al., 2007; Király et al., 2003), in contrast, provide evidence for the proposals by Csibra, Gergely and their colleagues (Csibra et al., 2003): young infants treat agents' actions as goal-directed when provided with appropriate behavioral information, even when these actions are novel or ambiguous to them. Together with increasing evidence indicating that young infants seem to reason about the actions of non-human agents which bear little physical semblance to human agents (e.g., Csibra, 2008; Luo, 2009; Luo & Baillargeon, 2005a, 2005b), these reports lend support to the system-based approach.

The present results support the conclusion that young infants are also sensitive to situational constraints

when reasoning about agents' actions. These results thus appear consistent with the account of Csibra, Gergely, and their colleagues (Csibra et al., 2003; Csibra & Gergely, 2007; Gergely & Csibra, 2003; Gergely et al., 1995): infants consider situational constraints to decide whether an agent's action within the situation is goal-directed or not. Along with similar results obtained with non-human primates (e.g., Buttelmann et al., 2007; Wood et al., 2007), this points to the possibility that abilities to "read" others' actions as goal-directed may have evolutionary roots and be innately based in infants, again supporting the system-based view.

However, there is no doubt that experience helps infants perceive more and more actions of agents, even those that are impoverished in behavioral cues, as goal-directed. Although experience does not seem to be a precondition for infants' recognition of agents and their goals, it remains highly likely that infants' abilities to attend to situational constraints imposed upon agents and behavioral cues embedded in agents' actions in their intentional understanding become more and more refined with learning and experience. For example, infants at 8 months may have encountered real-life situations in which one is separated from an object or one's hands are already full, which helps them make sense of the situations used in the present research. Therefore, it is worthwhile to make an attempt to synthesize the experience-based and system-based approaches. Infants may behave as though they are able to make use of available information, by relying on a predisposition to attend to behavioral cues and situational constraints, or by learning from prior experience about human agents and their actions, to "read" agents' actions. For example, when infants watch an agent, human or non-human, act on objects in a scene, they may respond as if taking note of the actions the agent undertakes (including whether the actions are familiar or unfamiliar to them and which behavioral cues are embedded in the actions), the physical setting of the scene (including situational constraints on the agent's actions), and if available, what type of end state the actions achieve (including how much information the agent can obtain). Assuming that to achieve a goal, the agent always selects actions that are causally appropriate and reasonably efficient within the situation, infants make predictions about the agent's actions that are consistent with the understanding that the agent performs these actions to fulfill certain goals.

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References

- Baillargeon, R. (1986). Representing the existence and the location of hidden objects: Object permanence in 6- and 8-month-old infants. *Cognition*, *23*, 21-41.
- Barna, J., & Legerstee, M. (2005). Nine and twelve-month-old infants relate emotions to people's actions. *Cognition and Emotion*, *19*, 53-67.
- Baron-Cohen, S. (1995). *Mindblindness: an essay on autism and theory of mind*. Cambridge, MA: MIT Press.
- Bates, E., Benigni, L., Bretherton, I., Camaioni, L., & Volterra, V. (1979). *The emergence of symbols: Cognition and communication in infancy*. New York: Academic Press.
- Behne, R., Carpenter, M., Call, J., & Tomasello, M. (2005). Unwilling versus unable: Infants' understanding of intentional action. *Developmental Psychology*, *41*, 328-337.
- Bíró, S., Csibra, G., & Gergely, G. (2007). The role of behavioral cues in understanding goal-directed actions in infancy. *Progress in Brain Research*, *164*, 303-323.
- Bíró, S., & Leslie, A. M. (2007). Infants' perception of goal-directed actions: Development through cue-based bootstrapping. *Developmental Science*, *10*, 379-398.
- Buttelmann, D., Carpenter, M., Call, J., & Tomasello, M. (2007). Enculturated chimpanzees imitate rationally. *Developmental Science*, *10*, F31-F38.
- Butterworth, G., Franco, F., McKenzie, B., Graupner, L., & Todd, B. (2002). Dynamic aspects of visual event perception and the production of pointing by human infants. *British Journal of Developmental Psychology*, *20*, 1-24.
- Butterworth, G., & Jarrett, N. (1991). What minds have in common is space: spatial mechanisms serving joint visual attention in infancy. *British Journal of Developmental Psychology*, *9*, 55-72.
- Carpenter, M., Call, J., & Tomasello, M. (2005). Twelve- and 18-month-olds copy actions in terms of goals. *Developmental Science*, *8*, F13-F20.
- Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention, and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development*, *63*(4).

- Corkum, V., & Moore, C. (1998). The origins of joint visual attention in infants. *Developmental Psychology, 34*, 28-38.
- Csibra, G. (2008). Goal attribution to inanimate agents by 6.5-month-old infants. *Cognition, 107*, 705-717.
- Csibra, G., Biró, S., Koós, O., & Gergely, G. (2003). One-year-old infants use teleological representations of actions productively. *Cognitive Science, 27*, 111-133.
- Csibra, G., & Gergely, G. (2007). 'Obsessed with goals': Functions and mechanisms of teleological interpretation of actions in humans. *Acta Psychologica, 124*, 60-78.
- Csibra, G., Gergely, G., Biró, S., Koós, O., & Brockbank, M. (1999). Goal attribution without agency cues: The perception of 'pure reason' in infancy. *Cognition, 72*, 237-267.
- D'Entremont, B., Hains, S. M. J., & Muir, D. (1997). A demonstration of gaze-following in 3- to 6-month-olds. *Infant Behavior and Development, 20*, 569-572.
- Daum, M. M., Prinz, W., & Aschersleben, G. (2008). Encoding the goal of an object-directed but uncompleted reaching action in 6- and 9-month-old infants. *Developmental Science, 11*, 607-619.
- Gergely, G., Bekkering, H., & Király, I. (2002). Rational imitation in preverbal infants. *Nature, 415*, 6873.
- Gergely, G., & Csibra, G. (2003). Teleological reasoning in infancy: The naïve theory of rational action. *Trends in Cognitive Sciences, 7*, 287-292.
- Gergely, G., Nádasdy, Z., Csibra, G., & Biró, S. (1995). Taking the intentional stance at 12 months of age. *Cognition, 56*, 165-193.
- Guajardo, J. J., & Woodward, A. L. (2004). Is agency skin-deep? Surface attributes influence infants' sensitivity to goal-directed action. *Infancy, 6*, 361-384.
- Hamlin, J. K., Hallinan, E. V., & Woodward, A. L. (2008). Do as I do: 7-month-old infants selectively reproduce others' goals. *Developmental Science, 11*, 487-494.
- Hamlin, J. K., Wynn, K., & Bloom, P. (2007). Social evaluation by preverbal infants. *Nature, 450*, 557-559.
- Hofer, T., Hauf, P., & Aschersleben, G. (2007). Infants perception of goal-directed actions on video. *British Journal of Developmental Psychology, 25*, 485-498.

Hofer, T., Hohenberger, T., Hauf, P. & Aschersleben, G. (2008). The link between maternal interaction style and infant action understanding. *Infant Behavior and Development, 31*, 115-126.

Johnson, S. C. (2003). Detecting agents. *Philosophical Transactions of the Royal Society of London, 358*, 549-559.

Johnson, S. C., Ok, S., & Luo, Y. (2007). The attribution of attention: Nine-month-olds' interpretation of gaze as goal-directed action. *Developmental Science, 10*, 530-537.

Johnson, S. C., Shimizu, Y., & Ok, S. (2007). Actors and actions: The role of agent behavior in infants' attribution of goals. *Cognitive Development, 22*, 310-322.

Jovanovic, B., Király, I., Elsner, B., Gergely, G., Prinz, W., & Aschersleben, G. (2007). The role of effects for infant's perception of action goals. *Psychologia, 50*, 273-290.

Király, I., Jovanovic, B., Prinz, W., Aschersleben, G., & Gergely, G. (2003). The early origins of goal attribution in infancy. *Consciousness & Cognition, 12*, 752-769.

Kuhlmeier, V. A., Wynn, K., & Bloom, P. (2003). Attribution of dispositional states by 12-month-olds. *Psychological Science, 14*, 402-408.

Leslie, A. M. (1994). ToMM, ToBY, and Agency: Core architecture and domain specificity. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 119-148). New York: Cambridge University Press.

Leslie, A. M. (1995). A theory of agency. In D. Sperber, D. Premack & A. J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 121-141). Oxford, UK: Clarendon Press.

Liszkowski, U., Carpenter, M., Henning, A., Striano, T., & Tomasello, M. (2004). Twelve-month-olds point to share attention and interest. *Developmental Science, 7*, 297-307.

Liszkowski, U., Carpenter, M., & Tomasello, M. (2007). Pointing out new news, old news, and absent referents at 12 months of age. *Developmental Science, 10*, F1-F7.

Luo, Y. (2009). *Three-month-old infants attribute goals to a non-human agent*. Manuscript under review.

Luo, Y., & Baillargeon, R. (2005a). Can a self-propelled box have a goal? Psychological reasoning in 5-month-old infants. *Psychological Science, 16*, 601-608.

Luo, Y., & Baillargeon, R. (2005b). *Infants' reasoning about agents' goals and perceptions*. Paper presented at the biennial meeting of the Society for Research in Child Development.

Luo, Y., & Baillargeon, R. (2007). Do 12.5-month-old infants consider what objects others can see when interpreting their actions? *Cognition*, *105*, 489-512.

Luo, Y., & Beck, W. (in press). Do you see what I see? Infants' reasoning about others' incomplete perceptions. *Developmental Science*.

Luo, Y., & Johnson, S. C. (2009). Recognizing the role of perception in action at 6 months. *Developmental Science*, *12*, 142-149.

Meltzoff, A. M. (1988). Infant imitation after a 1-week delay: long-term memory for novel acts and multiple stimuli. *Developmental Psychology*, *24*, 470-476.

Meltzoff, A. M. (1995). Understanding the intentions of others: re-enactments of intended acts by 18-month-old children. *Developmental Psychology*, *31*, 838-850.

Meltzoff, A. M. (1999). Origins of theory of mind, cognition, and communication. *Journal of Communication Disorders*, *32*, 251-269.

Meltzoff, A. M. (2005). Imitation and other minds: The "like me" hypothesis. In S. Hurley & N. Chater (Eds.), *Perspectives on imitation: From neuroscience to social science* (Vol. 2, pp. 55-77). Cambridge, MA: MIT Press.

Needham, A., Barrett, T., & Peterman, K. (2002). A pick-me up for infants' exploratory skills: Early simulated experiences reaching for objects using "sticky mittens" enhances young infants' exploration skills. *Infant Behavior and Development*, *25*, 279-295.

Onishi, K. H., & Baillargeon, R. (2005). Do 15-month-old infants understand false beliefs? *Science*, *308*, 255-258.

Phillips, A., & Wellman, H. M. (2005). Infants' understanding of object-directed action. *Cognition*, *98*, 137-155.

Phillips, A., Wellman, H. M., & Spelke, E. S. (2002). Infants' ability to connect gaze and emotional expressions to intentional action. *Cognition*, *85*, 53-78.

Premack, D. (1990). The infant's theory of self-propelled objects. *Cognition*, *36*, 1-16.

Premack, D., & Premack, A. J. (1995). Origins of human social competence. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 205-218). Cambridge, MA: MIT Press.

Premack, D., & Premack, A. J. (1997). Infants attribute value +/- to the goal-directed actions of self-propelled objects. *Journal of Cognitive Neuroscience*, *9*, 848-856.

Repacholi, B. (1998). Infants' use of attentional cues to identify the referent of another person's emotional expression. *Developmental Psychology*, *34*, 1017-1025.

Repacholi, B., & Gopnik, A. (1997). Early understanding of desires: Evidence from 14- and 18-month-olds. *Developmental Psychology*, *33*, 12-21.

Schwier, C., van Maanen, C., Carpenter, M., & Tomasello, M. (2006). Rational imitation in 12-month-old infants. *Infancy*, *10*, 303-311.

Shimizu, Y. A., & Johnson, S. C. (2004). Infants' attribution of a goal to a morphologically unfamiliar agent. *Developmental Science*, *7*, 425-430.

Sodian, B., & Thoermer, C. (2004). Infants' understand of looking, pointing, and reaching as cues to goal-directed action. *Journal of Cognition and Development*, *5*, 289-316.

Sodian, B., Thoermer, C., & Metz, U. (2007). Now I see it but you don't: 14-month-olds can represent another person's visual perspective. *Developmental Science*, *10*, 199-204.

Sommerville, J. A., & Woodward, A. L. (2005). Pulling out the structure of intentional action: The relation between action processing and production in infancy. *Cognition*, *95*, 1-30.

Sommerville, J. A., Woodward, A. L., & Needham, A. (2005). Action experience alters 3-month-old infants' perception of others' actions. *Cognition*, *96*, B1-B11.

Song, H., & Baillargeon, R. (2007). Can 9.5-month-old infants attribute to an agent a disposition to perform an action on objects? *Acta Psychologica*, *124*, 79-105.

Song, H., & Baillargeon, R. (2008). Infants' reasoning about others' false perceptions. *Developmental Psychology*, *44*, 1789-1795.

Song, H., Baillargeon, R., & Fisher, C. (2005a). Can infants attribute to an agent a disposition to perform a particular action? *Cognition*, *98*, B45-B55.

Song, H., Baillargeon, R., & Fisher, C. (2005b). *The development of infants' use of verbal information when reasoning about others' actions*. Paper presented at the Biennial meeting of the Society for Research in Child Development.

Song, H., Onishi, K. H., Baillargeon, R., & Fisher, C. (2008). Can an actor's false belief be corrected through an appropriate communication? Psychological reasoning in 18.5-month-old infants. *Cognition*, *109*, 295-315.

Southgate, V., Johnson, M. H., & Csibra, G. (2008). Infants attribute goals even to biomechanically impossible actions. *Cognition*, *107*, 1059-1069.

Southgate, V., Senju, A., & Csibra, G. (2007). Action anticipation through attribution of false belief by two-year-olds. *Psychological Science*, *18*, 587-592.

Surian, L., Caldi, S., & Sperber, D. (2007). Attribution of beliefs by 13-month-old infants. *Psychological Science*, *18*, 580-586.

Tomasello, M. (1999). Having intentions, understanding intentions, and understanding communicative intentions. In P. D. Zelazo, J. W. Astington & D. R. Olson (Eds.), *Developing theories of intention: Social understanding of self control* (pp. 63-75). Mahwah, NJ: Erlbaum.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and Brain Sciences*, *28*, 675-735.

Tomasello, M., Carpenter, M., & Liszkowski, U. (2007). A new look at infant pointing. *Child Development*, *78*, 705-722.

Wood, J. N., Glynn, D. D., Phillips, B. C., & Hauser, M. D. (2007). The perception of rational, goal-directed action in nonhuman primates. *Science*, *317*, 1402-1405.

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition*, *69*, 1-34.

Woodward, A. L. (1999). Infants' ability to distinguish between purposeful and nonpurposeful behavior. *Infant Behavior and Development*, *22*, 145-160.

Woodward, A. L. (2003). Infants' developing understanding of the link between looker and object. *Developmental Science*, *6*, 297-311.

Woodward, A. L. (2005). The infant origins of intentional understanding. In R. V. Kail (Ed.), *Advances in child development and behavior* (Vol. 33, pp. 229-262). Amsterdam: Elsevier.

Woodward, A. L., & Guajardo, J. J. (2002). Infants' understanding of the point gesture as an object-directed action. *Cognitive Development, 17*, 1060-1084.

Woodward, A. L., & Sommerville, J. A. (2000). Twelve-month-old infants interpret action in context. *Psychological Science, 11*, 73-77.

Woodward, A. L., Sommerville, J. A., & Guajardo, J. J. (2001). How infants make sense of intentional action. In B. Malle, L. Moses & D. Baldwin (Eds.), *Intentionality: A key to human understanding* (pp. 146-169). Cambridge, MA: MIT Press.

Zmyj, N., Daum, M. M., & Aschersleben, G. (2009). The development of rational imitation in 9- and 12-month-old infants. *Infancy, 14*, 131-141.

Footnotes

1. Finding significant interactions between order and event is not uncommon in looking-time studies (e.g., Baillargeon, 1986; Csibra et al., 1999; Gergely et al., 1995). The significant order x event interaction was due to the fact that the infants who saw the new-goal event first looked reliably longer at this event ($M = 31.1$, $SD = 4.3$) than at the old-goal event ($M = 14.3$, $SD = 2.3$), $F(1, 8) = 49.57$, $p < .00025$, while those who saw the old-goal event first looked numerically longer at the new-goal ($M = 12.3$, $SD = 4.6$) than at the old-goal event ($M = 11.7$, $SD = 1.7$), $F(1, 8) = 0.06$. As suggested by Baillargeon (1986), these results might be accounted for by assuming that two tendencies contributed to the infants' looking behavior. One was that the infants tended to look long at the first test event they saw; the other was that the infants looked long at the new-goal event because it was inconsistent with their expectations as to what the agent should do during test. Thus, the infants who saw the new-goal event first looked remarkably longer at the new-goal than at the old-goal event because these two tendencies worked in the same direction, whereas those who saw the old-goal event first tended to look equally at the two events because these two tendencies canceled each other out. However, it is noteworthy that regardless of the order, a greater number of infants looked longer at the new-goal than at the old-goal event, as confirmed by the Wilcoxon sign-ranks tests.

2. This marginally significant order x event interaction was due to the fact that in the large-window condition, while the infants who saw the new-goal event first looked about equally at the two test events, $F(1, 8) = 0.52$, although they looked slightly longer at the new-goal ($M = 12.1$, $SD = 4.6$) than at the old-goal event ($M = 10.8$, $SD = 2.7$), those who saw the old-goal event first looked reliably longer at the old-goal ($M = 16.6$, $SD = 4.5$) than at the new-goal event ($M = 12.5$, $SD = 3.1$), $F(1, 8) = 5.31$, $p = .05$. Since in the large-window condition, the infants formed no expectation as to what the agent should do during the test phase, neither the new-goal nor the old-goal event should elicit infants' long looking time for the reason that it violated the infants' expectations. Therefore, the infants only tended to look long at the first test event they saw, whether new-goal or old-goal.

3. In the small-window and hands-occupied conditions of the present experiments, what type of relationship did the infants encode between the agent's looking behavior and the target of her gaze, the football, during the familiarization trials? Throughout the text, this relationship has been referred to as a goal-directed one. However, another possibility

is that this relationship was dispositional: the agent looked at the football as opposed to the box because she preferred the football over the box, given the recent reports on infants' disposition attributions (e.g., Luo & Baillargeon, 2005a, 2007; Luo & Johnson, 2009; Repacholi, 1998; Repacholi & Gopnik, 1997; Song et al., 2005b). Both types of relationship would suggest that the infants should respond with increased attention when the agent looked at the box in the new-goal test event, because she acted in a manner inconsistent with her goal or her preference. The present results were insufficient to determine which relationship was at work.

Figure Captions

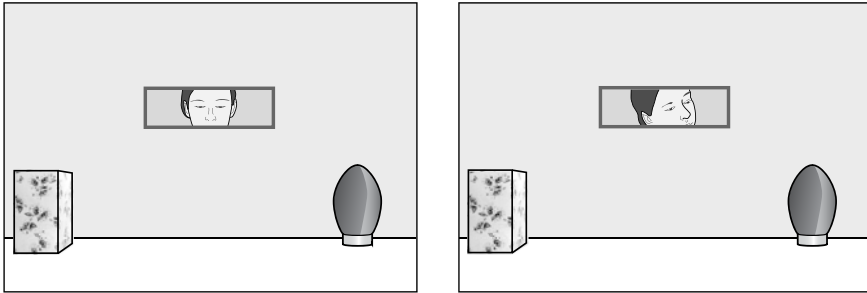
Figure 1. Schematic drawing of the familiarization and test events in Experiment 1

Figure 2. Mean looking times of the infants in Experiments 1 and 2 during the test trials. Error bars represent standard errors. A star (*) indicates $p < .05$.

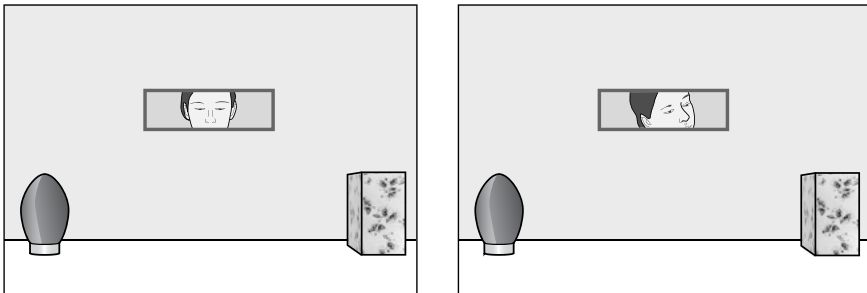
Figure 3. Schematic drawing of the familiarization and test events in Experiment 2

Small-window Condition

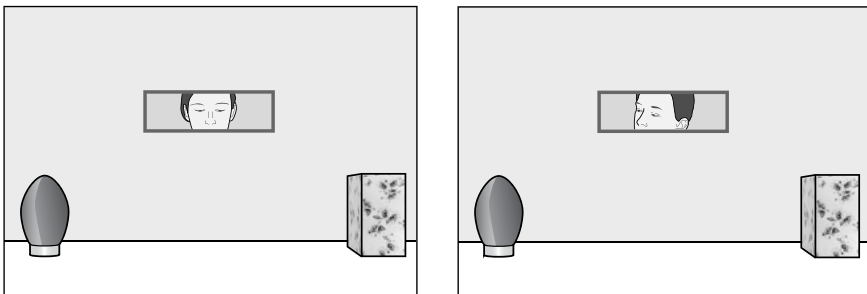
Familiarization Event



Test Events New-goal Event

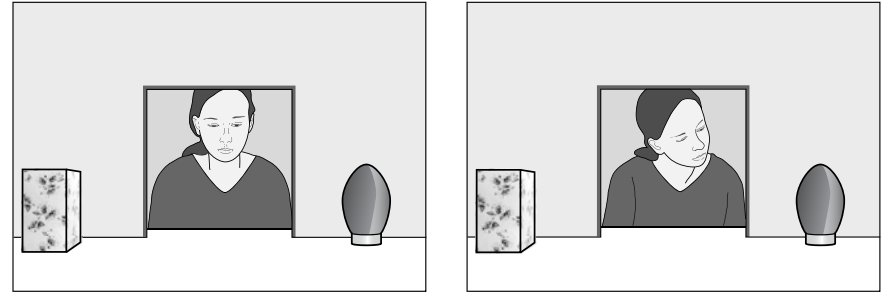


Old-goal Event

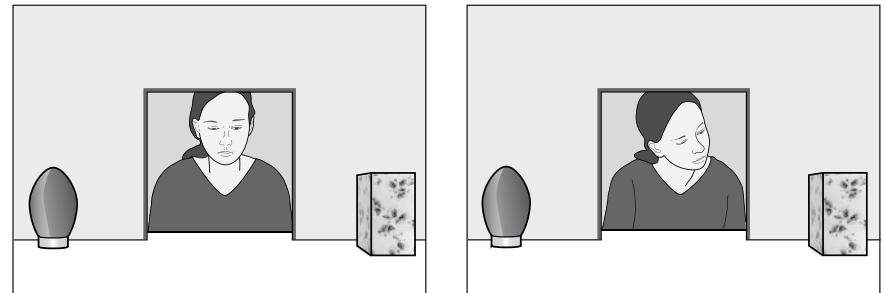


Large-window Condition

Familiarization Event



Test Events New-goal Event



Old-goal Event

