Available online at www.sciencedirect.com
ScienceDirect
Cognition 105 (2007) 489–512
COGNITION
www.elsevier.com/locate/COGNIT

Do 12.5-month-old infants consider what objects others can see when interpreting their actions? ☆

Yuyan Luo [a,*], Renée Baillargeon [b]

[a] *University of Missouri at Columbia, 20 McAlester Hall, Columbia, MO 65211, USA*
[b] *University of Illinois at Urbana-Champaign, 603 East Daniel Street, Champaign, IL 61820, USA*

Received 30 May 2006; revised 21 September 2006; accepted 20 October 2006

Abstract

The present research examined whether 12.5-month-old infants take into account what objects an agent knows to be present in a scene when interpreting the agent's actions. In two experiments, the infants watched a female human agent repeatedly reach for and grasp object-A as opposed to object-B on an apparatus floor. Object-B was either (1) visible to the agent through a transparent screen; (2) hidden from the agent (but not the infants) by an opaque screen; or (3) placed by the agent herself behind the opaque screen, so that even though she could no longer see object-B, she knew of its presence there. The infants interpreted the agent's repeated actions toward object-A as revealing a preference for object-A over object-B *only* when she could see object-B (1) or was aware of its presence in the scene (3). These results indicate that, when watching an agent act on objects in a scene, 12.5-month-old infants keep track of the agent's representation of the physical setting in which these actions occur. If the agent's representation is incomplete, because the agent is ignorant about some aspect of the setting, infants use the agent's representation, rather than their own more complete representation, to interpret the agent's actions.

Keywords: Psychological reasoning; Goals/dispositions; Perception; Infant cognition

☆ This manuscript was accepted under the editorship of Jacques Mehler.
* Corresponding author. Tel.: +1 573 882 0429.
E-mail address: luoy@missouri.edu (Y. Luo).

0010-0277/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.cognition.2006.10.007

1. Introduction

There is now considerable evidence that, beginning in the first year of life, infants attempt to make sense of others' intentional actions (e.g., Csibra, Gergely, Bíró, Koós, & Brockbank, 1999; Guajardo & Woodward, 2004; Király, Jovanovic, Prinz, Aschersleben, & Gergely, 2003; Sommerville & Woodward, 2005; Song & Baillargeon, in press). When watching an agent act on objects, for example, infants as young as 5 or 6 months of age may attribute to the agent goals and dispositions that help explain and predict the agent's actions (e.g., Bíró & Leslie, in press; Csibra, 2006; Kamerawi, Kato, Kanda, Ishiguro, & Hiraki, 2005; Luo & Baillargeon, 2005a; Woodward, 1998). Although the nature and development of early psychological reasoning remain the subjects of intense controversy (e.g., for recent reviews, see Csibra & Gergely, in press; Meltzoff, 2005; Tomasello, Carpenter, Call, Behne, & Moll, 2005; Woodward, 2005), the notion that infants in the first year of life already possess some understanding of intentional action is becoming widely accepted.

Investigations of early psychological reasoning have typically focused on situations where the infant and the agent share similar representations of the physical setting in which the agent's actions take place: both the infant and the agent know what objects are present in the setting and where these objects are located. Recently, however, researchers have begun to explore situations where the infant's and the agent's representations of the setting do *not* match, because the agent's representation deviates from reality (e.g., Onishi & Baillargeon, 2005; Surian, Caldi, & Sperber, in press). These experiments have involved situations in which the agent is absent when an object is moved to a new hiding location, so that the agent holds a false belief—in contrast to the infant's true belief—about the object's location. Results indicate that in such situations infants aged 13 months and older use the agent's representation, rather than their own, to make sense of the agent's actions.

In the following sections, we review some of the evidence that supports the preceding claims and then introduce the present research, which built on these findings. In Experiment 1, 12.5-month-old infants could see an object that was not visible to an agent, because of their different viewpoints; the experiment examined whether the infants would again use the agent's representation of the physical setting, rather than their own, to interpret the agent's actions.

1.1. Goals and dispositions

Research over the past 10 years indicates that infants aged 5 months and older can detect, in some situations at least, the *goals* that underlie agents' actions. A goal is defined as a particular state of affairs that an agent wants to achieve. The goals infants are able to successfully detect are typically simple and include contacting or obtaining an object (e.g., Guajardo & Woodward, 2004; Luo & Baillargeon, 2005a; Phillips & Wellman, 2005; Shimizu & Johnson, 2004; Sodian & Thoermer, 2004; Sommerville & Woodward, 2005; Woodward, 1998, 1999; Woodward & Sommerville, 2000), displacing an object (e.g., Király et al., 2003), poking or pointing to an object (e.g., Bíró & Leslie, in press; Woodward & Guajardo, 2002), visually inspecting an object (e.g., Johnson, Ok, & Luo, in press; Woodward, 2003), transforming an object (e.g., Gergely, Bekkering, & Király, 2002; Meltzoff, 1995, 1999), reaching an agent (e.g., Csibra et al., 1999; Gergely, Nádasdy, Csibra, & Bíró, 1995; Sodian, Schoeppner, & Metz, 2004), chasing an agent (e.g., Csibra, Bíró, Koós, & Gergely, 2003; Rochat, Striano, & Morgan, 2004; Schlottman & Surian, 1999; Wagner & Carey, 2005), and helping or hindering an agent (e.g., Kuhlmeier, Wynn, & Bloom, 2003; Premack & Premack, 1997).

More recent findings suggest that infants sometimes interpret others' intentional actions as stemming from particular *dispositions*. A disposition is defined as a tendency or state that helps explain why an agent may choose to pursue a particular goal or to engage in a particular activity. Again, the dispositions infants are able to attribute to others are typically simple and include a preference for one object over another (e.g., Luo & Baillargeon, 2005a; Repacholi & Gopnik, 1997; Song, Baillargeon, & Fisher, 2006), a positive inclination towards one agent as opposed to another (e.g., Kuhlmeier et al., 2003), and a predilection to engage in a certain activity, such as sliding objects (e.g., Song & Baillargeon, in press; Song, Baillargeon, & Fisher, 2005).

To illustrate infants' reasoning about goals and dispositions, consider an experiment adapted from Woodward (1998) in which 5-month-old infants were assigned to a two-object or a one-object condition (Luo & Baillargeon, 2005a). The infants in the *two-object* condition were first familiarized to an event involving a non-human agent, a self-propelled box. At the start of the event, the agent rested on an apparatus floor between two distinct objects, object-A on the right and object-B on the left (from the infants' perspective). During the event, the agent approached object-A and rested against it. Following familiarization, the locations of the two objects were reversed. During test, the agent approached either object-A in its new location (old-goal event) or object-B in the position formerly occupied by object-A (new-goal event). The infants in the *one-object* condition saw the same events, except that only object-A was present during the familiarization trials.

The infants in the two-object condition looked reliably longer at the new- than at the old-goal event, whereas those in the one-object condition tended to look equally at the two events. These results suggested that, during familiarization, the infants in the two-object condition attributed to the agent a particular disposition, a preference for object-A over object-B; after all, the agent consistently approached object-A, ignoring object-B. During test, the infants expected the agent to maintain this disposition and hence to form the goal of approaching object-A in its new position. The infants were thus surprised in the new-goal event when the agent approached object-B instead.

Unlike the infants in the two-object condition, those in the one-object condition could not attribute to the agent a preference for object-A over object-B during familiarization, because only object-A was present. The infants no doubt attributed to the agent the goal of contacting object-A, since the agent repeatedly approached this object across trials. However, when object-B was introduced, the infants had no basis for predicting how the agent would act: it might again approach object-A, or it might now approach object-B. The infants thus tended to look equally when the agent approached either object. The results of the one-object condition also provided evidence against the suggestion (e.g., Tomasello, 1999; Tomasello et al., 2005) that the infants in the two-object condition simply expected the agent "to be consistent in [its] interactions with the same object over a short span of time" (Tomasello et al., 2005, p. 678). Had the infants merely expected the agent to repeat its actions and to approach the object it had approached previously, there would have been no difference between the two- and one-object conditions, because the agent's actions were identical in the two conditions.

The preceding results have recently been replicated in an experiment with 7.5-month-old infants involving a human agent (Song et al., 2006); the agent grasped, lifted, and waved the objects, instead of simply contacting them. As in Luo and Baillargeon (2005a), the infants in the two-object condition looked reliably longer at the new- than at the old-goal event, whereas those in the one-object condition looked about equally at the two events, suggesting that only the infants in the two-object condition attributed to the agent a preference for object-A over object-B.

1.2. False beliefs

In the experiments described in the previous section, the infant and the agent shared similar representations of the physical setting: in each trial, both the infant and the agent could perceive whether one or two objects were present on the apparatus floor, and where each object was located. Recent experiments have begun to explore how infants respond when the agent's representation differs from their own, because the agent holds a false belief about the setting (e.g., Onishi & Baillargeon, 2005; Surian et al., in press).

For example, Onishi and Baillargeon (2005) familiarized 15-month-old infants to an event in which a female human agent hid a toy in location-A as opposed to location-B. Next, the infants received a trial in which the toy moved to location-B, either in the agent's presence (true-belief condition) or absence (false-belief condition). During test, the agent reached to location-A or location-B. The infants in the true-belief condition looked reliably longer when the agent reached to location-A as opposed to location-B, and the infants in the false-belief condition showed the reverse looking pattern. These and other results suggested that the infants (1) attributed to the agent the goal of retrieving the hidden toy; (2) recognized in the false-belief condition that, because the agent had not seen the toy move from location-A to location-B, she believed it to still be hidden in location-A; (3) expected the agent to reach to the location where she believed—truly or falsely—the toy to be hidden; and therefore (4) were surprised when she reached to other location instead. Surian et al. (in press) obtained similar results with 13-month-old infants, using computer-animated events involving a non-human agent.

The preceding results suggest that, when watching an agent act on objects, infants aged 13 months and older keep track of the agent's representation of the physical setting in which the actions take place: if infants witness the transfer of an object to a new hiding location but the agent does not, they recognize that the agent will hold a false belief about the object's location. Furthermore, infants use the agent's representation of the physical setting (e.g., the object is still in location-A), rather than their own (e.g., the object is now in location-B), when interpreting and predicting the agent's actions.

1.3. The present research

Experiment 1 sought new evidence of infants' ability to reason about an agent's actions in situations where the agent's representation of the physical setting deviates from reality. In the experiments of Onishi and Baillargeon (2005) and Surian et al. (in press), the infant's and the agent's representations of the setting differed because the infant witnessed an event—an object's transfer to a new hiding location—that the agent did not; as a result, the agent held a *false* representation of the setting. In Experiment 1, we began to explore a simpler situation, in which the infant's and the agent's representations of the setting differed because the infant could see an object that the agent could not; the agent's representation of the setting was thus *incomplete*, rather than false.

The infants in Experiment 1 were 12.5-month-old infants, and they were assigned to a transparent or an opaque condition (see Fig. 1). The infants in the *transparent* condition first received familiarization trials in which they saw the following event. At the start of the event, two distinct objects stood on the apparatus floor: a block, on the left, and a cylinder, on the right; behind each block was a large transparent

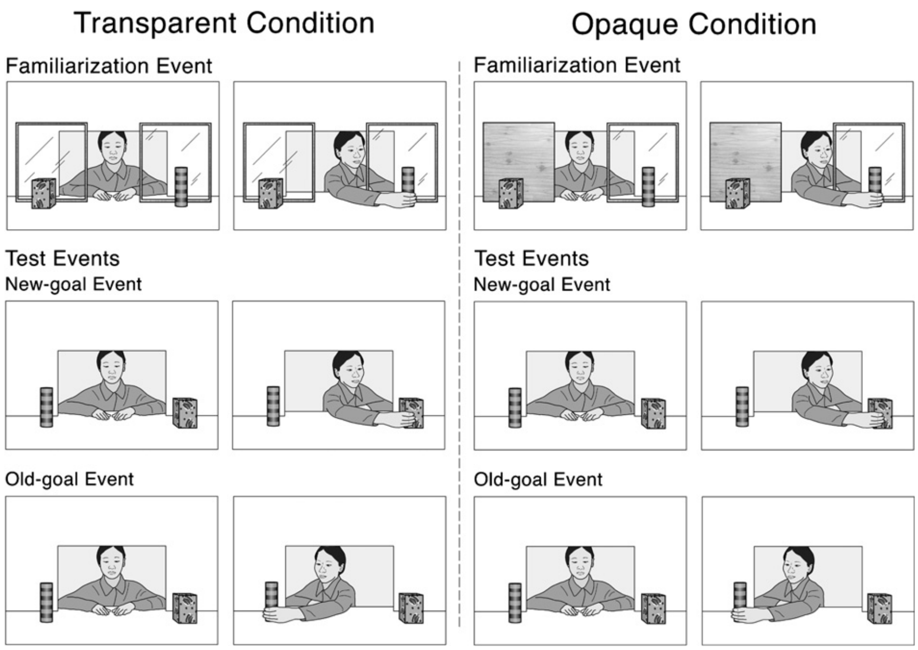

Fig. 1. Schematic drawing of the familiarization and test events shown in the transparent and opaque conditions of Experiment 1.

screen. A female human agent sat at a window in the back wall of the apparatus, behind and between the two transparent screens. From her viewpoint, the agent could see the block and the cylinder through the screens. During the event, the agent reached around the transparent screen on the right to grasp the cylinder; she then paused until the trial ended. The infants in the *opaque* condition watched a similar familiarization event, except that the screen behind the block was opaque; from her viewpoint, the agent could not see the block. Following the familiarization trials, the screens were removed and the objects' positions were reversed. The infants in the two conditions then received a single test trial in which they saw the agent reach for and grasp the cylinder (old-goal event) or the block (new-goal event); the agent then paused until the trial ended.

In the transparent condition, the infant and the agent could both see the block and the cylinder during the familiarization trials. Thus, we expected the infants in this condition to respond in the same manner as the infants in Woodward (1998) and in the two-object conditions of Luo and Baillargeon (2005a) and Song et al. (2006). Specifically, the infants should (1) attribute to the agent during the familiarization trials a particular disposition, a preference for the cylinder over the block; (2) expect the agent to maintain this disposition during the test trial and hence to form the goal of reaching for the cylinder in its new position; and therefore (3) be surprised in the new-goal event when the agent reached for the block instead. We thus expected the infants who saw the new-goal event to look reliably longer than those who saw the old-goal event.

Although in the opaque condition the infant could again see both the block and the cylinder during the familiarization trials, the agent could see only the cylinder. If the infants did *not* realize that the agent could not see the block, then they should respond in exactly the same manner as the infants in the transparent condition. On the other hand, if the infants *did* realize that the agent could not see the block, then they might respond differently. If the infants understood that, because the agent could not see the block, they could not interpret her repeated actions towards the cylinder during the familiarization trials as revealing a preference for the cylinder over the block, then they would have no basis for predicting which object the agent would reach for during the test trial: she might now reach for the block, or she might again reach for the cylinder. The infants who saw the new- and old-goal events should thus look about equally, as in the one-object conditions of Luo and Baillargeon (2005a) and Song et al. (2006). Recall that in these conditions only one object was present on the apparatus floor during the familiarization trials; the opaque condition was thus similar except that, instead of being entirely absent, the block was hidden from the agent's view.

The success of Experiment 1 depended crucially on the infants' being able to recognize that the agent could see the block through the transparent but not the opaque screen during the familiarization trials. How likely were the infants to do so? Prior findings indicate that infants in the second year of life already possess some understanding of others' perceptions (e.g., Brooks & Meltzoff, 2002; Butler, Caron, & Brooks, 2000; Caron, Kiel, Dayton, & Butler, 2002; Dunphy-Lelii & Wellman, 2004; Lempers, Flavell, & Flavell, 1977; Moll & Tomasello, 2004; Tomasello &

Haberl, 2003). In particular, infants aged 12 months and older realize that, for an agent to see an object, her line of sight must be unobstructed: infants are more likely to follow an agent's gaze to a target object when no barrier or a transparent barrier is present in her line of sight than when an opaque barrier is present (e.g., Butler et al., 2000; Caron et al., 2002; Dunphy-Lelii & Wellman, 2004). Finding the predicted results in Experiment 1 would thus provide converging evidence from a violation-of-expectation task that by 12.5 months infants realize that an agent can see an object through a transparent but not an opaque barrier.

2. Experiment 1

2.1. Method

2.1.1. Participants

Participants were 28 healthy term infants, 15 male and 13 female, ranging in age from 12 months, 5 days to 12 months, 29 days ($M = 12$ months, 17 days). Another 13 infants were tested but eliminated, eight because they looked for the maximum amount of time allowed on 75% or more of the trials they received, four because they were fussy (2), inattentive (1), or distracted (1), and one because her looking time during the test trial was more than 2.5 *SD* from the mean of her condition. Seven infants were randomly assigned to each of the four experimental groups formed by crossing the two screen (transparent or opaque) conditions and the two event (new- or old-goal) conditions (transparent/new-goal condition: $M = 12$ months, 16 days; transparent/old-goal condition: $M = 12$ months, 16 days; opaque/new-goal condition: $M = 12$ months, 21 days; opaque/old-goal condition: $M = 12$ months, 13 days).

The infants' names in this and in the following experiment were obtained from purchased mailing lists and 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 compensated for their participation.

2.1.2. Apparatus

The apparatus consisted of a wooden display booth 124 cm high, 102 cm wide, and 58 cm deep, that was mounted 76 cm above the room floor. The infant faced an opening 47.5 cm high and 95 cm wide in the front of the apparatus; between trials, a curtain consisting of a muslin-covered frame, 59.5 cm high and 101 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 granite-pattern contact paper. The back of the apparatus was made of white foam board. A rectangular window, 35 cm high and 58 cm wide, was centered in the back wall and extended from its lower edge.

The agent wore a solid blue shirt and sat on a wooden chair centered behind the window in the back wall of the apparatus; her face and upper body were visible to the infants. At the start of each trial, the agent's bare hands rested on the apparatus floor, palms down; the tips of the agent's middle fingers lay 5.5 cm apart, and were centered 4.5 cm in front of the window. A large muslin curtain behind the agent hid the test room from the infants' view.

Two transparent screens were used during the familiarization phase of the transparent condition. Each screen was 38 cm high, 35 cm wide, and 0.4 cm thick, was made of Plexiglas, was supported at the back by a Plexiglas base, and was outlined with a 1-cm strip of brown wood-pattern contact paper. The two screens stood 25 cm apart, 12 cm in front of and parallel to the back wall of the apparatus. The left screen was positioned 3.5 cm from the left wall, and the right screen 3.5 cm from the right wall. In the opaque condition, the left transparent screen was replaced with an opaque screen. This screen was 38 cm high, 35 cm wide, and 0.5 cm thick, was made of foam board, was supported at the back by a metal base, and was entirely covered with the same brown wood-pattern contact paper that was used to outline the edges of the transparent screens.

During the familiarization trials, a block was positioned 7 cm in front of the left screen and a cylinder was positioned 7 cm in front of the right screen (from the infants' perspective). To equate the distance of each object from the agent, the block stood 14 cm from the right edge of the left screen, and the cylinder stood 14 cm from the left edge of the right screen. The block was 12 cm high, 8 cm wide, and 8 cm deep; it was made of cardboard and was covered with a patterned contact paper consisting of blue teacups and black dots on a bright green background. The cylinder was 17.5 cm high and 5.5 cm in diameter and was made of cardboard; its top was covered with bright yellow contact paper, and its body was covered with black contact paper and decorated with five horizontal stripes of red tape, each 1.9 cm high.

The infants were tested in a brightly lit room. Three 20-W fluorescent light bulbs were attached to the front and back walls of the apparatus to provide additional light. Two wooden frames, each 182.5 cm high, 76 cm wide, and covered with blue cloth, stood at an angle on either side of the apparatus; these frames served to isolate the infants from the test room.

2.1.3. 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 camera mounted behind and next to 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 at the window in the back wall of the apparatus, with her hands on the floor and her eyes focused on a neutral mark on the floor centered between the cylinder and block. While acting on an object (e.g., reaching for and grasping the cylinder), the agent kept her gaze on the object. Thus, the agent did not make eye contact with the infant during the test session.

2.1.3.1. Transparent condition. 2.1.3.1.1. Familiarization event. Each familiarization trial consisted of a 2-s pre-trial followed by a main-trial. At the start of the pre-trial, the cylinder was on the right, the block on the left, and a transparent screen stood behind each object. The agent sat at the window, with her hands on the floor and her eyes focused on the neutral mark between the cylinder and block. During the pre-trial, the agent used her right hand to reach around the right transparent screen and grasp the cylinder (2 s); she then paused, with her eyes focused on the cylinder. During the main-trial, the infants watched this paused scene until the computer signaled that the trial had ended (see below). When this occurred, an experimenter lowered the curtain in front of the apparatus.

2.1.3.1.2. Test events. Prior to the test trial, the screens were removed and the positions of the cylinder and block were reversed. The test trial again consisted of a 2-s pre-trial followed by a main-trial. During the test trial, the infants saw either the new- or the old-goal event. During the pre-trial of the *new-goal* event, the agent used her right hand to reach for and grasp the block (2 s); she then paused, with her eyes focused on the block. During the main-trial, the infants watched this paused scene until the trial ended. The *old-goal* event was similar except that the agent used her left hand to reach for and grasp the cylinder (2 s).

When reaching for the block or cylinder in the test trial, the agent reached in the same manner she would have reached had the screens still been present. Although a slightly more direct reach was now possible, the less direct reach used in the familiarization trials still looked natural and plausible given the locations of the agent and objects. The agent's reaching actions thus looked similar in the familiarization and test trials (see Fig. 1).

2.1.3.1.3. Opaque condition. The familiarization and test events shown in the opaque condition were similar to those shown in the transparent condition, except that during the familiarization trials the left transparent screen was replaced with the opaque one. From her perspective, the agent could not see the block standing in front of the opaque screen.

2.1.4. Procedure

During the experiment, the infant sat on a parent's lap in front of the apparatus; the infant's head was approximately 50 cm from the curtain. Parents were instructed not to interact with their infant during the experiment; they were also asked to close their eyes during the test trial.

The infant's looking behavior during each trial was monitored by two naive observers who viewed the infant through peepholes in the cloth-covered frames on either side of the apparatus. Each observer held a button linked to a computer and depressed the button when the infant looked at the event. The looking times recorded by the primary observer were used to determine when a trial had ended (see below).

All infants first received three familiarization trials in which they saw the familiarization event appropriate for their screen condition (transparent or opaque). Looking times during the 2-s pre-trial (when the agent reached for and grasped the cylinder) and the main-trial (when the agent paused) were computed separately. Examination of the infants' mean looking times during the pre-trial at the start of each familiarization trial suggested that they were highly attentive (transparent/

new-goal condition: $M = 2.0$; transparent/old-goal condition: $M = 2.0$; opaque/new-goal condition: $M = 1.9$; opaque/old-goal event: $M = 2.0$). The main-trial portion of each familiarization 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 without looking away for 2 consecutive seconds.

All infants then received one test trial in which they saw the event appropriate for their event condition (new- or old-goal). As before, looking times during the 2-s pre-trial (when the agent reached for and grasped the cylinder or block) and the main-trial (when the agent paused) were computed separately. The infants were again highly attentive during the 2-s pre-trial at the start of the test trial (transparent/new-goal condition: $M = 2.0$; transparent/old-goal condition: $M = 1.9$; opaque/new-goal condition: $M = 2.0$; opaque/old-goal condition: $M = 2.0$). The main-trial portion of the test trial ended when the infant (1) looked away for 2 consecutive seconds after having looked for at least 7 cumulative seconds, or (2) looked for 30 cumulative seconds without looking away for 2 consecutive seconds.

To assess interobserver agreement during the familiarization and test trials, each trial was divided into 100-ms intervals, and the computer determined within each interval whether the two observers agreed on whether the infant was or was not looking at the event. Percent agreement was calculated for each trial by dividing the number of intervals in which the observers agreed by the total number of intervals in the trial. Interobserver agreement was measured for all 28 infants in Experiment 1 and averaged 95% per trial per infant.

Preliminary analyses of the test data revealed no significant interaction involving sex with screen condition and/or event condition, all $Fs(1, 20) < 2.31$, $ps > .14$; the data were therefore collapsed across sex in subsequent analyses.

2.2. Results

2.2.1. Familiarization trials

The infants' looking times during the main-trial portions of the three familiarization trials (see Fig. 2) were averaged and analyzed by means of a 2×2 analysis of variance (ANOVA) with screen condition (transparent or opaque) and event condition (new- or old-goal) as between-subjects factors. The main effects of screen condition, $F(1, 24) = 0.21$, and event condition, $F(1, 24) = 0.05$, were not significant, nor was the interaction between screen condition and event condition, $F(1, 24) = 0.68$, suggesting that the infants in the four experimental groups looked about equally during the familiarization trials (transparent/new-goal condition: $M = 19.6$, $SD = 4.6$; transparent/old-goal condition: $M = 17.4$, $SD = 6.3$; opaque/new-goal condition: $M = 16.9$, $SD = 5.2$; opaque/old-goal condition: $M = 18.1$, $SD = 5.9$).

2.2.2. Test trial

The infants' looking times during the main-trial portion of the test trial (see Fig. 2) were analyzed in the same manner as the familiarization data. The analysis yielded a significant main effect of event condition, $F(1, 24) = 6.02$, $p < .025$, and a

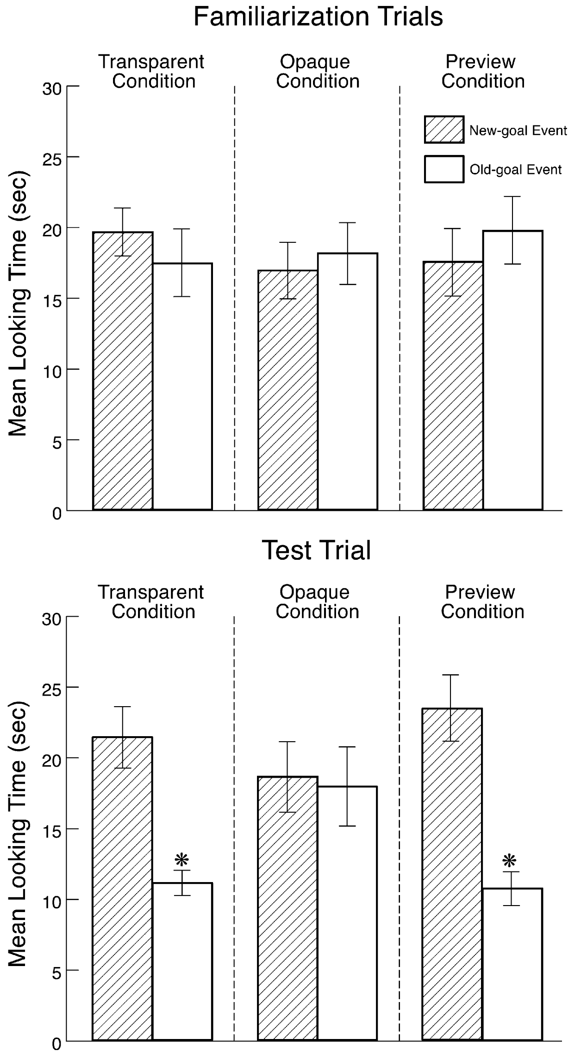

Fig. 2. Mean looking times during the familiarization and test trials of the infants in the transparent and opaque conditions of Experiment 1 and in the preview condition of Experiment 2. Error bars represent standard errors.

significant interaction between screen condition and event condition, $F(1, 24) = 4.67$, $p < .05$. Planned comparisons revealed that in the transparent condition, the infants who saw the new-goal event ($M = 21.4$, $SD = 5.8$) looked reliably longer than did those who saw the old-goal event ($M = 11.1$, $SD = 2.4$), $F(1, 24) = 10.66$, $p < .005$, Cohen's $d = 2.3$, whereas in the opaque condition, the infants who saw the new-goal event ($M = 18.6$, $SD = 6.7$) and those who saw the old-goal event ($M = 17.9$, $SD = 7.5$) looked about equally, $F(1, 24) = 0.04$, $d = 0.1$.

Non-parametric Wilcoxon rank-sum tests confirmed the results of the transparent ($W = 30$, $p < .01$) and opaque ($W = 50$, $p > .20$) conditions.

2.3. Discussion

In the transparent condition, the infants who saw the new-goal event looked reliably longer than those who saw the old-goal event; in the opaque condition, the infants looked about equally at the two events. These results suggested that the infants in the transparent condition: (1) interpreted the agent's actions during the familiarization trials as revealing a preference for the cylinder over the block; (2) expected the agent to maintain this preference during the test trial and hence to form the goal of reaching for the cylinder in its new position; and therefore (3) were surprised in the new-goal event when she reached for the block instead. These results confirm prior findings that infants interpret agents' actions, in some situations at least, in terms of dispositions and goals (e.g., Guajardo & Woodward, 2004; Luo & Baillargeon, 2005a; Shimizu & Johnson, 2004; Song et al., 2006; Woodward, 1998).

The results of Experiment 1 also suggested that the infants in the opaque condition: (1) realized that the agent could not see the block standing in front of the opaque screen, and hence (2) understood that her repeated actions towards the cylinder during the familiarization trials could *not* be taken to reveal a preference for the cylinder over the block. As a result, the infants had no basis for predicting whether the agent would reach for the cylinder or the block during the test trial, and they thus tended to look equally when she reached for either object.

Together, these results suggested that, when watching an agent act on objects, 12.5-month-old infants keep track of the agent's representation of the physical setting in which these actions occur. If the agent's representation is less complete than their own, because the agent is ignorant about some aspect of the setting, infants use the agent's representation, rather than their own, to interpret the agent's actions.

The preceding analysis predicted that infants tested with the opaque condition procedure should respond differently if given evidence that the agent *did* know that the block stood in front of the opaque screen. Experiment 2 tested this prediction.

In Experiment 2, 12.5-month-old infants were tested using the same procedure as in the opaque condition of Experiment 1, with one exception: prior to the familiarization trials, the infants received a *preview* trial (see Fig. 3). At the start of this trial, the block stood centered between the transparent and opaque screens, in plain view of the agent; the cylinder was absent. The agent pushed the block to the left until it stood in front of the opaque screen, as in the familiarization event; she then returned her hand to its starting position on the apparatus floor, and maintained this paused position until the trial ended. Following the preview trial, the infants saw exactly the same familiarization and test events as in the opaque condition of Experiment 1.

If the infants in Experiment 2: (1) realized, based on the preview trial, that the agent knew that the block stood in front of the opaque screen; (2) attributed to the agent a preference for the cylinder during the familiarization trials, since she repeatedly reached for the cylinder as opposed to the block; and (3) expected

Fig. 3. Schematic drawing of the preview, familiarization, and test events shown in the preview condition of Experiment 2.

the agent to maintain this disposition in the test trial and hence to again form the goal of obtaining the cylinder, then they should be surprised when she reached for the block instead. The infants who saw the new-goal event should thus look reliably longer than those who saw the old-goal event, as in the transparent condition of Experiment 1.

We reasoned that a positive result in Experiment 2 would not only support our analysis of the negative result of the opaque condition in Experiment 1, but would also help rule out low-level interpretations of this result. As is often the case with negative results, alternative interpretations were possible: perhaps the infants in the opaque condition looked equally at the new- and old-goal events simply because some aspects of the stimuli, events, or procedure were confusing to them. Because the infants in Experiment 2 saw exactly the same familiarization and test events as the infants in the opaque condition of Experiment 1, a positive finding would render such alternative explanations unlikely.

The success of Experiment 2 depended crucially on the infants' being able to remember that the agent had seen the block in the preview trial and had placed it in front of the opaque screen herself. How likely were the infants to remember this information? An experiment by Tomasello and Haberl (2003) suggested that they might be able to do so. In this experiment, 12-month-old infants participated in a task involving two agents, agent-A and agent-B. To start, the infant and agent-A examined a novel object together. Next, agent-A put the object away and agent-B entered the room. The infant and the two agents then examined two more novel objects together. Finally, agent-A produced all three objects and agent-B exclaimed: "Wow! Look! Look at that! So look at that! Give it to me, please" (Tomasello & Haberl, p. 909). Infants were more likely to select the first object, suggesting that they knew which objects agent-B had seen before and which object she had not. Finding the predicted result in Experiment 2 would thus provide converging evidence from a violation-of-expectation task that 12.5-month-old infants can keep track of which objects an agent has and has not seen in a scene.

3. Experiment 2

3.1. Method

3.1.1. Participants

Participants were 14 healthy term infants, seven male and seven female, ranging in age from 12 months, 2 days to 12 months, 29 days ($M = 12$ months, 16 days). Another 6 infants were tested but eliminated, four because they were inattentive (2), distracted (1), or overly active (1), and two because their test looking times were more than 2.5 *SD* from the mean of their condition. Half of the infants saw the new-goal event ($M = 12$ months, 17 days), and half saw the old-goal event ($M = 12$ months, 15 days).

3.1.2. Apparatus, events, and procedure

The apparatus, events, and procedure used in Experiment 2 were identical to those in Experiment 1, with one exception: the infants received a preview trial prior to the familiarization trials. This preview trial consisted of a 5-s pre-trial followed by a main-trial. At the start of the pre-trial, the block stood centered between and 7 cm in front of the transparent and opaque screens; the cylinder was not present in the apparatus. The agent sat at the window in the back wall of the apparatus with her hands on the floor and her eyes focused on the block. During the pre-trial, the agent took hold of the block with her left hand (1 s); she placed her thumb on top of the block and her palm against the right side of the block (from the infants' perspective). The agent then pushed the block in a straight line (3 s) until it stood in its standard position in front of the opaque screen (the right edge of the block was then 14 cm from the right edge of the opaque screen). Finally, the agent returned her left hand to its starting position on the apparatus floor (1 s), and paused, with her eyes on the neutral mark on the apparatus floor between the transparent and opaque screens. During the main-trial, the infants watched this paused scene until the trial ended.

As before, looking times during the pre-trial and main-trial portions of the preview trial were computed separately. The infants were highly attentive during the 5-s pre-trial (new-goal condition: $M = 4.9$; old-goal condition: $M = 4.9$). The main-trial portion of the 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. Analysis of the infants' looking times during the main-trial indicated that the main effect of event condition was not significant, $F(1, 12) = 0.31$, suggesting that the infants in the new-goal ($M = 26.6$, $SD = 6.1$) and old-goal ($M = 24.2$, $SD = 9.5$) conditions tended to look equally during the preview trial.

Following the preview trial, as in the opaque condition of Experiment 1, the infants received three familiarization trials followed by a single test trial in which they saw the new- or the old-goal event. The infants were highly attentive during the 2-s pre-trials at the start of the familiarization and test trials (familiarization trials: new-goal condition, $M = 1.9$; old-goal condition, $M = 2.0$; test trial: new-goal condition, $M = 1.9$; old-goal condition, $M = 2.0$).

Interobserver agreement was measured for all 14 infants in Experiment 2 and averaged 95% per trial per infant. Preliminary analyses of the test data revealed no significant interaction between sex and event condition, $F(1, 10) = 0.87$; the data were therefore collapsed across sex in subsequent analyses.

3.2. Results

The infants' looking times during the familiarization and test trials were compared to those of the infants in the opaque condition of Experiment 1.

3.2.1. Familiarization trials

The infants' looking times during the main-trial portions of the three familiarization trials (see Fig. 2) were averaged and analyzed by means of a 2×2 ANOVA with screen condition (preview or opaque) and event condition (new- or old-goal) as between-subjects factors. The main effects of screen condition, $F(1, 24) = 0.22$, and event condition, $F(1, 24) = 0.57$, were not significant, nor was the interaction between screen condition and event condition, $F(1, 24) = 0.04$, suggesting that the infants in the four experimental groups tended to look equally during the familiarization trials (preview/new-goal condition: $M = 17.5$, $SD = 6.3$; preview/old-goal condition: $M = 19.7$, $SD = 6.4$; opaque/new-goal condition: $M = 16.9$, $SD = 5.2$; opaque/old-goal condition: $M = 18.1$, $SD = 5.9$).

3.2.2. Test trial

The infants' looking times during the main-trial portion of the test trial (see Fig. 2) were analyzed in the same manner as the familiarization data. The analysis yielded a significant main effect of event condition, $F(1, 24) = 8.54$, $p < .01$, as well as a significant interaction between screen condition and event condition, $F(1, 24) = 6.95$, $p < .025$. Planned comparisons revealed that, in the preview condition, the infants who saw the new-goal event ($M = 23.4$, $SD = 6.1$) looked reliably longer than those who saw the old-goal event ($M = 10.7$, $SD = 3.2$), $F(1, 24) = 15.43$, $p < .001$, $d = 2.6$, whereas in the opaque condition, the infants who saw the new-goal event ($M = 18.6$, $SD = 6.7$) and those who saw the old-goal event ($M = 17.9$, $SD = 7.5$) looked about equally, $F(1, 24) = 0.04$, $d = 0.1$.

A non-parametric Wilcoxon rank-sum test confirmed the result of the preview condition ($W = 31$, $p < .01$).

3.3. Discussion

The infants who saw the new-goal event looked reliably longer than those who saw the old-goal event. This result suggested that the infants (1) assumed, based on the agent's actions during the preview trial, that she knew the block stood in front of the opaque screen; (2) interpreted her actions during the familiarization trials as revealing a preference for the cylinder over the block; (3) expected the agent to maintain this disposition during the test trial and hence to form the goal of obtaining the cylinder; and therefore (4) were surprised in the new-goal event when she reached for the block instead.

The positive result of Experiment 2 rules out low-level interpretations of the negative result of the opaque condition in Experiment 1. Had the infants in the opaque condition looked about equally at the new- and old-goal events merely because they were confused or misled by some aspect of the stimuli, events, or procedure, then the infants in the preview condition, who saw exactly the same familiarization and test events, should also have been confused and hence should also have looked about equally at the test events.

Together, the results of Experiments 1 and 2 make clear that, although the infants in the opaque condition knew that the block stood in front of the opaque screen, they did not automatically and egocentrically attribute this same knowledge to the agent. How did the infants construe the agent's ignorance? There are at least three possibilities. One is that the infants assumed that the agent believed that *no object* stood in front of the opaque screen, so that only the cylinder was present in the apparatus. Another possibility is that the infants assumed that the agent inferred that *some object* stood in front of the opaque screen—just as the cylinder stood in front of the transparent screen—but could not determine which object stood there since it was hidden from her view. Yet another possibility is that the infants assumed that the agent had *no firm expectation* as to whether or not an object stood in front of the opaque screen; either option was possible, and the agent simply did not have enough information to choose one.

Did the infants assume that the agent was ignorant about the *presence* or only about the *identity* of the block? Our data are insufficient to answer this question. What our results do indicate, however, is that the infants (1) recognized that the agent's representation of the physical setting was incomplete, since the agent was ignorant of at least the identity of the object standing in front of the opaque screen, and (2) used the agent's limited representation, rather than their own more complete representation, to interpret her actions.

4. General discussion

The present experiments indicate that, when watching an agent act on objects in a scene, 12.5-month-old infants take into account what objects the agent can see, or has seen, when interpreting her actions. During the familiarization trials, a block and a cylinder stood on the apparatus floor, and the agent repeatedly reached for and grasped the cylinder. Across conditions, the infants interpreted the agent's actions differently, depending on whether she could see, or had seen, the block.

In the transparent condition, transparent screens stood behind the block and cylinder during the familiarization trials, and the agent could see both objects through the screens. The infants interpreted the agent's actions as revealing a preference for the cylinder over the block, since she consistently ignored the block and selected the cylinder. During the test trial, the screens were removed and the objects' locations were reversed. The infants expected the agent to maintain her preference for the cylinder and hence to reach for it in its new position. They were therefore surprised when the agent reached for the block instead of the cylinder.

In the opaque condition, the transparent screen behind the block was replaced with an opaque screen. The infants realized that (1) the agent could not see the block from her viewpoint, and hence (2) her actions toward the cylinder could not be taken to reveal a preference for the cylinder over the block. During the test trial, the infants had no basis for predicting which object the agent would select now that both were visible to her, and they therefore tended to look equally whether the agent reached for the cylinder or the block.

Finally, in the preview condition, the infants received the same familiarization and test trials as in the opaque condition, with one exception: the infants first received a preview trial in which they saw the agent push the block in front of the opaque screen. During the familiarization trials, the infants assumed that the agent remembered the presence of the block in front of the screen, and accordingly took her actions to reveal a preference for the cylinder over the block. Like the infants in the transparent condition, the infants expected the agent to maintain this preference during the test trial and were therefore surprised when she reached for the block instead of the cylinder.

Together, the present results make clear that 12.5-month-old infants take into account what objects an agent can see, or has seen, when interpreting her actions.

As such, the results have implications for three bodies of findings. First, the results confirm and extend the results the one-object conditions in Luo and Baillargeon (2005a) and Song et al. (2006). Recall that in these conditions only object-A was present during the familiarization trials. The infants tended to look equally whether the agent approached object-A or object-B during the test trials, because they had no basis for predicting which object the agent might select. The opaque condition in the present research was similar to these one-object conditions except that, instead of being entirely absent, object-B was hidden from the agent during the familiarization trials.

Second, the present results provide converging evidence from violation-of-expectation tasks that infants aged 12 months and older (1) realize that, for an agent to see an object, her line of sight must be unobstructed (e.g., Butler et al., 2000; Caron et al., 2002; Dunphy-Lelii & Wellman, 2004), and also (2) can keep track of the objects an agent has and has not seen in a scene (Tomasello & Haberl, 2003). To respond as they did, the infants in Experiment 1 had to recognize that the agent could see the block through the transparent but not the opaque screen; and the infants in Experiment 2 had to remember that the agent had placed the block in front of the opaque screen in the preview trial.

Third, and most importantly for the issues addressed here, the present results provide new evidence that, when watching an agent act on objects, infants in the second year of life keep track of the agent's representation of the physical setting in which these actions take place; when this representation deviates from reality, infants use the agent's representation to interpret her actions. In the false-belief conditions of Onishi and Baillargeon (2005) and Surian et al. (in press), the agent possessed a false belief about the location of an object. In the opaque condition used here, the agent was ignorant about the identity and perhaps also the presence of the object standing in front of the opaque screen. The present results thus extend those of Onishi, Surian, and their colleagues to situations in which the agent's representation of the physical setting is incomplete, rather than false.

A few experiments have examined situations where the *infant's* representation of a physical setting is incomplete, because the infant cannot see an object that the agent can see (e.g., Csibra et al., 2003; Moll & Tomasello, 2004). In these experiments, infants aged 12 months and older readily inferred the presence of a hidden object, based on the agent's responses. For example, infants who saw an agent look behind an opaque barrier with facial and vocal expressions of excitement moved around the barrier in order to see what the agent could see (Moll & Tomasello, 2004). In another experiment, infants were habituated to an event in which a non-human agent, a small ball, approached another non-human agent, a larger ball (Csibra et al., 2003). The small ball jumped on its way to the larger ball, and the area it jumped over was occluded by a screen, leaving open the possibility that the small ball jumped over an obstacle hidden by the screen. During test, the screen was removed, and the infants saw the same event with an obstacle or no obstacle present in the path of the small ball. The infants looked reliably longer when no obstacle was present, suggesting that they inferred during habituation that an obstacle stood behind the screen.

In the experiments just described, the agent could detect an object that the infants could not; the infants readily inferred the presence of this object, based on cues provided by the agent, and used this information to guide their own responses (Moll & Tomasello, 2004) or to reason about the agent's subsequent actions (Csibra et al., 2003). These findings suggest that, when infants realize that their representation of a physical setting appears less complete than that of an agent—because the agent's behavior signals the presence of an additional object in the setting—infants readily update their own representation to include this additional, unseen object. The present research focused on the complementary situation, in which the *agent's* representation of the physical setting was incomplete: the infants in the opaque condition could see an object that the agent could not see, and no obvious cues helped signal the presence of this object to the agent. Our results suggest that, in such situations, 12.5-month-old infants do not automatically and egocentrically attribute to the agent their own representation of the setting: they resist "the pull of the real" (Moll & Tomasello, 2004), and use the agent's limited representation, rather then their own more complete representation, to interpret the agent's actions.

4.1. Future research

The present findings suggest several directions for future research. One such direction might be to seek converging evidence for our results using other actions. Researchers have found that infants interpret an agent's actions as intentional if she pushes, pokes, points to, or even simply looks at object-A as opposed to object-B (e.g., Bíró & Leslie, in press; Johnson et al., in press; Király et al., 2003; Woodward, 2003; Woodward & Guajardo, 2002). Replicating the present results with various actions would provide additional support for our conclusions.

Other directions involve examining whether results similar to those reported here would again be obtained if infants younger than 12.5 months were tested, or if a non-human agent was used. Preliminary results by Luo and her colleagues suggest that 5- to 6-month-old infants may indeed take into account what objects a human or a non-human agent can detect when interpreting the agent's actions (Luo & Baillargeon, 2005b; Luo & Johnson, 2006). In one experiment, for example, 6-month-old infants watched a familiarization event in which a female human agent sat in a cut-out area in an apparatus floor, between object-A and object-B; the agent reached for and grasped object-A (Luo & Johnson, 2006). An opaque screen stood between the agent and object-B; this screen was either short, so that the agent could see object-B protruding above it (short-screen condition), or tall, so that the agent could not see object-B (tall-screen condition). In both conditions, the infants could see object-A as well as object-B. During test, the screen was removed and the objects' positions were reversed; the agent reached for either object-A (old-goal event) or object-B (new-goal event). The infants in the short-screen condition looked reliably longer at the new- than at the old-goal event, whereas those in the tall-screen condition looked about equally at the events. Consistent with the results of the present research, the infants thus attributed a preference for object-A over object-B to the agent *only* when she could see object-B. Luo and Baillargeon (2005b) obtained similar results in an experiment involving a non-human agent, a self-propelled box.

4.2. An account of early psychological reasoning

What are the implications of the present findings for theory and research on infants' understanding of intentional action? There is currently an intense debate as to the nature and development of early psychological reasoning. Some researchers have suggested that infants are born with an abstract computational system, a psychological-reasoning system, that guides from the start their interpretation of agents' intentional actions (e.g., Baron-Cohen, 1995; Gergely & Csibra, 2003; Gergely et al., 1995; Johnson, 2003; Leslie, 1994, 1995; Onishi & Baillargeon, 2005; Premack, 1990; Premack & Premack, 1995; Shimizu & Johnson, 2004). Other researchers have emphasized the role of experience in infants' ability to understand agents' intentional actions: as infants become increasingly adept at producing intentional actions, they become able to understand similar actions in others, in part due to innate pathways for establishing equivalences between their own actions and mental states and those of others (e.g., Carpenter, Nagell, & Tomasello, 1998; Meltzoff, 1995, 1999; Sommerville, Woodward, & Needham, 2005; Tomasello, 1999; Woodward, Sommerville, & Guajardo, 2001; for recent reviews, see Meltzoff, 2005; Tomasello et al., 2005; Woodward, 2005). One key difference between these two approaches concerns non-human agents. The *system-based* approach predicts that young infants should be able to reason about the actions of any individual they identify as an agent, whether human or non-human. In contrast, the *experience-based* approach predicts that infants should initially be limited to reasoning about the actions of human agents, and should gradually become more flexible with experience. Because there is increasing evidence that infants aged 5 to 6.5 months can reason about agents with no physical similarity to humans (e.g., Csibra, 2006; Luo & Baillargeon, 2005a, 2005b), we find the system-based approach more compelling.[1]

How would a system-based approach account for the present findings? Leslie (1994, 1995) has proposed that early psychological reasoning depends on two distinct subsystems (see also Premack, 1990, and Gergely & Csibra, 2003, for related accounts). Subsystem1 develops early in the first year of life and allows infants to understand that agents detect their environment and act on the basis of goals and dispositions; subsystem2 develops in the second year of life and allows infants to understand that agents' actions may be caused by false or pretend perceptions and beliefs (e.g., Onishi & Baillargeon, 2005; Onishi, Baillargeon, & Leslie, in press).

[1] This is not to say, of course, that we believe experience plays little or no role in the development of early psychological reasoning. In infants' physical reasoning, where core principles again are assumed to provide a skeletal causal framework for interpreting events, experience has been shown to play a crucial role in helping infants attend to relevant information both to predict the outcomes of physical events and to guide their own responses on objects (e.g., Hespos & Baillargeon, 2001, 2006; for recent reviews, see Baillargeon, Li, Luo, & Wang, 2006; Baillargeon, Li, Ng, & Yuan, in press).

Subsystem1 is arguably sufficient to explain all of the present results (as well as those of Luo & Baillargeon, 2005b, and Luo & Johnson, 2006), as long as one is willing to accept the following, plausible hypotheses. First, infants hold the default assumption that agents (whether human or non-human) cannot detect objects through opaque barriers. Thus, if no part of an object protrudes from a barrier, then an agent on the other side of the barrier will be unable to detect its presence. Second, once detected, objects remain a part of an agent's representation of a physical setting even if they subsequently become hidden. This second assumption ensures, among other things, that as an agent moves through a physical setting and loses sight of an object, infants do not conclude that the object is no longer a part of the agent's representation of the setting. Thus, if a human agent jumps over a barrier on her way to a friend, infants would presumably assume that she is still aware of the presence and location of the barrier behind her, even if she can no longer see it. Subsystem1 would thus lead infants to expect agents to *detect* as well as to *remember* the presence of objects in a setting. As such, subsystem1 could explain the results of the opaque condition (the infants understood that the agent could not detect the block through the opaque screen; the block was therefore not a part of her representation of the physical setting and could not affect her intentional actions) as well as those of the preview condition (the agent could remember that the block stood in front of the opaque screen; the block was therefore a part of her representation of the physical setting and could affect her intentional actions).

An alternative to Leslie's (1994, 1995) *two-subsystem* account is a *one-system* account, which assumes that infants possess from the start a single system of psychological reasoning. For example, it could be that, when watching an agent act on objects in a scene, infants build a specialized psychological representation which specifies the agent's actions, the physical setting in which these actions occur, and the internal states that led the agent to perform these actions. These internal states would be of two kinds: *informational* states—such as perceptions and beliefs—would specify how the physical setting is represented by the agent; *motivational* states—such as goals and dispositions—would specify the agent's motivation in the scene (e.g., Premack, 1990). These informational and motivational states—together with core biases such as that agents select actions that are not only causally appropriate but also reasonably efficient to achieve their goals (e.g., Csibra et al., 1999; Gergely et al., 1995)—would provide a causal analysis of the agent's actions in the scene. On this one-system account, the present results would simply reflect infants' ability to keep track of the agent's informational states in the scene.

To decide between the two-subsystem and the one-system accounts, we will need to determine, among other things, whether infants in the first year of life can deal with situations in which the agent's representation of the physical setting is not merely incomplete, as in the present research, but false. Our intuition is that this is likely to be the case. If infants can keep track of what *objects* an agent has seen, it would not be surprising if they could also keep track of what *events* the agent has seen—for example, whether the agent has seen the transfer of an object from one hiding location to another. Experiments are under way to examine this possibility.

Acknowledgments

This research was supported by research funds from the University of Missouri at Columbia to the first author and by a grant from the National Institute of Child Health and Human Development (HD-21104) to the second author. We thank Gergo Csibra, Jerry DeJong, Cindy Fisher, George Gergely, Alan Leslie, and the members of the Infant Cognition Reading Group (Matthias Bolz, Zijing He, Dong-Bo Hsu, Jackie Jaszka, Jie Li, and Di Wu), for helpful discussions and suggestions; the staff of the University of Illinois Infant Cognition Laboratory for their help with the data collection, and the parents and infants who participated in the research.

References

Baillargeon, R., Li, J., Luo, Y., & Wang, S. (2006). Under what conditions do infants detect continuity violations? In Y. Munakata, & M. H. Johnson (Eds.), *Processes of change in brain and cognitive development* (Attention and Performance XXI, pp. 163–188). New York: Oxford University Press.

Baillargeon, R., Li, J., Ng, W., & Yuan, S. (in press). An account of infants' physical reasoning. In A. Woodward, & A. Needham (Eds.), *Learning and the Infant Mind*. New York: Oxford University Press.

Baron-Cohen, S. (1995). *Mindblindness: An essay on autism and theory of mind*. Cambridge, MA: MIT Press.

Bíró, S., & Leslie. A. M. (in press). Infants' perception of goal-directed actions: Development through cue-based bootstrapping. *Developmental Science*.

Brooks, R., & Meltzoff, A. N. (2002). The importance of eyes: How infants interpret adult looking behavior. *Developmental Psychology, 38*, 958–966.

Butler, S. C., Caron, A. J., & Brooks, R. (2000). Infants understanding of the referential nature of looking. *Journal of Cognition and Development, 1*, 359–377.

Caron, A. J., Kiel, E. J., Dayton, M., & Butler, S. (2002). Comprehension of the referential intent of looking and pointing between 12 and 15 months. *Journal of Cognition and Development, 3*, 445–464.

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*.

Csibra, G. (2006). Goal attribution to inanimate agents by 6.5-month-old infants. Manuscript under review.

Csibra, G., Bíró, 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. (in press). 'Obsessed with goals': Functions and mechanisms of teleological interpretation of actions in humans. *Acta Psychologica* (special issue).

Csibra, G., Gergely, G., Bíró, S., Koós, O., & Brockbank, M. (1999). Goal attribution without agency cues: The perception of 'pure reason' in infancy. *Cognition, 72*, 237–267.

Dunphy-Lelii, S., & Wellman, H. M. (2004). Infants' understanding of occlusion of others' line-of-sight: Implications for an emerging theory of mind. *European Journal of Developmental Psychology, 1*, 49–66.

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., & Bíró, S. (1995). Taking the intentional stance at 12 months of age. *Cognition, 56*, 165–193.

Guajardo, J. J., & Woodward, A. L. (2004). Is agency skip-deep? Surface attributes influence infants' sensitivity to goal-directed action. *Infancy, 6*, 361–384.

Hespos, S. J., & Baillargeon, R. (2001). Infants' knowledge about occlusion and containment events: A surprising discrepancy. *Psychological Science, 12*, 140–147.

Hespos, S. J., & Baillargeon, R. (2006). Décalage in infants' knowledge about occlusion and containment events: Converging evidence from action tasks. *Cognition, 99*, B31–B41.

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

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

Kamerawi, K., Kato, M., Kanda, T., Ishiguro, H., & Hiraki, K. (2005). Six-and-a-half-month-old children positively attribute goals to human action and to humanoid-robot motion. *Cognitive Development, 20*, 303–320.

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.

Lempers, J. D., Flavell, E. R., & Flavell, J. H. (1977). The development in very young children of tacit knowledge concerning visual perception. *Genetic Psychology Monographs, 95*, 3–53.

Leslie, A. M. (1994). ToMM, ToBy, and Agency: Core architecture and domain specificity. In L. Hirschfeld & S. 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: Clarendon Press.

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*, Atlanta, GA.

Luo, Y., & Johnson, S. C. (2006). Young infants' knowledge about others' goals and perceptions. *Paper presented at the biennial international conference on infant studies*, Kyoto, Japan.

Meltzoff, A. N. (1995). Understanding the intentions of others: Re-enactment 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.

Moll, H., & Tomasello, M. (2004). 12- and 18-month-old infants follow gaze to spaces behind barriers. *Developmental Science, 7*, F1–F9.

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

Onishi, K. H., Baillargeon, R. & Leslie, A. M. (in press). 15-month-old infants detect violations in pretend scenarios. *Acta Psychologica* (special issue).

Phillips, A. T., & Wellman, H. M. (2005). Infants' understanding of object-directed action. *Cognition, 98*, 137–155.

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

Rochat, P., Striano, T., & Morgan, R. (2004). Who is doing what to whom? Young infants' developing sense of social causality in animated displays. *Perception, 33*, 355–369.

Schlottman, A., & Surian, L. (1999). Do 9-month-olds perceive causation-at-a-distance?. *Perception, 28*, 1105–1113.

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

Sodian, B., Schoeppner, B., & Metz, U. (2004). Do infants apply the principle of rational action to human agents? *Infant Behavior and Development, 27*, 31–41.

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.

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. (in press). Can 9.5-month-old infants attribute to an agent a disposition to perform an action on objects? *Acta Psychologica* (special issue).

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

Song, H., Baillargeon, R., & Fisher, C. (2006). The development of infants' use of verbal information when reasoning about others' actions. Manuscript under review.

Surian, L., Caldi, S., & Sperber, D. (in press). Attribution of beliefs by 13-month-old infants. *Psychological Science*.

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., & Haberl, K. (2003). Understanding attention: 12- and 18-month-olds know what is new for other persons. *Developmental Psychology, 39*, 906–912.

Wagner, L., & Carey, S. (2005). 12-month-olds represent probable endings of motion events. *Infancy, 7*, 73–83.

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*, 1061–1084.

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.