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Attributing false beliefs about non-obvious properties at 18 months

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Abstract

Reports that infants in the second year of life can attribute false beliefs to others have all used a *search* paradigm in which an agent with a false belief about an object's location searches for the object. The present research asked whether 18-month-olds would still demonstrate false-belief understanding when tested with a novel *non-search* paradigm. An experimenter shook an object, demonstrating that it rattled, and then asked an agent, "Can you do it?" In response to this prompt, the agent selected one of two test objects. Infants realized that the agent could be led through inference (Experiment 1) or memory (Experiment 2) to hold a false belief about which of the two test objects rattled. These results suggest that 18-month-olds can attribute false beliefs about non-obvious properties to others, and can do so in a non-search paradigm. These and additional results (Experiment 3) help address several alternative interpretations of false-belief findings with infants.

As adults, we routinely interpret others' behavior in terms of underlying mental states. Thus, we readily understand that Harry Potter *wants* to escape from his horrible relatives and return to Hogwarts, *does not know* his friends are coming to rescue him in an enchanted car, and *falsely believes* he will spend yet another day locked up in his room. Developmental psychologists have long been interested in determining how the ability to attribute mental states to others develops in children.

In particular, a great deal of research has focused on the question of when children are first able to attribute false beliefs to others. Although traditional investigations indicated that this ability did not emerge until about 4 years of age (e.g., Baron-Cohen, Leslie, & Frith, 1985; Gopnik & Astington, 1988; Perner, Leekam, & Wimmer, 1987; Wellman & Bartsch, 1988; Wimmer & Perner, 1983), recent reports using violation-of-expectation (VOE) and anticipatory-looking (AL) tasks have suggested that this ability may be present much earlier (e.g., Onishi & Baillargeon, 2005; Scott & Baillargeon, 2009; Song & Baillargeon, 2008;

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Surian, Caldi, & Sperber, 2007; Southgate, Senju, & Csibra, 2007). These reports have obtained positive results with infants aged 13 to 25 months in a range of belief-inducing situations including false perceptions, false beliefs about location, and false beliefs about identity (for a review, see Baillargeon, Scott, & He, 2010). Together, these results suggest that the ability to attribute false beliefs to others may already be present in the second year of life.

However, one important limitation of the VOE and AL false-belief reports published to date is that all of them have employed the same *search* paradigm: in each case, infants reasoned about the behavior of an agent who was searching for an object and falsely believed it to be hidden in one location when it was actually hidden in another. Reliance on this common paradigm gives rise to two difficulties. First, it leaves the reports open to similar alternative interpretations (described in a later section) that question whether infants are really attributing a false belief to the searching agent and offer lower-level explanations for infants' expectations about the agent's behavior. Second, one of the reasons why 4-year-olds are said to possess a robust understanding of false belief is that they perform correctly when tested with *non-search* as well as with search tasks. For example, after manipulating a fake object (e.g., a sponge that looks like a rock), most 4-year-olds expect a naive agent to be deceived by the object's misleading appearance (e.g., Gopnik & Astington, 1988; Moore, Pure, & Furrow, 1990). Similarly, after being shown that a familiar, commercially available package holds unexpected contents (e.g., a candy box that holds pencils), 4-year-olds typically expect a naive agent to falsely believe the package holds its usual contents (e.g., Gopnik & Astington, 1988; Perner et al., 1987). In order to determine whether infants possess a robust understanding of false belief, it is thus crucial to determine whether they, too, can succeed at a non-search task.

Here, we attempted to remedy these difficulties by testing infants in a novel *non-search* false-belief paradigm. In the next sections, we review previous VOE and AL false-belief reports, discuss the alternative interpretations that investigators have offered for these reports, and then introduce the present experiments.

Early False-Belief Understanding: Evidence from VOE and AL tasks

Initial investigations into early false-belief understanding focused on whether infants could attribute to an agent a false belief about an object's location. In the first of these investigations, Onishi and Baillargeon (2005) tested 15-month-olds in a VOE task. The infants first received three familiarization trials. In the first trial, a toy stood on an apparatus floor between a green and a yellow box; a female agent hid the toy inside the green box and then paused, with her hand inside the box, until the trial ended. In the second and third familiarization trials, the agent reached inside the green box (as though to grasp her toy) and then paused. Next, the infants received a belief-induction trial that varied across conditions: for example, in the false-belief-green condition, the toy moved from the green to the yellow box in the agent's absence; in the false-belief-yellow condition, the toy moved to the yellow box while the agent was present, but returned to the green box after she left. During the test trial, the agent reached inside the green (green-box event) or the yellow (yellow-box event) box and then paused. In the false-belief-green condition, the infants who saw the yellow-box event looked reliably longer than those who saw the green-box event, suggesting that they attributed to the agent the false belief that her toy was in the green box and thus expected her to reach there. This pattern reversed in the false-belief-yellow condition: the infants who saw the green-box event looked reliably longer than those who saw the yellow-box event, suggesting that they attributed to the agent the false belief that her toy was in the yellow box and thus expected her to search there.

Subsequent VOE investigations confirmed (Träuble, Marinović, & Pauen, 2010) and extended these results in several ways. Surian et al. (2007) provided evidence that even 13-month-olds can attribute to an agent a false belief about the location of an object, and that this agent need not be human. In the familiarization trials, a caterpillar watched as an experimenter's hand hid an apple behind one screen and a piece of cheese behind another screen; the caterpillar always approached the same screen to chew on the same, preferred food. In the test trial, the hand hid the two food items in the reverse locations before the caterpillar entered the scene. Infants expected the caterpillar to falsely assume its preferred food had been hidden in the same location as before. Song, Onishi, Baillargeon, and Fisher (2008) showed that 18-month-olds realize that an agent's false belief about an object's location can be corrected by an appropriate, though not an inappropriate, communication. In one experiment, for example, an agent hid a ball in a box and was absent when an experimenter moved it to a cup. When the agent returned, infants expected her to search in the cup if the experimenter told her "The ball is in the cup!", but to search in the box if the experimenter told her "I like the cup!" Infants thus recognized that only the first utterance was sufficient to correct the agent's false belief about the ball's location.

Finally, building on prior AL results with 3-year-olds (e.g., Clements & Perner, 1994; Garnham & Ruffman, 2001), Southgate et al. (2007) examined in a non-verbal AL task whether 25-month-olds would anticipate where an agent with a false belief about an object's location would look for the object. In the familiarization trials, a bear puppet hid a toy in one of two boxes while a female agent looked on; her head was visible above a panel with two small, closed doors, one above each box. After the bear hid the toy, the two doors lit up, and then the agent opened the correct door to retrieve the toy. During the test trial, the agent saw the bear hide the toy in the left box. At that point, a phone rang behind the agent, who turned toward the sound; while she was facing away, the bear removed the toy from the left box, briefly hid it in the right box, and then left with it. The phone then stopped ringing, the agent turned back toward the boxes, and the doors lit up. Most infants correctly anticipated the agent's behavior and looked at the door above the left box, where she falsely believed the toy to be hidden. Another condition, in which the agent falsely believed the toy to be in the right box, produced similar results.

Alternative Interpretations

Researchers have offered a number of alternative interpretations for the VOE and AL findings described in the previous section; these interpretations call into question the conclusion that infants aged 13 to 25 months can already attribute false beliefs to agents.

The Association Interpretation

A first alternative interpretation is that, when shown an event in which an agent watches an object being hidden in one location, infants form a three-way association linking the agent, the object, and its location (Perner & Ruffman, 2005; Ruffman & Perner, 2005). This association then drives infants' anticipatory responses in AL tasks and leads them to look longer in VOE tasks when test events deviate from the association (i.e. when the agent searches for the object in a different location). If one assumes that infants can form such a three-way association in a single trial, and that any new association trumps previous associations, then one can explain all of the results in the last section.

There are two difficulties with the association interpretation. First, Csibra and Southgate (2006) cast serious doubt on the neurological arguments marshaled by Perner and Ruffman (2005) to support their claim that infants can form three-way associations as described above. Second, considerable evidence in the psychological-reasoning literature contradicts the notion that infants merely form associations that encode "configurations of persons relating to objects" and then look longer at events with "low level similarity to previous encodings" (Ruffman & Perner, 2005, p. 462). This evidence indicates that, when watching an agent act on objects in a simple scene, infants attribute at least two kinds of mental states to the agent: *motivational* and *reality-congruent informational* states (e.g., Bíró & Leslie, 2007; Csibra, 2008; Gergely, Nádasdy, Csibra, & Bíró, 1995; Hamlin, Wynn, & Bloom, 2007; Kuhlmeier, Wynn, & Bloom, 2003; Liszkowski, Carpenter, Striano, & Tomasello, 2006; Luo, in press; Luo & Baillargeon, 2005; Shimizu & Johnson, 2004; Sommerville, Woodward, & Needham, 2005; Tomasello & Haberl, 2003; Woodward, 1998). The motivational states specify the agent's motivation in the scene and include goals and dispositions. The reality-congruent informational states correspond to states of knowledge and ignorance: they specify what accurate information (as construed by the infants) the agent possesses or lacks about the scene. The agent's knowledge may come about through perception (i.e. what the agent can see), through memory (i.e. what the agent has seen), or through inference (i.e. what the agent can reasonably infer based on previous experiences in the scene or in the world more generally).

To illustrate these various attributions, consider a series of experiments that examined whether 12.5-month-olds would take into account an agent's knowledge about what objects were present in a scene when interpreting the agent's actions (Luo & Baillargeon, 2007). In the first experiment, modeled after Woodward (1998), the infants received three familiarization trials in which a female agent sat behind and between two large transparent screens; a block stood in front of the left screen and a cylinder stood in front of the right screen. In each trial, the agent reached around the right screen to grasp the cylinder and then paused. Following the familiarization trials, the screens were removed and the objects' positions were reversed. During the test trial, the agent reached for the cylinder (old-object event) or the block (new-object event) and then paused. The infants who saw the new-object event looked reliably longer than those who saw the old-object event, suggesting that (1) during the familiarization trials, the infants attributed to the agent a particular disposition, a preference for the cylinder over the block, and (2) during the test trial, the infants expected the agent to maintain this preference and to form the goal of reaching for the cylinder in its new position. In a second experiment, an opaque screen replaced the transparent screen behind the block, so that the agent could no longer see the block (though the infants still could). The infants now looked about equally at the new- and old-object events, suggesting that (1) during the familiarization trials, the infants no longer interpreted the agent's actions as revealing a preference for the cylinder over the block, since she was ignorant about the block's presence in the scene, and (2) during the test trial, the infants had no basis for determining which of the two objects the agent would prefer now that she could see both. In a final experiment, the agent placed the block in front of the opaque screen herself at the start of the test session. The infants looked reliably longer at the new- than at the old-object event, suggesting that they once again attributed to the agent a preference for the cylinder, since she consistently reached for it even though she knew of the block's presence in front of the opaque screen.[1]

The infants in these experiments kept track of what objects the agent could see or had seen, and they used this information to determine whether or not the agent's actions signaled a

[1]Infants keep track of the knowledge an agent possesses and lacks about a scene and use this information not only to interpret the agent's actions but also to guide their own (e.g., Liszkowski et al., 2006; Tomasello & Haberl, 2003). To illustrate, in one experiment, 12-month-olds participated in a task involving an experimenter and an agent (Tomasello & Haberl, 2003). To start, the experimenter and the infant examined a novel object together. Next, the experimenter put the object away and the agent entered the room. The experimenter, the agent, and the infant then examined two more novel objects together. Finally, the experimenter produced all three objects and then the agent exclaimed: "Wow! Look! Look at that! So look at that! Give it to me, please" (Tomasello & Haberl, 2003, p. 909). Infants were more likely to select the first object that they had examined, suggesting that they knew which objects the agent had seen before and which object she had not.

preference for the cylinder over the block. These results would be difficult to explain using an association interpretation: because the agent always reached for the cylinder in the familiarization trials, the new-object event was always the one with “low level similarity to previous encodings,” and yet the infants did not consistently look longer at the new- than at the old-object event across all three experiments. These and many other psychological-reasoning experiments make it clear that, far from responding to agents’ actions solely on the basis of low-level associations formed during the course of the experiments, infants reason about the mental states that underlie these actions (see also Luo & Baillargeon, in press).

The Ignorance and Search-Rule Interpretations

Two additional interpretations have been offered for the results of the VOE and AL false-belief tasks with infants. In line with the evidence discussed in the last section, both interpretations assume that infants can attribute to agents motivational and reality-congruent informational states. At issue is whether infants can *also* attribute to agents *reality-incongruent informational states*, such as false beliefs, or whether alternative mechanisms can explain infants’ apparent success in these tasks.

The *ignorance* interpretation assumes that infants bring to the laboratory general expectations about how ignorant agents typically behave. There are two distinct versions of this interpretation. According to one version (the *error* version; Southgate et al., 2007; see also Ruffman, 1996; Saxe, 2005), infants possess a general expectation that ignorance leads to error. Thus, if an agent is absent when an object is moved from location-A to location-B, infants (1) realize that the agent is ignorant about the object’s current location; (2) expect the agent to search in the incorrect location, location-A; and (3) are surprised if the agent searches in the correct location, location-B. According to the other version (the *uncertainty* version; Wellman, in press), infants expect ignorance to lead to uncertainty, rather than to error. To return to our example, infants (1) realize that the agent is ignorant about the object’s current location, location-B, and (2) are surprised if the agent approaches location-B confidently, as opposed to tentatively or hesitatingly, as would befit an ignorant agent. Although either version of the ignorance interpretation can explain the VOE false-belief results described earlier, neither version can explain the AL false-belief results of Southgate et al. (2007). Had the infants simply expected the ignorant agent to search for the toy in an incorrect location (as suggested by the error version), they would have had no basis for predicting which box she would select: because the bear left with the toy, *both* boxes were incorrect locations. Furthermore, had the infants only been able to wonder post hoc why the ignorant agent approached the correct location with confidence (as suggested by the uncertainty version), they could not have anticipated where the agent would search for the toy.

Finally, the *search-rule* interpretation (Perner & Ruffman, 2005; Ruffman & Perner, 2005) assumes that infants bring to the laboratory, not general expectations about how ignorant agents typically behave, but more specific expectations or behavioral rules about how ignorant agents search for hidden objects. These rules specify that agents who are ignorant about an object’s current location will search for it where they saw it last, where it has typically been hidden in the past, where they are told it is hidden, and so on. If we suppose that most infants acquire the same search rules, then we can account for all of the VOE and AL false-belief results described earlier.

A test of the Ignorance Interpretation

Recent VOE false-belief investigations have pursued two goals. A first goal has been to explore infants’ ability to reason about false beliefs other than those involving objects’ locations. For example, Song and Baillargeon (2008) found that 14.5-month-olds realized that an agent who was searching for an object could be driven by misleading perceptual information to form a *false perception* of a part protruding from a hiding place (i.e. to believe it was a part of the object when it was not). A second goal has been to examine the alternative interpretations that have been offered for early demonstrations of false-belief understanding. In a recent series of experiments with 18-month-olds, Scott and Baillargeon (2009) pursued both research goals. One (false-belief) experiment asked whether infants would realize that an agent could be led by outdated contextual information to form a false belief about the *identity* of an object (i.e. to believe it was one particular object token when it was actually another). Another (ignorance) experiment tested the ignorance interpretation discussed in the last section: it examined whether infants would respond differently when the agent was merely ignorant, as opposed to mistaken, about the object's identity.

The false-belief experiment involved two toy penguins that were identical except that one could come apart (2-piece penguin) and one could not (1-piece penguin). The infants first received four familiarization trials. In each trial, while a female agent watched, an experimenter's gloved hands placed the 1-piece penguin and the two pieces of the disassembled 2-piece penguin on platforms or in shallow containers. The agent then placed a key in the bottom piece of the 2-piece penguin and stacked the two pieces; the two penguins were then indistinguishable. The familiarization trials thus served to establish that the agent had the goal of hiding her key inside the 2-piece penguin. Next, the infants received two test trials. In each trial, the agent was initially absent. The gloved hands assembled the 2-piece penguin, covered it with a transparent cover, and then covered the 1-piece penguin with an opaque cover. The agent then returned with her key, reached for either the transparent (transparent-cover event) or the opaque (opaque-cover event) cover, and then paused. The infants looked reliably longer at the transparent- than at the opaque-cover event, suggesting that they expected the agent (1) to falsely believe that the penguin visible under the transparent cover was the 1-piece penguin (since the 2-piece penguin was always disassembled at the start of the preceding trials); (2) to falsely conclude that the 2-piece penguin was under the opaque cover (since both penguins were always present in the preceding trials); and hence (3) to reach for the opaque cover. This and other results indicated that 18-month-olds realize that an agent can be led by outdated contextual information to form a false belief about an object's identity.

The ignorance experiment was similar to the false-belief experiment except that the test events involved two opaque covers. The infants looked about equally when the agent reached for either cover, suggesting that they understood she had no basis for determining which cover hid the 2-piece penguin (a control experiment showed that the infants did remember which cover hid which penguin). These results argue against the proposal that infants in VOE false-belief tasks attribute ignorance, rather than false beliefs, to agents. Had the infants in the false-belief experiment simply expected the agent to look for her 2-piece penguin in the incorrect location (*error* version), or had they merely been surprised when she reached confidently in the correct location (*uncertainty* version), then the infants in the ignorance experiment would have responded in exactly the same manner. The fact that they did not suggests that, by 18 months of age, infants treat false belief and ignorance as distinct informational states.

The Present Research

The research summarized in the previous sections casts doubt on the association and ignorance interpretations, two of the three alternative interpretations that have been proposed for reports of early false-belief understanding. In the present research, we sought to address the third alternative interpretation, the search-rule interpretation. As was mentioned at the start of this article, one limitation of the VOE and AL false-belief experiments conducted to date is that all of them have relied on the same *search* paradigm. As such, findings from these experiments remain open to the search-rule interpretation. Here we examined whether 18-month-old infants would still demonstrate an understanding of false belief when tested with a novel *non-search* paradigm.

Our experimental approach was suggested by findings from inductive-reasoning experiments by Baldwin, Graham, and their colleagues, which indicate that (1) infants expect similar, but not dissimilar, objects to share non-obvious properties and (2) the greater the similarity between two objects, the greater the likelihood that infants will generalize a non-obvious property from one object to the other (e.g., Baldwin, Markman, & Melartin, 1993; Graham & Kilbreath, 2007; Graham, Kilbreath, & Welder, 2004; Keates & Graham, 2008; Welder & Graham, 2001). For example, in one experiment with 16- to 21-month-olds (M = 18 months; Welder & Graham, 2001), an experimenter first introduced a target object with an interesting non-obvious property that could be elicited by a relevant action (e.g., a felt-covered object that rattled when shaken, or a rayon-covered object that squeaked when squeezed). The infants were allowed to explore the target object for 10 s, and then they were given one of several test objects to explore for 20 s. The test objects did not possess the non-obvious property (e.g., they produced no noise when shaken or squeezed), and they varied in their similarity to the target object: the high-similarity test object was similar to the target object in texture and shape but differed in color and size; the low-similarity test object was similar in texture but differed in shape, color, and size; and the dissimilar test object differed from the target object in texture, shape, color, and size. Across trials, the infants performed significantly more relevant actions on the high-similarity objects than on the low-similarity objects, and they performed significantly more relevant actions on the low-similarity objects than on the dissimilar objects. These and other results suggest that, by 18 months of age, infants rely on the degree of similarity between objects to draw inferences about their non-obvious properties.

The non-search false-belief paradigm used in the present research rested on three main assumptions: (1) infants would expect objects that are perceptually identical to have the same non-obvious properties; (2) infants would be less certain whether objects that differ in color and pattern have the same non-obvious properties; and (3) infants would attribute the same expectations to other agents. The first two assumptions were based on the findings reviewed above, and the third assumption was based on recent evidence that infants aged 6 months and older ascribe their own background knowledge about the world to other agents (e.g., Buresh & Woodward, 2007; Egyed, Király, Krekó, Kupán, & Gergely, 2007; He & Baillargeon, 2009, 2010). For instance, once infants learn that a wide object cannot fit into a narrow container, or that a tall object cannot fit into a short container, they expect other agents to possess the same knowledge (He & Baillargeon, 2009, 2010). In line with these findings, we reasoned that infants might attribute to other agents their general expectations about which objects are more or less likely to share non-obvious properties.

Participants in Experiment 1 were 18-month-olds and they were tested in a novel VOE task. As an agent watched, an experimenter demonstrated that her object had an interesting non-obvious property: it produced a rattling noise when shaken. Next, the experimenter asked the agent “Can you do it?” The agent then chose between two test objects: one was identical to the experimenter’s object (identical test object) and the other differed from it in color and pattern (different test object). The infants (but not the agent) were shown in a prior trial that the different test object rattled when shaken, but the identical test object did not.

If the infants reasoned that the agent (1) would falsely believe that the identical test object rattled when shaken (since objects that are perceptually identical typically have the same non-obvious properties) and (2) would be less certain whether the different test object rattled when shaken (since objects that differ in color and pattern may be less likely than identical objects to have the same non-obvious properties), then they should expect the agent to choose the identical test object, and they should look reliably longer when the agent chose the different test object instead.[2]

We believed that positive results in Experiment 1 would be important for three reasons. First, such results would indicate that, at 18 months of age, false-belief reasoning extends to false beliefs about the non-obvious properties of objects. Second, these results would demonstrate that infants in the second year of life show evidence of false-belief understanding even when tested with a non-search paradigm. Finally, these results would argue against the search-rule interpretation of previous VOE and AL false-belief tasks, all of which employed a search paradigm.

Experiment 1

The infants in Experiment 1 were assigned to a false-belief or a knowledge condition (see Fig. 1). The infants in the *false-belief* condition received one familiarization and one test trial. In the familiarization trial, a female experimenter sat at a window in the right wall of the apparatus. In front of her was a red cylindrical object decorated with silver stars (experimenter's object). In front of a closed window in the back wall of the apparatus were two test objects; one was perceptually identical to the experimenter's object (identical test object), and the other was a green cylindrical object decorated with orange stripes (different test object). The experimenter first shook her object three times, demonstrating that it made a rattling noise when shaken. Next, she shook the different test object, which also made a noise, and then she shook the identical test object, which made no noise. The experimenter repeated this procedure, shaking each object in turn, until the trial ended. In the test trial, the experimenter was joined by a female agent who sat at the window in the back wall of the apparatus, behind the two test objects. The experimenter picked up her object, turned to the agent, and said, "Look!" She shook her object three times, demonstrating that it produced a rattling noise, and then (while still holding her object in midair) she asked the agent, "Can you do it?" In response to the experimenter's prompt, the agent grasped either the identical test object (identical-object trial) or the different test object (different-object trial), and then she paused until the trial ended. The infants in the *knowledge* condition received similar trials except that the agent was present in the familiarization trial and thus knew which test object rattled when shaken and which did not.

If the infants in the false-belief condition (1) attributed to the agent the goal of producing the same rattling noise as the experimenter, (2) remembered that the agent was absent during the familiarization trial and thus was ignorant about which test object rattled and which did not, (3) reasoned that the agent would falsely expect the identical test object to rattle, but would be less certain whether the different test object rattled (since objects that are perceptually identical typically share the same non-obvious properties, whereas objects that differ in color and pattern may be less likely to do so), then they should expect the agent to reach for the identical test object and they should look longer when she reached for the different test

[2]Readers might wonder why we chose a different test object that differed from the experimenter's object only in color and pattern. There were two possible advantages to using such an object as opposed to a more dissimilar object. First, had we used an identical test object that did not rattle and a dissimilar object that did rattle, infants might have been inclined to simultaneously attribute to the agent *two* false beliefs—one about the identical test object and one about the dissimilar test object—and this added complexity might have interfered with their performance. As a first step, it seemed more prudent to use a different test object infants would expect to rattle (e.g., Baldwin et al., 1993; Graham & Kilbreath, 2007; Graham et al., 2004; Keates & Graham, 2008; Welder & Graham, 2001), though with less certainty than they would the identical test object. Second, using objects that differed only in color and pattern meant that the experimenter's and the agent's actions on all of the objects were highly similar, which helped rule out possible contributions from low-level and extraneous factors.

object instead. The infants who received the different-object trial should thus look reliably longer than those who received the identical-object trial.

As for the infants in the knowledge condition, if they (1) attributed to the agent the goal of producing the same rattling noise as the experimenter and (2) remembered that the agent was present during the familiarization trial and thus knew which test object rattled and which did not, then they should expect her to reach for the different test object and they should look longer when she reached for the identical test object instead. The infants who received the identical-object trial should look reliably longer than those who received the different-object trial. Opposite looking patterns were thus predicted for the infants in the false-belief and knowledge conditions.

As stated above, the success of Experiment 1 depended in part on the infants' ability to keep track of whether the agent was absent (false-belief condition) or present (knowledge condition) during the familiarization trial. It seemed highly likely that the infants would be able to do so, because there is extensive evidence from tasks on reality-congruent and reality-incongruent informational states that infants aged 12 months and older notice, and appreciate the significance of, agents' presence or absence during events (e.g., Liszkowski et al., 2006; Luo & Beck, 2010; Moll & Tomasello, 2007; Scott & Baillargeon, 2009; Tomasello & Haberl, 2003). To illustrate, most of the VOE false-belief reports published to date included both a false-belief and a knowledge condition; across conditions, infants kept close track of when the agent was present or absent and what events the agent did or did not witness (e.g., Onishi & Baillargeon, 2005; Scott & Baillargeon, 2009; Song & Baillargeon, 2008; Surian et al., 2007).

Finally, the success of Experiment 1 also depended in part on the infants' ability to interpret correctly the experimenter's question to the agent, "Can you do it?" Specifically, the infants had to assume that the experimenter was asking whether the agent could produce a rattling noise, and not whether the agent could shake a red object, shake any object, lift a red object, lift any object, and so on. Since infants are highly sensitive to the effects of actions on objects (e.g., Elsner & Pauen, 2007; Hauf & Aschersleben, 2008; Hauf, Elsner, & Aschersleben, 2004), and since the rattling noise produced by our objects was quite salient, we felt reasonably confident that the infants would assume that the experimenter meant something like "Can you produce a rattling noise?" and that they would attribute the same interpretation to the agent.

Method

Participants—Participants were 36 healthy term infants, 18 male and 18 female, ranging in age from 18 months, 9 days to 19 months, 9 days (*M* = 18 months, 22 days). Another 10 infants were tested but excluded, 5 because they were active (2), inattentive (1), distracted (1), or fussy (1), 3 because their test looking times were over 3 standard deviations from the mean of their condition, 1 because he refused to give up his bottle, and 1 because of equipment failure. Half the infants were randomly assigned to the false-belief condition (*M* = 18 months, 20 days), and half to the knowledge condition (*M* = 18 months, 24 days). Within each condition, half the infants were randomly assigned to receive the identical-object test trial, and half the different-object test trial.

The infants' names in this and the following experiments were obtained from purchased mailing lists and from birth announcements in the local newspaper. Parents were offered reimbursement for their transportation expenses but were not compensated for their participation. The racial and ethnic composition of the infants in the present experiments was 84% Caucasian, 7% Asian (or mixed Asian-Caucasian), 3% Hispanic (or mixed Hispanic-Caucasian), 4% African American (or mixed African American-Caucasian), and

2% American Indian (or mixed American Indian-Caucasian). No information was collected on parents' education, occupation, and income.

Apparatus—The apparatus consisted of a wooden display booth 124 cm high, 102 cm wide, and 56.5 cm deep, mounted 77 cm above the room floor. The infant faced an opening 46 cm high and 95 cm wide in the front of the apparatus; between trials, a curtain consisting of a muslin-covered wooden frame 59.5 cm high and 101.5 cm wide was lowered in front of this opening. The side walls of the apparatus were painted white, the back wall was made of white foam board, and the floor was covered with beige paperboard.

The agent wore a green shirt and a green visor (the agent wore a visor to prevent infants from simply focusing on her eyes to predict which test object she would grasp). The agent sat on a wooden chair centered behind a large window 63.5 cm high and 42 cm wide in the back wall of the apparatus. This back window extended from the apparatus floor, was located 7 cm from the right wall (from the infants' perspective), and had a door that could be closed to hide the agent; the door was made of white foam board and was 63.5 cm high and 42 cm wide. A large muslin screen behind the agent hid the test room.

The experimenter wore a denim shirt and a white visor (the experimenter wore a visor so that the infants did not think the experimenter could give the agent hints, in the form of eye gaze, about which test object to select). The experimenter knelt at a window 51 cm high and 38 cm wide in the right wall of the apparatus. This right window was located 4 cm above the apparatus floor and 7.5 cm from the back wall.

The three cylindrical objects used in the experiment were plastic cups closed with plastic lids; each object was 9.5 cm tall, 8 cm in diameter at the top, and 5 cm in diameter at the base. The experimenter's object and the identical test object were made of red plastic and were decorated with silver stars; their lids were covered with red contact paper. The different test object was made of green plastic and was decorated with horizontal orange stripes; its lid was covered with green contact paper. The experimenter's object and the different test object contained four marbles that caused them to produce a rattling noise when shaken; the identical test object was empty. The experimenter's object stood centered 6 cm in front of the right window, and the test objects stood centered 9 cm in front of the back window; the different test object stood 5 cm to the right of the identical test object.

The infants were tested in a brightly lit room, and three fluorescent tubes attached to the front and back walls of the apparatus provided additional light. Two frames, each 183 cm high and 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.

Trials—In the following descriptions, the numbers in parentheses indicate the number of seconds taken to perform the actions described. To help the experimenter and agent adhere to the events' scripts, a metronome beat softly once per second. A camera mounted above and behind the infant captured an image of the events, and a second camera mounted beneath the apparatus floor captured an image of the infant; the two images were combined using a mixer, projected onto a TV set located behind the apparatus, and recorded onto a computer. During the test session, the supervisor monitored the events on the TV set to confirm that they followed the prescribed scripts. Recorded sessions were also checked offline to ensure that the correct actions were performed in each trial.

False-belief condition familiarization trial: Only the experimenter was present during the false-belief condition familiarization trial: the agent was absent and the door in the back window was closed (see Fig. 1). The experimenter knelt at the right window, with her hands on the window ledge. To start, the experimenter grasped her object (1 s), shook it twice per second for 3 s (the object rattled when shaken), and then set it back on the apparatus floor (1 s). She then grasped the different test object (1 s), shook it twice per second for 3 s (the object rattled when shaken), and placed it back on the apparatus floor (1 s). Finally, she grasped the identical test object (1 s), shook it twice per second for 3 s (the object was silent when shaken), and placed it back on the apparatus floor (1 s). The experimenter then repeated these actions, shaking each object in turn, until the computer signaled that the trial had ended (see below for the specific criteria used to end trials). When this signal occurred, the supervisor lowered the curtain in front of the apparatus and the stimuli were readied for the next trial. Inter-trial intervals lasted approximately 10 s, and each new trial began with the raising of the curtain.

False-belief condition test trials: The infants in the false-belief condition received an identical- or a different-object test trial. Each trial consisted of an initial phase followed by a final phase. During the initial phase, the experimenter and agent performed the scripted actions appropriate for the trial, ending with a paused scene; during the final phase, the infant watched this paused scene until the trial ended. The duration of the initial phase was fixed and lasted 12 s; the duration of the final phase was infant-controlled.

At the start of the initial phase in each test trial, the experimenter again knelt at the right window, and the agent now sat at the back window, with her hands resting on the apparatus floor (the tips of her middle fingers were centered 3.5 cm behind the test objects). The agent watched as the experimenter performed her scripted actions. To start, the experimenter grasped her object (1 s) and lifted it about 12 cm above the apparatus floor (1 s). She then turned to the agent, said, “Look!” (1 s), and shook her object as before for 3 s. Next, the experimenter (still holding her object in midair) asked the agent, “Can you do it?” (1 s). The experimenter then placed her object on the apparatus floor (1 s), returned her hands to the window ledge (1 s), and looked down at her object. The agent then looked at a neutral point on the apparatus floor between the two test objects (1 s) and paused for 1 s. Next, she grasped either the identical (identical-object trial) or the different (different-object trial) test object with her right hand (1 s) and paused, with her eyes on the object. During the final phase of the trial, the infants watched this paused scene until the trial ended.

Knowledge condition familiarization and test trials: The familiarization and test trials in the knowledge condition were identical to those in the false-belief condition, except that the agent was present during the familiarization trial. At the start of the trial, the agent sat at the back window with her hands in her lap and her gaze focused on the neutral point on the apparatus floor between the two test objects. During the trial, the agent watched the experimenter as she performed her scripted actions.

Procedure—The infant sat on a parent’s lap centered about 45 cm in front of the apparatus. The parents were instructed to remain silent and neutral and to close their eyes during the test trial. Prior to the start of the test session, the agent and experimenter introduced themselves to the infant, showing the infant their shirts and visors.

The infants’ looking behavior was monitored by two naïve 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 pressed the button when the infant attended to the events shown in the trial. The looking times recorded by the primary observer were used to determine when a trial had ended.

The infants first received the familiarization trial appropriate for their condition. This trial was programmed to end when the infant either (1) looked away for 2 consecutive seconds after having looked for at least 15 cumulative seconds (the time it took the experimenter to shake all three objects once) or (2) looked for 60 cumulative seconds without looking away for 2 consecutive seconds. All infants were highly attentive during the familiarization trial and looked for the maximum time of 60 seconds.

Next, the infants received a test trial; half the infants in each condition received the identical-object trial, and half received the different-object trial. Looking times during the initial and final phases of the trial were computed separately using the primary observer's responses. Examination of the looking times during the 12-s initial phase indicated that the infants in both the false-belief (M = 11.9) and the knowledge (M = 11.7) condition were highly attentive. The final phase of each test trial ended when the infant either (1) looked away for 0.5 consecutive second after having looked for at least 5 cumulative seconds or (2) looked for 30 cumulative seconds without looking away for 0.5 consecutive second.

To assess interobserver agreement during the familiarization and test trials, each trial was divided into 100-ms intervals. For each interval, the computer determined whether the observers agreed on whether or not the infant was looking at the events shown in the trial. Percent agreement was calculated for each trial by dividing the number of intervals in which the observers agreed by the total number of intervals in the trial. Interobserver agreement was measured for 34 of the 36 infants (only one observer was present for the other infants), and averaged 98% per trial per infant.

Preliminary analyses of the test data in this and the following experiments revealed no interactions of condition and trial with sex, all Fs < 1.84; the data were therefore collapsed across sex in subsequent analyses.

Results

The infants' looking times during the final phase of the test trial (see Fig. 2) were analyzed using a 2 × 2 analysis of variance (ANOVA) with condition (false-belief or knowledge) and trial (identical- or different-object) as between-subjects factors. The analysis yielded a significant interaction between condition and trial, $F(1, 32) = 11.73$, $p < .0025$, $\eta_p^2 = .27$. There was no significant effect of condition or trial, both Fs < 1. Planned comparisons revealed that in the false-belief condition, the infants who received the different-object trial (M = 23.3, SD = 8.6) looked reliably longer than those who received the identical-object trial (M = 13.6, SD = 5.4), $F(1, 32) = 7.78$, $p < .01$, Cohen's d = 1.43, whereas in the knowledge condition, the infants who received the identical-object trial (M = 20.6, SD = 8.2) looked reliably longer than those who received the different-object trial (M = 13.5, SD = 7.0), $F(1, 32) = 4.21$, $p < .05$, d = .99.

Discussion

In the knowledge condition, the infants who received the identical-object trial looked reliably longer than those who received the different-object trial. This result suggested that, during the test trial, the infants (1) attributed to the agent the goal of producing the same rattling noise as the experimenter; (2) remembered that the agent was present during the familiarization trial and thus knew which test object rattled and which did not; and therefore (3) expected the agent to reach for the different test object and looked longer when she reached for the identical test object instead.

In the false-belief condition, in contrast, the infants who received the different-object trial looked reliably longer than those who received the identical-object trial. This result suggested that, during the test trial, the infants (1) attributed to the agent the goal of producing a rattling noise; (2) remembered that the agent was absent during the familiarization trial and thus was ignorant about which test object rattled and which did not;

(3) reasoned that the agent would falsely believe that the identical test object rattled, but would be less certain whether the different test object rattled (since objects that are perceptually identical typically share the same non-obvious properties, whereas objects that differ in color and pattern may be less likely to do so); and hence (4) expected the agent to reach for the identical test object and looked longer when she reached for the different test object instead.[3]

Together, the results of Experiment 1 suggest that, by 18 months of age, infants can attribute to others false beliefs about objects' non-obvious properties. In addition, the results suggest that infants give evidence of false-belief understanding even when tested with a non-search task. The infants in the false-belief condition reasoned about which of two visible objects a naive agent was likely to select to reproduce an interesting effect, rather than about which of two locations an agent was likely to search to find a hidden object. As such, the results of Experiment 1 cast doubt on the search-rule interpretation that has been offered for previous VOE and AL false-belief results (Perner & Ruffman, 2005; Ruffman & Perner, 2005).

Experiment 2

Experiment 2 had two goals. The first was to confirm the key findings from Experiment 1, that 18-month-olds can attribute a false belief about an object's non-obvious property to an agent, and that they can demonstrate this ability even when tested with a non-search task. The second goal was to address a possible alternative interpretation of these findings.

It might be suggested that, although the results of the false-belief condition in Experiment 1 could not be explained by appealing to search rules (since no search took place), they could still be explained by invoking additional rules. A broad behavioral-rule interpretation might hold that, just as infants form rules about how agents search for hidden objects, they also form rules about how agents select objects to reproduce effects. Thus, infants might learn the following rule: when an agent (1) observes an individual demonstrate that an object with a non-obvious property can be used to produce an interesting effect, (2) wants to reproduce this effect, and (3) is ignorant about which of a set of objects possesses the same non-obvious property, then the agent is likely to select whichever object in the set is most perceptually similar to—or best matches—the individual's object. Using this *object-matching* rule, one could argue that the infants in the false-belief condition of Experiment 1 did not in fact attribute to the agent the false belief that the identical test object would rattle when shaken. Instead, the infants simply expected the ignorant agent to match the experimenter's actions by selecting the identical test object. The second goal of Experiment 2 was to test this alternative interpretation.

[3]To succeed in the false-belief condition of Experiment 1, the infants had to distinguish between two types of knowledge: general knowledge that most agents would be expected to possess (e.g., objects that are perceptually identical typically have the same non-obvious properties) and situation-specific knowledge that an agent could only gather through appropriate experiences in a situation (e.g., the identical test object did not rattle when shaken). What factors generally help infants distinguish between these two types of knowledge? Recent research on 18-month-olds' sensitivity to pedagogical cues bears on this question (e.g., Egyed et al., 2007). If a first agent used ostensive-communicative cues (e.g., addressed the infant) before emoting positively toward object-A and emoting negatively toward object-B, the infants took this demonstration to mean that object-A was pleasing whereas object-B was not, and they expected a second agent to share the same knowledge and preference. However, if the first agent did *not* use ostensive-communicative cues, then the infants took the agent's actions to reflect only her own preference for object-A, and they had no expectation about which object the second agent would prefer (see also Buresh & Woodward, 2007). These findings have interesting implications for paradigms (such as the present one) where infants receive demonstration phases showing whether objects possess non-obvious properties. If an experimenter used ostensive-communicative cues when demonstrating that a test object rattled but another test object did not, would infants then treat their newly-acquired knowledge as general rather than as situation-specific knowledge and expect a naive agent to share this knowledge? Such experiments should help shed light on some of the factors that affect how infants distinguish between general and situation-specific knowledge.

The infants were again assigned to a false-belief or a knowledge condition. In both conditions, the infants now received two familiarization trials. The first trial was identical to the familiarization trial in the knowledge condition of Experiment 1: while the agent watched, the experimenter demonstrated the properties of her object and the two test objects by shaking each object in turn. The second familiarization trial differed across the two conditions. In the false-belief condition, the agent was now absent and her back window was closed. The experimenter removed the lids from the two test objects, poured the marbles from the different test object into the identical test object, and then replaced the lids. The experimenter then shook each of the three objects again, demonstrating that the identical test object now made noise whereas the different test object did not. In the knowledge condition, the agent remained present for the second familiarization trial and thus knew which test object rattled and which did not. Following the two familiarization trials, all infants received an identical- or a different-object test trial, as in Experiment 1.

The infants in the knowledge condition should expect the agent to reach for the test object that she knew rattled when shaken. Since in Experiment 2 this was the identical test object, the infants should expect the agent to reach for that object and they should look longer when she reached for the different test object instead. The infants' looking pattern should thus be the reverse from that observed in the knowledge condition of Experiment 1 (recall that in that condition the agent knew the different test object rattled when shaken).

As for the infants in the false-belief condition, two possibilities existed. If the infants in the false-belief condition of Experiment 1 were using a simple object-matching rule to predict which test object the ignorant agent would select, then the infants in the false-belief condition of Experiment 2 should do the same: they should once again expect the ignorant agent to reach for the test object that matched the experimenter's object, the identical test object, and they should look longer when she reached for the different test object instead. According to this first alternative, the results of the false belief-condition in Experiment 2 should thus be identical to those of the false-belief condition in Experiment 1.

On the other hand, if (as we supposed) the infants in the false-belief condition of Experiment 1 were reasoning about the agent's likely beliefs about the non-obvious properties of the test objects, rather than merely applying an object-matching rule, then the infants in the false-belief condition of Experiment 2 should reason as follows: since the agent was present during the first but not the second familiarization trial, she should falsely believe that the different test object rattled but the identical test object did not. The infants should therefore expect the agent to reach for the different test object, and they should look longer when she reached for the identical test object instead. As in Experiment 1, we thus expected that opposite looking patterns would be obtained in the knowledge and false-belief conditions of Experiment 2—although in each condition the predicted pattern was the reverse from that observed in Experiment 1.

Method

Participants—Participants were 32 healthy term infants, 16 male and 16 female, ranging in age from 18 months, 9 days to 19 months, 6 days (M = 18 months, 21 days). Another 3 infants were tested but excluded, 2 because they were active (1) or fussy (1), and 1 because her test looking time was over 3 standard deviations from the mean of her condition. Half the infants were randomly assigned to the false-belief condition (M = 18 months, 24 days), and half to the knowledge condition (M = 18 months, 20 days). Within each condition, half the infants were randomly assigned to receive the identical-object test trial, and half the different-object test trial.

Apparatus—The apparatus was identical to that used in Experiment 1.

Trials

False-belief condition familiarization trials: The infants in the false-belief condition received two familiarization trials. The first trial was identical to the familiarization trial in the knowledge condition of Experiment 1: as the agent watched, the experimenter shook each object in turn until the trial ended; the experimenter's object and the different test object made a rattling noise when shaken, but the identical test object did not. The second familiarization trial consisted of a 17-s initial phase followed by a final phase; in both phases, the agent was absent and the back window remained closed. At the start of the initial phase, the experimenter knelt at the right window, with her hands on the window ledge. She first grasped the identical test object (1 s), removed its lid (1 s), and placed it in front of the object on the apparatus floor (1 s). She then repeated these actions with the different test object (3 s). Next, the experimenter poured the marbles of the different test object into the identical test object (2 s), and then she returned the different test object to its original position on the apparatus floor (1 s). She replaced the lid on the different test object (3 s) and on the identical test object (3 s), returned her hands to the ledge of her window (1 s), and paused (1 s). During the final phase of the trial, the experimenter shook each object in turn, as in the first familiarization trial, except that now her object and the identical test object rattled when shaken, whereas the different test object did not. The experimenter continued shaking the objects until the computer signaled that the trial had ended.

False-belief condition test trials: The infants in the false-belief condition received an identical or a different-object test trial, as in Experiment 1.

Knowledge condition familiarization and test trials: The infants in the knowledge condition received the same familiarization and test trials as in the false-belief condition, except that the agent was present during the second familiarization trial and thus knew that the identical test object now rattled and the different test object did not.

Procedure

All infants received two familiarization trials: The first was the same in the false-belief and knowledge conditions, and the criteria used to end the trial were the same as in Experiment 1. The second trial differed across the two conditions. Looking times during the initial and final phases of the trial were computed separately. Examination of the looking times during the 17-s initial phase indicated that the infants in both the false-belief (M = 16.8) and knowledge (M = 16.7) conditions were highly attentive. The criteria used to end the final phase of the trial were the same as for the first familiarization trial. Looking times during the two familiarization trials were averaged and analyzed by means of a 2 × 2 ANOVA with condition (false-belief or knowledge) and test trial (identical- or different-object) as between-subject factors. The condition x event interaction was not significant, $F < 1$, suggesting that the infants in the four experimental groups tended to respond similarly during the familiarization trials (false-belief/identical-object: M = 57.2, SD = 4.2; false-belief/different-object, M = 53.3, SD = 8.3; knowledge/identical-object M = 51.1, SD = 9.0; knowledge/different-object M = 51.6, SD = 7.1).

Next, the infants in the two conditions received either the identical- or the different-object test trial. Examination of the looking times during the 12-s initial phase of the trial indicated that the infants in both the false-belief (M = 11.8) and knowledge (M = 11.3) conditions were highly attentive. The criteria used to end the final phase of the trial were the same as in Experiment 1. Interobserver agreement during the familiarization and test trials was measured for all 32 infants and averaged 98% per trial per infant.

Results

The infants' looking times during the final phase of the test trial (see Fig. 2) were analyzed as in Experiment 1. The analysis yielded a significant main effect of condition, $F(1, 28) = 7.91$, $p < .01$, $\eta_p^2 = .22$, as well as a significant interaction between condition and event, $F(1, 28) = 11.74$, $p < .0025$, $\eta_p^2 = .30$. The main effect of event was not significant, $F < 1$. Planned comparisons revealed that in the false-belief condition, the infants who received the identical-object trial ($M = 23.1$, $SD = 8.5$) looked reliably longer than those who received the different-object trial ($M = 16.0$, $SD = 4.4$), $F(1, 28) = 4.65$, $p < .05$, $d = 1.12$, whereas in the knowledge condition, the infants who received the different-object trial ($M = 17.4$, $SD = 8.7$) looked reliably longer than those who received the same-object trial ($M = 8.6$, $SD = 2.3$), $F(1, 28) = 7.22$, $p < .025$, $d = 1.48$.

Comparison of Experiments 1 and 2—As mentioned earlier, we predicted that reverse patterns would be observed in the false-belief and knowledge conditions of Experiments 1 and 2. To test this prediction, the test data from the two experiments were analyzed using a 2 × 2 × 2 ANOVA with Experiment (1 or 2), condition (false-belief or knowledge), and trial (identical- or different-object) as between-subjects factors. The analysis yielded a significant main effect of condition, $F(1, 60) = 5.39$, $p < .025$, $\eta_p^2 = .08$. The infants in the false-belief conditions ($M = 18.9$, $SD = 8.0$) looked reliably longer overall than the infants in the knowledge conditions ($M = 15.1$, $SD = 8.1$), presumably because the reasoning process required to interpret the agent's actions was generally more demanding in the false-belief conditions. This finding is consistent with recent evidence that 4-year-olds and adults take longer to provide correct answers to questions about an agent's false belief than to questions about reality (e.g., Apperly, Riggs, Simpson, Chiavarino, & Samson, 2006; Kikuno, Mitchell, & Ziegler, 2007).

As predicted, the ANOVA also yielded a significant Experiment × condition × trial interaction, $F(1, 60) = 8.46$, $p < .0001$, $\eta_p^2 = .12$. Planned interaction comparisons confirmed that (1) the infants in the false-belief conditions of Experiments 1 and 2 differed reliably in their responses to the identical- and different-object trials, $F(1, 60) = 12.13$, $p < .001$, $\eta_p^2 = .17$, and (2) the infants in the knowledge conditions of Experiments 1 and 2 also differed reliably in their responses to the two test trials, $F(1, 60) = 10.95$, $p < .0025$, $\eta_p^2 = .15$. In addition, planned comparisons confirmed that, within each condition of Experiments 1 and 2, responses to the two test trials were reliably different (Experiment 1/false belief: $F(1, 60) = 8.65$, $p < .005$; Experiment 1/knowledge: $F(1, 60) = 4.67$, $p < .05$; Experiment 2/false belief: $F(1, 60) = 4.06$, $p < .05$; Experiment 1/knowledge: $F(1, 60) = 6.30$, $p < .025$).

Finally, the combined data of Experiments 1 and 2 were subjected to two non-parametric Wilcoxon rank-sum tests. The first test focused on the combined false-belief conditions of Experiments 1 and 2. In this analysis, we classified each test trial as *expected* when the agent acted in accordance with her false belief (identical-object trial in Experiment 1, different-object trial in Experiment 2) and as *unexpected* when she did not (different-object trial in Experiment 1, identical-object trial in Experiment 2). As predicted, the infants looked reliably longer when the agent's action was unexpected, $Ws = 217$, $p < .01$. The second test focused on the combined knowledge conditions of Experiments 1 and 2. We classified each test trial as *expected* when the agent acted in accordance with her knowledge (different-object trial in Experiment 1, identical-object trial in Experiment 2) and as *unexpected* when she did not (identical-object trial in Experiment 1, different-object trial in Experiment 2). Here again, as predicted, the infants looked reliably longer when the agent's action was unexpected, $Ws = 213.5$, $p < .01$.

Discussion

The infants in the knowledge condition who received the different-object trial looked reliably longer than those who received the identical-object trial. This result suggested that the infants (1) attributed to the agent the goal of making the same rattling noise as the experimenter and (2) expected the agent to reach for the identical test object because she knew, based on the second familiarization trial, that the identical test object now made noise whereas the different test object did not.

In contrast to the infants in the knowledge condition, those in the false-belief condition looked reliably longer if they were given the identical- as opposed to the different-object trial. This result suggested that the infants (1) again attributed to the agent the goal of producing a rattling noise; (2) realized that, because the agent was present during the first but not the second familiarization trial, she falsely believed that the different test object rattled but the identical test object did not; and hence (3) expected the agent to reach for the different test object and looked longer when she reached for the identical test object instead.

The result of the false-belief condition in Experiment 2 suggested three conclusions. First, it confirmed and extended the result of the false-belief condition in Experiment 1: infants again attributed to an agent a false belief about an object's non-obvious property, although in this case the agent's false belief was derived from her prior encounter with the object rather than from a general expectation that identical objects tend to have identical non-obvious properties.

Second, the result provided additional evidence that infants in the second year of life can demonstrate their false-belief understanding even when tested with non-search tasks. As such, the result cast further doubt on the suggestion that previous AL and VOE false-belief results simply reflect the application of search rules that infants acquire in everyday life and retrieve in the laboratory when they observe an ignorant agent search for a hidden object.

Finally, the result of the false-belief condition in Experiment 2 also called into question the notion that the infants in the false-belief condition of Experiment 1 used a simple object-matching rule to interpret the agent's actions. According to this rule, when an agent (1) observes an individual demonstrate that an object with a non-obvious property can be used to produce an interesting effect, (2) wants to reproduce this effect, and (3) is ignorant about which of a set of objects possesses the non-obvious property, the agent will select the object that is perceptually most similar to the individual's object. Had the infants in the false-belief conditions of Experiments 1 and 2 followed this rule, they would have shown the same response pattern and looked reliably longer when the ignorant agent reached for the different (non-matching) as opposed to the identical (matching) test object. Instead, the infants in the false-belief condition of Experiment 2 showed the *opposite* response pattern from that predicted by the rule: they looked reliably longer when the agent reached for the identical (matching) as opposed to the different (non-matching) test object. Together, these results suggest that, rather than applying a simple object-matching rule, the infants in Experiments 1 and 2 were reasoning about the agent's beliefs about the non-obvious properties of the test objects.

Rules Revisited—It might be suggested that, although no *single* rule could explain the results of the false-belief conditions of Experiments 1 and 2—since the infants received identical test trials and yet produced opposite responses—the results could still be explained by assuming that the infants brought *two* object-selection rules to the laboratory. Rule-1 would be the object-matching rule described above and would account for the results of the false-belief condition in Experiment 1. Rule-2 would be a modification of the first rule and would account for the results of the false-belief condition in Experiment 2: specifically, when an agent (1) observes an individual produce an interesting effect using an object with a non-obvious property, (2) wants to reproduce this effect, (3) is ignorant about which of a set of objects possesses the non-obvious property, and (4) has evidence that one of the objects in the set, object-A, possesses the non-obvious property, then the agent will select object-A to reproduce the effect.

The critical difficulty with Rule-2 is that the conjunction of points (3) and (4) is effectively a description of the agent's false belief: (3) and (4) can both be true *only* if the evidence available to the agent about object-A is now false. If the agent's evidence about object-A was still true, then (3) would be false: instead of being ignorant about which object possesses the non-obvious property, the agent would *know* that object-A does so. Rule-2 thus implicitly recognizes that an agent may possess and act on evidence that is no longer true—in other words, that an agent may possess and act on a false belief.

To restate this argument more broadly, a behavioral-rule interpretation of the results of the false-belief conditions in Experiments 1 and 2 would need to specify that (1) infants generally expect an agent who is ignorant about some critical aspect of a situation to follow the behavioral rule applicable to the situation, but at the same time (2) infants also expect an agent who has evidence that a rule does not apply in a situation to act in accordance with this evidence rather than with the rule—even when they know the evidence available to the agent is no longer valid. Implicit in this account is thus an acknowledgment that infants expect agents to act in accordance with the evidence available to them, even when outdated or false.

Clearly, a behavioral-rule interpretation cannot provide a viable alternative explanation for infants' responses in VOE and AL false-belief tasks if some of the rules invoked to explain these responses themselves imply an ability to attribute false beliefs.

The Two-Mechanism Interpretation—Apperly and Butterfill (2009) proposed that humans are equipped with two distinct mechanisms for reasoning about agents' beliefs: an early-emerging mechanism that is efficient but inflexible (this mechanism would account for infants' success in VOE and AL false-belief tasks), and a late-emerging mechanism that is dependent on the development of language and executive-function abilities and is flexible but demanding in terms of processing resources (this mechanism would account for children's success, beginning at about age 4, in standard false-belief tasks). This *two-mechanism* interpretation differs from the association, ignorance, and behavioral-rule interpretations of VOE and AL false-belief results in that it *does* grant infants the ability to attribute false beliefs to others. However, this account assumes that this ability is sharply limited. Apperly and Butterfill speculated that some of the "signature limits" of the early-emerging mechanism might include: limitations in the types of beliefs (including false beliefs) that can be attributed to agents; difficulties in understanding causal interactions among beliefs and other mental states; and an inability "to use all cognitively available facts to ascribe any belief that the subjects can themselves entertain" (p. 964).

The findings reviewed in this article and those of Experiments 1 and 2 do not support the notion that early false-belief understanding suffers from these particular limitations. First, there is rapidly accumulating evidence that infants can attribute a variety of reality-incongruent informational states to agents, including pretense (Onishi, Baillargeon, & Leslie, 2007), false perceptions (Song & Baillargeon, 2008), and false beliefs about location (e.g., Onishi & Baillargeon, 2005; Southgate et al., 2007; Surian et al., 2007; Träuble et al., 2010), identity (Scott & Baillargeon, 2009), and non-obvious properties (Experiments 1 and 2).

Second, in several of the experiments just cited, infants could succeed only by attributing to the agent a coherent set of causally interrelated mental states including dispositions, goals, knowledge of specific facts about the scene, and false beliefs (e.g., Scott & Baillargeon, 2009; Song & Baillargeon, 2008). To illustrate, consider once again the false-belief experiment of Scott and Baillargeon (2009), described in the Introduction. In order to respond correctly in the test trials, the infants had to understand that the agent had the *goal* of hiding her key in the 2-piece penguin and was therefore looking for that penguin. The infants also had to consider the agent's *knowledge* about the scene: she could perceive the opaque cover, the transparent cover, and the penguin visible under the transparent cover; and she could infer, based on the preceding trials, that the 1- and 2-piece penguins were both present in the scene. Finally, the infants had to reason that the agent would *falsely expect* the 2-piece penguin to be disassembled (as it had been at the start of the preceding trials) and hence would *falsely conclude* that the penguin visible under the transparent cover was the 1-piece penguin and that the two pieces of the disassembled 2-piece penguin were hidden under the opaque cover. This complex, interlocking set of mental states is difficult to reconcile with the claim that infants have difficulty understanding causal interactions among beliefs and other mental states.

Third, the present results suggest that infants *do* "use all cognitively available facts to ascribe" beliefs to others. The infants in Experiments 1 and 2 kept track of what events the agent did and did not witness in the familiarization trials, and they considered that information when computing her belief about which of the two test objects was likely to rattle when shaken. Thus, in Experiment 1, the infants in the false-belief condition expected the agent to reach for the identical test object, whereas those in the knowledge condition expected her to reach for the different test object; in Experiment 2, this pattern reversed. This systematic and context-sensitive variation in the infants' responses suggests that, by 18 months of age, infants take into account all of the relevant information available to them when ascribing beliefs to agents (see He, Bolz, & Baillargeon, in press, for a similar argument about 2.5-year-olds' responses in VOE tasks focusing on false beliefs about location and contents). This is not to say, of course, that infants find it no more demanding (in terms of processing resources) to attribute reality-incongruent as opposed to reality-congruent informational states to agents. To the contrary, the finding that the infants in the combined false-belief conditions of Experiments 1 and 2 looked reliably longer overall than did the infants in the combined knowledge conditions suggests that the infants found it more challenging to reason about the agent's behavior when she held a false belief about which test object would rattle—even when she acted in accordance with this belief.

Together, the various findings discussed above suggest that, far from being inflexible and sharply limited, early false-belief understanding is flexible, causally coherent, and context-sensitive. This conclusion naturally gives rise to the question of why—given their remarkable competence at false-belief reasoning—young children consistently fail at standard false-belief tasks until about age 4; we take up this issue in the General Discussion.

Experiment 3

We have argued that the results of the false-belief conditions in Experiments 1 and 2 suggest that infants can attribute to others false beliefs about the non-obvious properties of objects; that these results cannot be explained in terms of a single object-matching rule (although the infants in the false-belief condition of Experiment 1 expected the agent to select the test object that matched the experimenter's object, those in the false-belief condition of Experiment 2 expected the agent to select the other, non-matching test object); and that positing an additional rule to explain the results of the false-belief condition in Experiment 2 creates critical difficulties for a behavioral-rule interpretation because this new rule must implicitly acknowledge that an agent can hold and act on false beliefs.

Could the present results be explained in some other way, without reference to behavioral rules? In particular, how would the results fare when examined in light of the *ignorance* interpretation discussed in the Introduction (Southgate et al., 2007; Wellman, in press)? It might be argued that such an interpretation could be offered for our results. Specifically, one might suggest that the infants in the false-belief conditions of Experiments 1 and 2 realized that the agent was ignorant about which test object rattled and looked reliably longer (1) when she failed to reach for the *incorrect* test object (on the *error* version, which states that ignorant agents typically err in their actions; Southgate et al., 2007) or (2) when she reached confidently for the *correct* test object (on the *uncertainty* version, which states that, although ignorant agents may occasionally stumble onto correct actions, they are unlikely to produce these actions with confidence or certainty; Wellman, in press). In the Introduction, we reviewed recent findings (Scott & Baillargeon, 2009) that call into question both the error and uncertainty versions of the ignorance interpretation. In Experiment 3, we sought to test the ignorance interpretation of the results of the false-belief conditions in Experiments 1 and 2 and to provide converging evidence for the findings of Scott and Baillargeon.

Experiment 3 tested infants in a false-belief-control condition similar to the false-belief condition of Experiment 1 with one exception: all three objects on the apparatus floor were identical in appearance (all were red with silver stars). In the familiarization trial, in the agent's absence, the experimenter shook all three objects in turn, demonstrating that her object and the right test object (the one that occupied the same location as the different test object in the previous experiments) made noise when shaken, whereas the left test object did not. In the test trial, the agent joined the experimenter; as before, the experimenter shook her object to demonstrate that it rattled and then she asked the agent "Can you do it?" The agent then selected either the noisy (noisy-object trial) or the silent (silent-object trial) test object.

If the infants in the false-belief conditions of Experiments 1 and 2 simply expected the agent's ignorance to lead to error or uncertainty, then the infants in the false-belief-control condition of Experiment 3 should hold the same expectation. They should realize that the agent was ignorant about which test object would rattle when shaken, and they should look reliably longer when she either failed to reach for the incorrect, silent test object (error version) or reached confidently for the correct, noisy test object (uncertainty version). In either case, the infants who received the noisy-object trial should look reliably longer than those who received the silent-object trial.

In contrast, if the infants in the false-belief conditions of Experiments 1 and 2 expected the agent to select the test object that she falsely believed would rattle when shaken, then the infants in the false-belief-control condition of Experiment 3 should again expect the agent to reason about the test objects' likely non-obvious properties. Because the two test objects were perceptually identical to the experimenter's object, the agent should falsely believe that *both* objects were equally likely to rattle when shaken. The infants should thus expect the agent to select a test object at random, since she had no basis for choosing one over the other, and they should therefore look about equally whether they received the noisy- or the silent-object trial.

Method

Participants—Participants were 16 healthy term infants, 8 male and 8 female, ranging in age from 18 months, 9 days to 19 months, 8 days (M = 18 months, 22 days). Another infant was tested but excluded because he was distracted. Half the infants were randomly assigned to receive the noisy-object test trial, and half the silent-object trial.

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Apparatus, Trials, and Procedure—The apparatus, trials, and procedure in the false-belief-control condition of Experiment 3 were identical to those in the false-belief condition of Experiment 1 with one exception: the different test object was replaced with another red object decorated with silver stars. As in Experiment 1, only the experimenter's object and the right test object (which corresponded to the different test object in the previous experiments) made noise when shaken. The infants were highly attentive during the familiarization trial (noisy-object: $M = 59.1$; silent-object $M = 59.1$) and during the 12-s initial phase of the test trial (noisy-object: $M = 12.0$, silent-object $M = 11.9$). Interobserver reliability was calculated for 14 of the 16 infants and averaged 99% per trial per infant.

Results

The looking times of the infants in the false-belief-control condition of Experiment 3 at the noisy- and silent-object test trials (see Fig. 2) were compared to those of the infants in the combined false-belief conditions of Experiments 1 and 2 at the unexpected and expected test trials (see analyses above comparing the data of Experiments 1 and 2). For the purposes of this analysis, the noisy-object trial was classified as unexpected and the silent-test trial as expected; recall that, according to the two versions of the ignorance interpretation, the infants should look reliably longer when the agent reached for the noisy as opposed to the silent test object.

The infants' looking times during the final phase of the test trial were analyzed using a 2 × 2 ANOVA with condition (false-belief or false-belief-control) and trial (unexpected or expected) as between-subjects factors. The analysis yielded a significant interaction between condition and trial, $F(1, 46) = 5.85$, $p < .025$, $\eta_p^2 = .11$. There was no significant main effect of condition, $F < 1$, or trial, $F(1, 46) = 2.03$, $p = .16$, $\eta_p^2 = .04$. Planned comparisons revealed that in the combined false-belief conditions of Experiments 1 and 2, the infants looked reliably longer if they received an unexpected ($M = 23.2$, $SD = 8.3$) as opposed to an expected ($M = 14.7$, $SD = 5.0$) trial, $F(1, 46) = 11.52$, $p < .0025$, $d = 1.28$, whereas in the false-belief-control condition of Experiment 3, the infants looked about equally during the unexpected ($M = 17.9$, $SD = 7.5$) and expected ($M = 20.1$, $SD = 8.9$) trials, $F(1, 46) = 0.36$. A Wilcoxon rank-sum tests confirmed the results of Experiment 3 ($Ws = 73$, $p > .2$).

Further Results—The infants in the false-belief-control condition tended to look equally during the noisy- and silent-object test trials, casting doubt on the notion that infants generally expect ignorance to lead to error or uncertainty. However, proponents of the ignorance interpretation might object that the infants could have looked equally during the two test trials (instead of looking longer during the noisy-object trial, as predicted by the ignorance interpretation) simply because they forgot which of the two identical test objects rattled when shaken. To examine this possibility, a final group of 18-month-olds was tested in a knowledge condition similar to the false-belief-control condition except that the agent was present during the familiarization trial.

If the infants in the false-belief-control condition looked equally during the two test trials because they had difficulty remembering which test object rattled when shaken, then the infants in the knowledge condition should experience the same difficulty and show the same looking pattern. On the other hand, if the infants in the false-belief-control condition looked equally because they expected the agent to falsely believe that both test objects would rattle and hence to select either test object at random, then the infants in the knowledge condition should produce a different looking pattern. Since the agent knew that only one test object rattled, the infants should expect her to reach for that object, and they should look reliably when she reached for the silent object instead. The infants who received the silent-object trial should thus look reliably longer than those who received the noisy-object trial.

Participants were 16 infants, 8 male and 8 female (18 months, 10 days to 19 months, 7 days; *M* = 18 months, 23 days). Another infant was tested but excluded because his test looking time was over 3 standard deviations from the mean of his condition. Half the infants received the noisy-object test trial, and half received the silent-object test trial. The infants who received the silent-object trial ($M = 18.4$, $SD = 6.1$) looked reliably longer than those who received the noisy-object trial ($M = 12.1$, $SD = 3.1$), $F(1, 14) = 6.78$, $p < .025$, $d = 1.39$, $Ws = 48.5$, $p < .05$. The infants thus remembered which of the two test objects rattled, and expected the agent—who was present during the familiarization trial—to reach for that object.[4]

Discussion

The infants in the knowledge condition looked reliably longer if they received the silent- as opposed to the noisy-object test trial, whereas those in the false-belief-control condition looked about equally during either trial. Together, these results suggest that the infants in the false-belief-control condition (1) remembered which test object rattled when shaken; (2) expected the agent to falsely believe both test objects would rattle (since perceptually identical objects typically share the same non-obvious properties); and hence (3) expected the agent to choose either test object at random, since she had no basis for selecting one over the other.

Proponents of the ignorance interpretation might offer a different account of the results of Experiment 3: perhaps the infants in the knowledge condition remembered which test object rattled in the test trial but the infants in the false-belief-control condition did not (or at least gave no evidence that they did) because they were distracted by the arrival of the agent. In the knowledge condition, the agent was present during both the familiarization and the test trial; in the false-belief-control condition, in contrast, the agent was present during the test trial only, opening the possibility that her arrival interfered with the infants' reasoning. This alternative interpretation seems to us unlikely for two reasons. First, recall that in the false-belief condition of Experiment 1 the agent was also absent during the familiarization trial and present during the test trial; had the infants in this condition been distracted by the agent's arrival, they would have looked equally whether they received the identical- or the different-object test trial, but they did not. Second, many experiments on infants' ability to attribute motivational, reality-congruent informational, and reality-incongruent informational states have obtained positive results with situations where agents are absent during portions of the experimental session, suggesting that infants can usually keep track of agents' comings and goings without undue difficulty (e.g., Buresh & Woodward, 2007; Egyed et al., 2007; He & Baillargeon, 2010; Liszkowski et al., 2006; Luo & Beck, 2010; Onishi & Baillargeon, 2005; Scott & Baillargeon, 2009; Song & Baillargeon, 2008; Surian et al., 2007; Tomasello & Haberl, 2003). In short, it seems to us likely that the infants in the false-belief-control condition *did* remember which test objects rattled, but expected the agent to falsely believe that both test objects would rattle and hence had no expectation about which object she would select.

Links to Prior Findings—According to the ignorance interpretation, the infants in the false-belief conditions of Experiments 1 and 2 looked reliably longer when the ignorant

[4]A final manipulation check was conducted to ensure that the experimenter did not inadvertently provide auditory cues (e.g., when shaking the objects or when asking "Can you do it?") that could have led the infants to respond differentially during the unexpected and expected test trials in the false-belief and knowledge conditions of Experiments 1 and 2 and in the knowledge condition of Experiment 3. A naive coder listened to the recorded sessions of 20 infants (10 with an unexpected test trial and 10 with an expected test trial), randomly selected across the five conditions of these experiments (all of which yielded positive results). For each infant, the coder listened to the entire session and then guessed whether the infant had received an unexpected or an expected test trial. The coder guessed correctly for only 40% of the 20 infants, suggesting that inadvertent auditory cues played little role in the infants' responses.

agent failed to select the silent test object (error version) or selected the noisy test object with unwarranted confidence (uncertainty version). The ignorance interpretation predicted that the infants in the false-belief-control condition of Experiment 3 would produce the same looking pattern: because the agent did not know which of the two identical test objects rattled when shaken, the infants were expected to again look reliably longer when she failed to choose the silent test object or chose the noisy test object confidently. Contrary to this prediction, however, the infants looked about equally when the agent reached for either test object.

The result of the false-belief-control condition in Experiment 3 thus provides evidence against the ignorance interpretation and, as such, extends the result (discussed in the Introduction) of the ignorance experiment in Scott and Baillargeon (2009). Together, these results suggest that 18-month-olds do not generally expect ignorance to lead to error or uncertainty: when an agent does not know which of two covers hides her goal object, or which of two test objects can be used to reproduce an interesting effect, infants expect the agent to select a cover or object at random (see He et al., in press, for similar findings with 2.5-year-olds). These results may appear inconsistent with previous findings in the infancy literature. Here, we discuss two such findings with infants aged 16 to 18 months (Koenig & Echols, 2003; Poulin-Dubois, Sodian, Metz, Tilden, & Schoeppner, 2007).

Koenig and Echols (2003) presented 16-month-olds with color slides of five objects whose labels are usually familiar to infants at this age (chair, duck, cat, ball, and shoe). Each infant received 12 trials; in each trial, one of the objects was presented, and an agent seated next to the infant labeled the object either correctly (true-label condition) or incorrectly (false-label condition). When the agent *faced* the objects, the infants in the false-label condition looked reliably longer at the agent than those in the true-label condition, suggesting that they realized the agent could see the objects, they expected her to know the objects' labels, and they were therefore surprised when she labeled them incorrectly. In contrast, when the agent faced *away* from the objects, the reverse pattern was found: the infants in the true-label condition looked reliably longer at the agent than those in the false-label condition. One interpretation of this last result, consistent with the error version of the ignorance interpretation, is that the infants expected the ignorant agent to err and were therefore surprised when she labeled the objects correctly. However, another possible interpretation is that the infants were surprised that the ignorant agent consistently provided a correct label on all 12 trials. The infants in the ignorance experiment of Scott and Baillargeon (2009) and in the false-belief-control condition of Experiment 3 saw the agent reach for the correct object only once, and they did not seem surprised when she did so. It might well be that infants keep track of agents' choices across trials and notice when their responses begin to depart from the random pattern that would be expected by chance. Adults, of course, respond in the same way. We might not be particularly surprised if an agent who was facing away from a color slide correctly guessed “a ball”, but we would immediately smell a rat if she correctly guessed “the Parthenon under moonlight”, followed by “three anchovies on a plate” and “Marilyn Monroe in a dentist's chair”; we would realize that the likelihood of an ignorant agent correctly guessing all three (or even just one) of these stimuli is infinitesimally small. Recent research suggests that infants, too, have some ability to keep track of the probability of outcomes (e.g., Téglás, Girotto, Gonzales, & Bonatti, 2007; Xu & Garcia, 2008); it thus seems plausible that infants would become perplexed if an ignorant agent correctly guessed objects' labels 12 times in a row.

Poulin-Dubois et al. (2007) tested 18-month-olds in a preferential-looking task to determine whether they had expectations about where a knowledgeable or an ignorant agent would search for a toy. All of the infants received a knowledge test trial followed by an ignorance test trial; each trial had an initial and a final phase. During the initial phase of the knowledge trial, the infants watched a videotaped event in which an agent sat between two buckets; an experimenter stood behind the agent and said (looking straight ahead, as though speaking to the infant) “Hi Baby, we’re going to play a game.” Next, the experimenter covered the agent’s mouth with a blindfold and then lifted each bucket to reveal that a cup was hidden under one of the buckets (e.g., the left bucket). Finally, the experimenter left the scene, the agent removed her blindfold, and the experimenter asked, off-screen, “Where is my cup?” In the final phase of the trial, the infants saw two still pictures side by side: in one, the agent pointed to the bucket that hid the cup (e.g., the left bucket), and in the other picture she pointed to the other, empty bucket (e.g., the right bucket). The ignorance trial was identical except that the experimenter covered the agent’s eyes with the blindfold and revealed a toy car under the opposite bucket (e.g., the right bucket). In the final phase of the knowledge trial, the infants looked reliably longer at the picture where the agent pointed at the empty bucket (e.g., the right bucket); in the ignorance trial, the infants looked reliably longer at the picture where the agent pointed to the bucket covering the car (e.g., the right bucket). One interpretation of this last result, consistent with the error version of the ignorance interpretation, is that the infants expected the ignorant agent to point to the empty bucket and thus looked longer at the picture where she pointed to the bucket that hid the car. However, other interpretations are possible. For example, it could be that the infants were confused by the task and tended to perseverate across trials; as a result, they looked longer at the same picture in the first and second trials (e.g., in our example, the one where the agent pointed to the right bucket). Another, more intriguing interpretation is that the infants expected the ignorant agent to falsely assume that the toy was hidden under the same bucket across trials (just as the infants tested by Surian et al. (2007) expected the caterpillar to assume that the apple and cheese had been hidden behind the same screens; see also Topál, Gergely, Miklósi, Erdőhegyi, & Csibra, 2008). Thus, the infants expected the agent to falsely believe the toy was again hidden under the left bucket, and so they looked longer when she pointed to the right bucket instead.[5]

The previous speculations make clear that many interesting questions remain concerning infants’ expectations about the actions of ignorant agents under various conditions. Although the results of Scott and Baillargeon (2009) and of the false-belief-control condition in Experiment 3 suggest that infants do not expect an ignorant agent to necessarily err when selecting between two choices on one or two trials (i.e. they realize the agent could stumble onto the correct choice by chance), infants might well expect errors to occur as the number of choices or trials increases.

General Discussion

The present experiments examined whether 18-month-old infants could attribute to an agent the false belief that an object possessed a non-obvious property when it did not. In the false-belief condition of Experiment 1, the infants first received a familiarization trial in which an experimenter demonstrated that her object made a rattling noise when shaken. She then shook two test objects at the rear of the apparatus: one object differed from the experimenter’s test object in color and pattern (different test object) and also rattled when shaken; the other object was perceptually identical to the experimenter’s object (identical test object) but did not rattle when shaken. In the test trial, an agent sat at a window in the rear wall of the apparatus, behind the two test objects. The experimenter demonstrated that

[5]Part of the reason for supposing that infants carried over expectations from the knowledge to the ignorance test trial comes from a second experiment in which the order of the two test trials was counterbalanced. Significant results were again obtained in the knowledge and ignorance trials, but only when the infants received the knowledge trial first. Poulin-Dubois et al. (2007) speculated that the use of the blindfold was confusing for the infants, so that they performed better if they received the knowledge trial first. However, Brooks and Meltzoff (2002) have found that even 14-month-olds realize that a blindfolded person cannot see, casting some doubt on this interpretation.

her object produced a rattling noise when shaken, and then prompted the agent to select one of the test objects by asking her, “Can you do it?” In response to this prompt, the agent selected one of the test objects and then paused. The infants looked reliably longer when the agent selected the different test object, suggesting that they expected the agent (1) to falsely believe that the identical test object also rattled (since objects that are perceptually identical typically have the same non-obvious properties); (2) to be less certain whether the different test object rattled (since objects that differ in color and pattern may be less likely than identical objects to have the same non-obvious properties); and hence (3) to select the identical test object. In the knowledge condition of Experiment 1, the agent was present during the familiarization trial and thus watched as the experimenter demonstrated the internal properties of the two test objects. The infants now expected the agent to select the different test object and they looked reliably longer when she selected the (silent) identical test object instead.

In the false-belief condition of Experiment 2, the agent was present in the first familiarization trial when the experimenter demonstrated which objects rattled and which did not. However, the agent was absent in the second familiarization trial when the experimenter opened the two test objects, poured the marbles from the different test object into the identical test object, and demonstrated that the identical test object now made noise but the different test object did not. In the test trial, the agent returned and again the experimenter prompted her to select one of the test objects. The infants now looked reliably longer when the agent selected the identical test object, suggesting that they expected her (1) to falsely believe that the different test object rattled whereas the identical test object did not, and hence (2) to select the different test object. In the knowledge condition of Experiment 2, the agent was present during the second familiarization trial and thus saw the experimenter switch the marbles. The infants expected the agent to choose the identical test object and they looked reliably longer when she grasped the (silent) different test object instead.

Finally, the false-belief-control condition of Experiment 3 was similar to the false-belief condition of Experiment 1 except that both test objects were perceptually identical to the experimenter’s object. The infants looked about equally when the agent reached for either test object, suggesting that they expected the agent (1) to falsely believe that both test objects would rattle when shaken (since perceptually identical objects typically have the same non-obvious properties), and hence (2) to select either test object at random (results from a knowledge condition suggested that infants did remember which test object rattled).

The results of these experiments contribute to our understanding of early psychological reasoning in two ways. First, they confirm recent VOE and AL findings that infants in the second year of life can attribute false beliefs to agents (Onishi & Baillargeon, 2005; Scott & Baillargeon, 2009; Song & Baillargeon, 2008; Song et al., 2008; Southgate et al., 2007; Surian et al., 2007; Träuble et al., 2010), and they extend these findings to a new type of false belief, false beliefs about non-obvious properties. Second, they demonstrate that 18-month-olds can give evidence of false-belief understanding even when tested with a non-search paradigm. In the false-belief tasks cited above, infants faced an agent who was searching for an object and falsely believed (through inference or prior evidence) that it was hidden in one specific location. In the present research, infants watched an agent who wanted to reproduce an interesting effect and falsely believed (again, through inference or prior evidence) that a specific object possessed the requisite non-obvious property. Together, these various results provide strong support for the conclusion that infants in the second year of life already possess a genuine understanding of false belief: this understanding can be demonstrated with non-search as well as with search paradigms, and using VOE and AL tasks tapping a wide range of belief-inducing situations including false perceptions (Song &

Baillargeon, 2008), false beliefs about location (Onishi & Baillargeon, 2005; Song et al., 2008; Southgate et al., 2007; Surian et al., 2007; Träuble et al., 2010), false beliefs about identity (Scott & Baillargeon, 2009), and now false beliefs about non-obvious properties.

Alternative Interpretations of VOE and AL False-Belief Tasks

The present research also contributes to ongoing efforts to test the alternative interpretations that have been offered for early demonstrations of false-belief understanding. To date, three such alternative explanations have been proposed: the *association* interpretation (Perner & Ruffman, 2005; Ruffman & Perner, 2005), the *ignorance* interpretation (Southgate et al., 2007; Wellman, in press), and the *search-rule* interpretation (Perner & Ruffman, 2005; Ruffman & Perner, 2005).

With respect to the association interpretation, as was discussed in the Introduction, many psychological-reasoning experiments have produced results inconsistent with the notion that infants simply encode associations between agents and objects and then look longer at events that deviate from these associations (e.g., Bíró & Leslie, 2007; Csibra, 2008; Gergely et al., 1995; Hamlin et al., 2007; Johnson, Shimizu, & Ok, 2007; Kuhlmeier et al. 2003; Luo & Baillargeon, 2005, 2007; Luo & Johnson, 2009; Woodward, 1998). Although infants in one condition may look longer at the test event with "low level similarity" to the preceding familiarization event, infants in other, very similar conditions do not do so. For example, after watching familiarization trials in which an agent repeatedly grasps object-A, infants look longer if the agent grasps object-B in test, but *only* if object-B is present and visible to the agent during the familiarization trials, so that infants have evidence that the agent prefers object-A over object-B (e.g., Luo, in press; Luo & Baillargeon, 2005, 2007; Luo & Johnson, 2009). Similarly, if the agent inspects but does not grasp object-A during the familiarization trials, young infants look longer if the agent inspects object-B in test, but *only* if there is a rational explanation for why the agent does not reach for the objects during the familiarization trials (e.g., she looks at them through a small window, or her hands are already occupied; Luo, 2010). These subtle patterns of successes and failures make clear that infants do not merely form low-level associations between agents and objects, but consider the mental states that underlie agents' actions.

With respect to the ignorance interpretation, we reviewed recent findings in the Introduction that cast doubt on this interpretation (Scott & Baillargeon, 2009), and the results of the false-belief-control condition in Experiment 3 provided further evidence that 18-month-old infants do not expect an agent who is ignorant about some aspect of a scene to always err or act tentatively.

Finally, Experiments 1 and 2 addressed the search-rule interpretation: they used a non-search paradigm and still yielded evidence of false-belief understanding, suggesting that search rules are not sufficient to explain infants' apparent success in false-belief tasks.

A broader, behavioral-rule interpretation might suggest that the infants in the false-belief conditions of Experiments 1 and 2 brought to the laboratory additional rules about how ignorant agents typically select objects to produce effects. There are two difficulties with this approach. First, as the number of behavioral rules needed to account for positive results in infant false-belief tasks steadily grows, the claim that most infants come to the laboratory equipped with the same extensive list of acquired rules becomes less plausible (for discussion of a similar point in relation to infant understanding of pretense, see Friedman & Leslie, 2007). Second, and more importantly, to account for the results of the false-belief conditions in Experiments 1 and 2, a behavioral-rule interpretation would need to specify that (1) infants generally expect an agent who is ignorant about some critical aspect of a situation to follow the behavioral rule applicable in the situation, but at the same time (2) infants expect an agent who has evidence that a behavioral rule does not apply in a situation to act in accordance with this evidence rather than with the rule—even when the agent does not know that the evidence is no longer valid. Implicit in this account is an acknowledgment that infants keep track of the evidence available to agents, and expect agents to act in accordance with this evidence, even when outdated or false. If the behavioral-rule interpretation must concede that, in at least some situations, infants realize that agents can hold and act on false evidence, then this interpretation does not provide a viable alternative account of early false-belief findings.

Why do toddlers fail when infants succeed?

The present experiments, together with other recent VOE and AL investigations, suggest that infants (Onishi & Baillargeon, 2005; Scott & Baillargeon, 2009; Song & Baillargeon, 2008; Song et al., 2008; Southgate et al., 2007; Surian et al., 2007; Träuble et al., 2010) and toddlers (He et al., in press) can attribute false beliefs to others. If this conclusion is correct, then why do children across countries typically fail at standard false-belief tasks until about age 4 (e.g., Callaghan et al., 2005; Liu, Wellman, Tardif, & Sabbagh, 2008; Sabbagh, Xu, Carlson, Moses, & Lee, 2006; Wellman, Cross, & Watson, 2001)? While this issue is far from resolved, we suggest that this discrepancy results from differences in the *processing load* imposed by these two sets of tasks (for an alternative hypothesis, see Leslie's (2005) analysis contrasting *automatic* responses produced by an early, modular mechanism and deliberate, *voluntary* responses produced by a later process). As explained below, the greater processing load imposed by standard tasks may come about for two complementary reasons: these tasks are *elicited-response* and *interactive* tasks.

Elicited- vs. Spontaneous-response tasks—Standard false-belief tasks differ from VOE and AL false-belief tasks in the type of response they require. Standard tasks are *elicited-response* tasks: children must answer direct questions (through points or verbal responses) about the likely actions of an agent who has a false belief. VOE and AL tasks, in contrast, are *spontaneous-response* tasks: children reveal their understanding of an agent's false belief through their spontaneous responses as they watch a scene unfold (just as adults watching characters interact in a movie may spontaneously produce behaviors that reveal their understanding of the characters' thoughts and feelings).

Elicited-response tasks may be more difficult for young children than spontaneous-response tasks because they require additional processes. To illustrate, consider the standard Sally-Anne task (Baron-Cohen et al., 1985), in which children listen to the following story enacted with props: Sally faces a basket and a box; she hides a marble in the basket and then leaves; in her absence, Anne moves the marble to the box. Children are then asked where Sally will look for her marble when she returns. Beginning at about age 4, children typically answer correctly and point to the basket; prior to age 4, children typically point to the box, the marble's current location. Success in the Sally-Anne task depends on at least three separate processes (Scott & Baillargeon, 2009). First, as the story unfolds, the *false-belief-representation process* allows children to represent Sally's false belief about the marble's location. Second, when asked the test question ("Where will Sally look for her marble?"), children must process the question, choose to answer it, and then tap their representation of Sally's belief in order to select a response; all of this is part of the *response-selection process*. Finally, children must inhibit any prepotent tendency to answer the test question based on their knowledge of the marble's current location; this involves the *response-inhibition process* (e.g., Birch & Bloom, 2003; Carlson & Moses, 2001; Kovács, 2009; Leslie, German, & Polizzi, 2005; Leslie & Polizzi, 1998). In marked contrast, success in spontaneous-response tasks such as VOE and AL tasks depends on only one process, the false-belief-representation process; the response-selection and response-inhibition processes are not activated because children produce their responses spontaneously rather than in answer to direct questions.

According to the present analysis, young children's difficulties with elicited-response tasks thus lie not in the false-belief-representation process, but rather in the response-selection and response-inhibition processes. Both of these difficulties are substantial: in false-belief tasks where little or no inhibition is required (e.g., Anne takes the marble away, so that children do not know its current location), young children typically perform at chance (e.g., Bartsch, 1996; Wellman et al., 2001; Wimmer & Perner, 1983; see also Kovács, 2009).

Why does the activation of the response-selection process create such difficulties for young children? One possibility is that the simultaneous activation of the false-belief-representation and response-selection processes simply overwhelms young children's limited attentional and working-memory resources. Another possibility comes from neuroscience findings which suggest that (1) the right temporo-parietal junction plays an important role in adults' and children's false-belief representation process (e.g., Kobayashi, Glover, & Temple, 2007; Perner, Aichhorn, Kronbichler, Staffen, & Ladurner, 2006; Sabbagh, Bowman, Evraire, & Ito, 2009; Saxe & Wexler, 2005; Sommer et al., 2007); (2) regions of the anterior cingulate cortex and the prefrontal cortex play an important role in the response-selection process (e.g., Herwig, Prinz, & Waszak, 2007; Mueller, Brass, Waszak, & Prinz, 2007; Waszak et al., 2005; see also Obhi & Haggard, 2004); and (3) the connections between frontal and temporal brain regions tend to mature later and more slowly than other connections (e.g., Johnson, 2001; Lebel, Walker, Leemans, Philips, & Beaulieu, 2008). Together, these findings give rise to the possibility that the neural connections between the brain regions that serve the false-belief-representation and the response-selection processes are immature and inefficient in early childhood. Thus, although the false-belief-representation process may represent Sally's false belief, the response-selection process has difficulty tapping this representation due to the weak connections between the brain regions that serve these different processes.

The preceding analysis makes three predictions. First, infants and toddlers should succeed not only at VOE and AL but also at other spontaneous-response false-belief tasks. In support of this prediction, toddlers have now been found to succeed at two novel spontaneous-response false-belief tasks, one involving preferential looking and the other language comprehension (e.g., Scott, Baillargeon, & Cummins, 2010; Scott, Brown-Schmidt, Fisher, & Baillargeon, 2009). Second, toddlers might succeed at elicited-response low-inhibition false-belief tasks (i.e. tasks that activate only the false-belief-representation and response-selection processes) if first given practice trials designed to reduce response-selection demands. Experiments testing this prediction are under way, with promising results (Setoh, Scott, & Baillargeon, 2010). Finally, infants and toddlers should succeed at indirect-elicited-response tasks that require them to respond to questions or prompts that only indirectly tap their representation of an agent's false belief. Two such tasks have now been reported, with positive results (Buttelmann, Carpenter, & Tomasello, 2009; Southgate, Chevallier, & Csibra, in press).

Interactive vs. Non-interactive tasks—Standard false-belief tasks may also be difficult for young children because they take place in an interactive, conversational setting. When two speakers are participating in a conversation about a scene, they must hold in mind their own perspective on the scene as well as that of the other speaker. Actively holding in mind both perspectives is necessary for producing appropriate utterances as well as for correctly interpreting the other speaker's utterances. For instance, suppose a friend asks you "Where did you put that book that I like?" In order to interpret her sentence and produce a response, you must first determine which book she is referring to by considering her mental states (i.e.

which book does she like?) and then access your own knowledge to determine where that book is located. Because standard tasks involve verbal exchange with the experimenter, they require children to actively hold mind multiple perspectives, including their own and that of the main character in the task (e.g., Sally). This may be difficult for young children because (1) they lack sufficient attentional and working memory resources to actively hold in mind these different perspectives or (2) their inhibitory skills are too immature to enable them to inhibit their own perspective when answering questions based on the main character's perspective. VOE and AL false-belief tasks, in contrast, typically involve little or no verbal interaction. As a result, as children watch an agent act in a scene, they do not have to actively hold in mind their own perspective on the scene; they can focus solely on the agent's flawed perspective, making it easier to predict and interpret the agent's actions. As an analogy, consider how we as adults typically respond when watching characters interact in a movie; although we do not entirely lose track of our own perspective (e.g., we still know we are sitting in a cinema), we tend to become absorbed in the characters' perspectives so that our own recedes and becomes less salient.

The preceding hypothesis makes two predictions. First, inhibition should predict performance in any false-belief task that involves verbal interaction with an experimenter, regardless of the type of response required. Thus, spontaneous-response tasks in which children are required to interact with an experimenter should impose a greater processing load than tasks in which children are passive observers, and success in these interactive tasks should be predicted by children's inhibitory skills. As of yet, there is no evidence to support this prediction because all of the spontaneous-response tasks reported so far have been non-interactive.

Second, inhibition should play a role whenever children engage in a verbal interaction with a speaker whose perspective differs from their own, regardless of whether the speaker is mistaken or simply ignorant about some aspect of the scene. Evidence for this second prediction comes from recent research with 4.5-year-olds by Nilsen and Graham (2009). Each child sat on one side of a display case while a speaker sat on the other. The display case contained several cubby holes, each of which had a sliding door that could be closed to hide the contents of the hole from the speaker's view (the objects were always visible to the child). On each trial, the speaker was blindfolded while an experimenter placed objects in four of the holes, one of which had its door closed. The speaker then removed her blindfold and asked the child to pick up one of the objects. In one condition, two identical objects, such as toy ducks, were placed in the display; one of the ducks was visible to the speaker but the other was not (the door to its cubby hole was closed). The speaker then asked the child, "Pick up the duck." Most children (1) recognized that the speaker could only see one of the two ducks; (2) interpreted her request as referring to the duck she could see; and thus (3) handed that duck to the speaker. Success in this task was positively correlated with performance in an inhibitory-control task. In comparison to children with high inhibitory control, children with low inhibitory control spent more time gazing at the incorrect duck (the duck only they could see) and were more likely to select the incorrect duck. These results suggest two conclusions: first, children who are engaged in an interactive task hold in mind their own perspective as well as that of their interlocutor; and second, children's skill at inhibiting their own perspective affects their ability to correctly interpret their interlocutor's utterances.

Summary Remarks

The present research adds to recent findings that infants in the second year of life can attribute false beliefs to agents; it extends these findings to false beliefs about non-obvious properties; and, through its use of a novel non-search paradigm, it helps rule out alternative interpretations that have been offered for these findings. Finally, the present research confirms the marked discrepancy between spontaneous- and elicited-response false-belief tasks. In the last sections, we have offered two complementary explanations for this discrepancy, and we hope to continue evaluating these explanations in future experiments.

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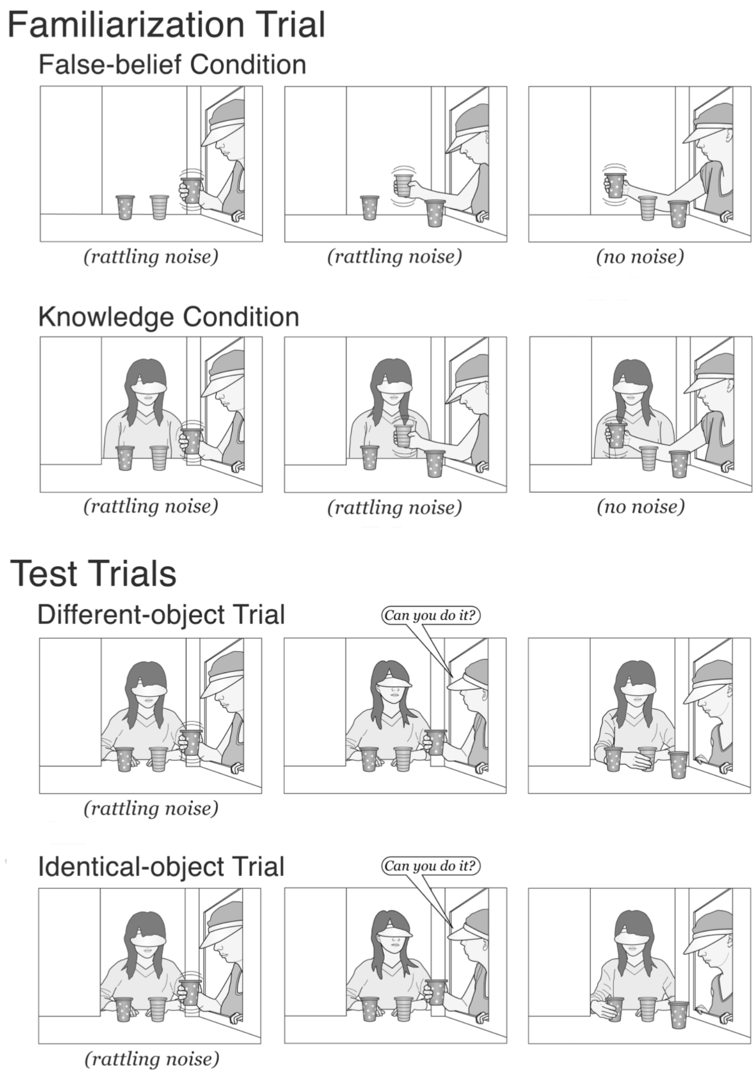

Figure 1.
Schematic drawing of the events shown during the familiarization and test trials in the false-belief and knowledge conditions of Experiment 1.

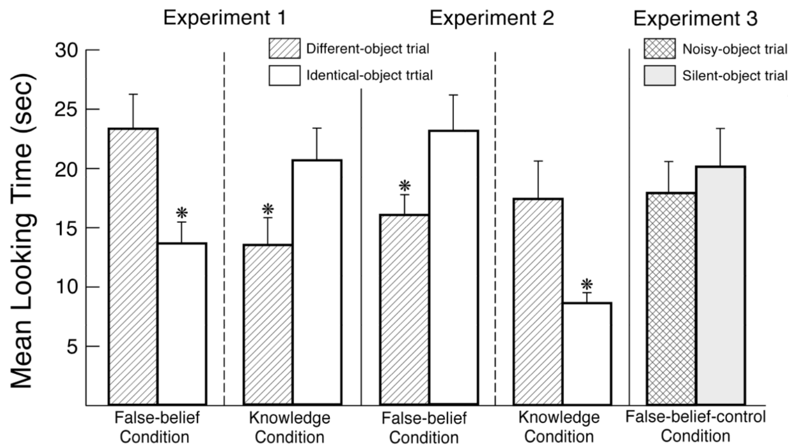

Figure 2.
Mean looking times in the false-belief and knowledge conditions of Experiments 1 and 2 and in the false-belief-control condition of Experiment 3. Error bars represent standard errors, and asterisks indicate significant differences (*p* < .05 or better).