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Surprise! 20-month-old infants understand the emotional consequences of false beliefs

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Abstract

Recent studies suggest that by the second year of life, infants can attribute false beliefs to agents. However, prior studies have largely focused on infants' ability to predict a mistaken agent's physical actions on objects. The present research investigated whether 20-month-old infants could also reason about belief-based emotional displays. In Experiments 1 and 2, infants viewed an agent who shook two objects: one rattled and the other was silent. Infants expected the agent to express surprise at the silent object if she had a false belief that both objects rattled, but not if she was merely ignorant about the objects' properties. Experiment 3 replicated and extended these findings: if an agent falsely believed that two containers held toy bears (when only one did so), infants expected the agent to express surprise at the empty, but not the full, container. Together, these results provide the first evidence that infants in the second year of life understand the causal relationship between beliefs and emotional displays. These findings thus provide new evidence for false-belief understanding in infancy and suggest that infants, like older children, possess a robust understanding of belief that applies to a broad range of belief-based responses.

Keywords: false-belief understanding; psychological reasoning; social cognition; infant development; cognitive development

1. Introduction

The ability to predict and interpret others' behavior in terms of their underlying mental states plays a vital role in everyday social interactions. Developmental psychologists have long been interested in when and how this important ability develops. In particular, considerable research has focused on when children first understand that other people can be mistaken, or hold false beliefs, about the world. Early investigations into this question used elicited-response tasks in which children had to answer direct questions about the behavior of an individual who held a false belief (e.g., Baron-Cohen, Leslie, & Frith, 1985; Gopnik & Astington, 1988; Perner, Leekam, & Wimmer, 1987; Wellman & Bartsch, 1988; Wimmer & Perner, 1983). The results of such tasks suggested that the ability to attribute false beliefs to others did not emerge until at least 4 years of age (for reviews, see Devine & Hughes, 2014; Wellman, Cross, & Watson, 2001). Recently, however, researchers have developed a number of alternative paradigms for assessing false-belief understanding in much younger children (e.g., Buttelmann, Carpenter, & Tomasello, 2009; Kovács, Téglás, & Endress, 2010; Luo, 2011; Onishi & Baillargeon, 2005; Scott, Baillargeon, Song, & Leslie, 2010; Southgate, Senju, & Csibra, 2007). Positive results have now been obtained with infants aged 8 to 25 months using a variety of response measures (for reviews, see Baillargeon et al., 2015; Scott, Roby, & Smith, in press), leading many investigators to conclude that the capacity to attribute false belief to others emerges by at least the end of the first year of life (e.g., Baillargeon, Scott, & He, 2010; Barrett et al., 2013; Buttelmann et al., 2009; Carruthers, 2013; Kovács et al., 2010; Luo, 2011; Scott, in press; Southgate et al., 2007; Surian, Caldi, & Sperber, 2007).

However, several researchers have offered alternative accounts for these recent findings (e.g., Apperly & Butterfill, 2009; Butterfill & Apperly, 2013; Heyes, 2014; Perner, 2010; Perner

& Roessler, 2012; Ruffman, 2014). These accounts differ from one another in many respects, including the level of conceptual sophistication that they attribute to infants and the mechanisms that they assume underlie development (e.g., compare Butterfill & Apperly, 2013, to Heyes, 2014). Nevertheless, they share two common assumptions. First, they assume that infants' success in false-belief tasks does not reflect a genuine understanding of belief. Instead, they argue that infants' responses are driven by various alternative factors such as low-level perceptual novelty (e.g., Heyes, 2014), learned behavioral rules for how agents typically behave in particular situations (e.g., Ruffman, 2014), or an early-developing system for tracking belief-like states (e.g., Apperly & Butterfill, 2009). Responses based on these factors sometimes coincide with the responses infants' would produce if they were tracking an agent's false belief, yielding what appears to be successful false-belief reasoning. Second, these accounts assume that infants' performance in false-belief tasks should exhibit sharp limits: they should fail tasks in which responses to these various alternative factors diverge from responses to beliefs.

One way to test these alternative accounts of infants' performance in false-belief tasks is thus to explore the range of situations in which infants succeed. When older children succeed in traditional elicited-response false-belief tasks, they do so in a variety of belief-inducing situations, such as those involving false beliefs about the location (e.g., Baron-Cohen et al., 1985), identity (e.g., Gopnik & Astington, 1988), or contents (e.g., Hogrefe, Wimmer, & Perner, 1986) of an object. They also demonstrate an understanding of a complex array of belief-based responses produced by a mistaken agent. For instance, they are able to predict and to explain (1) an agent's physical actions, such as where the agent searches, reaches, or points (e.g., Baron-Cohen et al., 1985; Low, 2010), (2) an agent's verbal behaviors, such as what the agent will say is in a particular container (e.g., Hogrefe et al., 1986), and (3) the agent's emotional responses

when she discovers that her beliefs about a situation are false (e.g., Hadwin & Perner, 1991; Wellman & Banerjee, 1991). This ability to reason about a rich set of belief-based responses across a range of belief-inducing situations indicates that older children possess a robust understanding of false belief (e.g., Apperly, 2011; Low & Wang, 2011; Perner & Ruffman, 2005). If infants are capable of attributing false beliefs to agents, then they should be able to demonstrate the “flexible use of belief understanding” that is seen in older children (Perner & Ruffman, 2005, p. 216). If infants were instead limited to reasoning about an arbitrary subset of belief-inducing situations and belief-based responses, then this might suggest that infants’ performance was driven by mechanisms other than an understanding of belief (e.g., Apperly & Butterfill, 2009; Heyes, 2014; Low & Watts, 2013; Perner & Roessler, 2012).

Are infants able to understand a range of belief-inducing situations and belief-based responses? A number of studies have now confirmed that infants can reason about different belief-inducing scenarios, including those involving false beliefs about the presence (e.g., Kampis, Parise, Csibra, & Kovács, 2015; Kovács et al., 2010; Southgate & Vernetti, 2014), location (e.g., Onishi & Baillargeon, 2005; Surian et al., 2007), identity (e.g., Buttelmann, Suhrke, & Buttelmann, 2015; Scott & Baillargeon, 2009; Scott, Richman, & Baillargeon, 2015; Song & Baillargeon, 2008), contents (e.g., Buttelmann, Over, Carpenter, & Tomasello, 2014), and properties (e.g., Scott et al., 2010) of objects. With regards to belief-based responses, however, studies have focused almost exclusively on infants’ ability to predict and interpret a mistaken agent’s physical actions on objects (e.g., Buttelmann et al., 2009; Luo, 2011; Scott & Baillargeon, 2009; Song & Baillargeon, 2008; Senju, Southgate, Snape, Leonard, & Csibra, 2011; Surian & Geraci, 2012; Träuble, Marinović, & Pauen, 2010; for an exception, see Southgate, Chevallier, & Csibra, 2010). It thus remains unclear whether infants understand the

broad range of belief-based responses grasped by older children and, consequently, whether they possess a robust understanding of false belief.

In the present research, we sought to address this issue by examining infants' understanding of belief-based emotional responses. Specifically, *surprise* is a belief-based emotion: it occurs when one discovers that one's beliefs about a situation are false (e.g., Roseman, Antoniou, & Jose, 1996; Roseman, 2001). To illustrate, imagine that Sarah sees her mother place an apple in her lunchbox. Her mother later decides to replace the apple with a banana. If Sarah does not witness the swap and falsely believes that her lunchbox contains an apple, then she will be surprised when she opens the lunchbox and discovers a banana. However, if she sees her mother make the exchange, then she will not be surprised when she sees the banana because surprise does not occur when one's beliefs are confirmed. Surprise also does not occur when one is merely ignorant and holds no particular expectation about a situation: if Sarah does not know which fruit her mother placed in the lunchbox, then she should not be surprised to find either a banana or an apple inside¹. Do infants expect an agent to express surprise when (and only when) she discovers that her beliefs are false?

To date, children's understanding of the causal relationship between false belief and surprise has been investigated using elicited-response tasks in which children were asked direct questions about a mistaken agent's inner emotional state (e.g., how the agent would feel) or external emotional display (e.g., which object would cause the agent to make a surprised face) (e.g., Hadwin & Perner, 1991; MacLaren & Olsen, 1993; Ruffman & Keenan, 1996; Wellman & Banerjee, 1991; Wellman & Bartsch, 1988). For instance, MacLaren and Olsen (1993) tested

¹ Note that Sarah would be surprised if she were to find a snake in her lunchbox. Although Sarah holds no particular expectation about which fruit should be present (and hence should find neither surprising), she has a host of expectations about how the world typically works, including the kinds of things that mothers put in lunchboxes. Objects that violate these "background beliefs" about the world would be unexpected and elicit surprise (Ruffman & Keenan, 1996, p. 43).

children in a task adapted from the classic “Smarties” task (e.g., Gopnik & Astington, 1988; Hogrefe et al., 1986). Children were first shown a container that had unexpected contents. On some trials, the contents were desirable (e.g., a toothpaste container that held candy) and on others the contents were undesirable (e.g., a Smarties container that held rocks). This container was then placed alongside a second, visually identical container that held typical/expected contents. Children were asked which of these two containers would surprise a puppet that had not seen inside. 5- to 6-year-old children correctly indicated that the puppet would be surprised by the container with unexpected contents, irrespective of the contents’ desirability. In contrast, 4-year-olds tended to select the container with desirable contents regardless of whether those contents were expected (e.g., a Smarties container with candy) or unexpected (e.g., a toothpaste container with candy). These results suggest that prior to age 5, children might incorrectly view surprise as resulting from something desirable.

Ruffman and Keenan (1996) argued that young children also incorrectly treat surprise as an ignorance-based rather than a belief-based emotion. In their task, children were introduced to two puppets, John and Katy, who wished to take one of two objects (e.g., a spoon or a bandaid) to their grandmother’s house in a box. While John was outside, Katy placed one of the objects in the box (e.g., the spoon) and then left. In her absence, the experimenter replaced the contents of the box with the other object (e.g., the bandaid). Thus, Katy held a false belief about the contents of the box (she believed it was a spoon when it was a bandaid), while John was merely ignorant about which object was in the box (either a spoon or a bandaid). Both puppets returned and looked inside the box. Children were then asked which puppet felt surprised when they saw what was inside. Only the oldest children (7- to 8-year-olds) reliably chose the individual who held a false belief. Younger children (4- to 6-year-olds) chose randomly, suggesting that they viewed

surprise as resulting from discovering something that one does not know (experienced by both puppets) rather than from discovering that one's beliefs are false.

Prior results from elicited-response tasks thus suggest that an understanding that surprise results specifically from discovering that one is mistaken may not emerge until middle childhood. However, as described above, considerable research has now shown that when tested using alternative measures, children demonstrate false-belief understanding at much younger ages than they do when asked a direct question about the behavior of a mistaken agent. It is therefore possible that younger children might also demonstrate an understanding of the relationship between false beliefs and surprise if tested with measures that do not require them to answer direct questions about an agent's emotional responses.

Support for this possibility comes from recent work by Moll and colleagues, who used 3-year-olds' spontaneous facial expressions as a measure of their understanding of the affective consequences of false beliefs (Moll, Kane, & McGowan, 2016). Children viewed puppet shows in which an agent had a true belief, had a false belief, or was ignorant about the contents of a box (e.g., how many cookies it contained). At the end of each puppet show, the agent approached the box, picked it up, and then left with it (the agent did not open the box). Examination of children's facial expressions during this final sequence revealed that children tended to produce facial expressions that signaled tension (e.g., biting their lip, placing a hand over their mouth, furrowing their brow) when the agent held a false belief about the box's contents. They rarely produced such facial expressions when the agent held a true belief or was ignorant. These results indicate that children anticipated that discovering the contents of the box would elicit an emotional response in the mistaken agent – an emotional response that was specific to discovering that one's beliefs are false rather than confirming one's beliefs or alleviating one's

ignorance (i.e. surprise). These findings thus suggest that elicited-response tasks do underestimate children's understanding of the relationship between false belief and emotional responses and raise the possibility that even younger children might demonstrate this understanding if tested appropriately.

Here we examined whether 20-month-old infants would demonstrate an understanding of belief-based emotional responses when tested using a novel violation-of-expectation paradigm. Our experimental approach was based on MacLaren and Olsen's (1993) experiments with older children. However, because infants are less likely than school-aged children to possess expectations about the contents of commercial containers (i.e. Smarties), it seemed doubtful that they would be able to infer an agent's beliefs about such objects based on their external appearance. We therefore presented infants with situations in which an agent first interacted with two objects, leading her to believe that both objects possessed desirable properties (Experiments 1 and 2) or contents (Experiment 3). One of the objects was then altered in the agent's absence such that when she returned, she held a true belief about one object and a false belief about the other². We asked whether infants expected the agent to produce an external emotional display of surprise when, and only when, she interacted with the object about which she was mistaken, thereby discovering her false belief. Such an expectation could result either from an understanding that when agents discover their false beliefs they experience an inner affective state of surprise and hence produce surprised expressions or from a more limited understanding that agents produce surprised expressions when they discover their false beliefs, without any attribution of an internal affective state. We return to the question which understanding infants possess in the general discussion. In either case, such results would provide the first

² Because the agent believed that both objects were desirable, it was reasonable for her to act on either object. This ensured that the infants' responses were driven by how the agent should react emotionally rather than where she should reach.

demonstration that infants in the second year of life understand the causal relationship between false belief and the expression of surprise. These results would constitute a new type of evidence for false-belief understanding in infancy and demonstrate that this understanding applies not only to physical actions on objects but also to belief-based emotional displays. As such, these findings would play an important role in demonstrating that infants, like older children, possess a robust concept of belief that they can flexibly apply to a range of belief-inducing situations and belief-based responses.

2. Experiment 1

Scott et al. (2010) demonstrated that by 18 months, infants readily attribute to an agent a false belief about the non-obvious properties of an object (i.e. whether the object produced a rattling sound when shaken). In Experiment 1, we adapted their procedure to examine whether infants could also reason about an agent's emotional display when she discovered that she was mistaken about an object's non-obvious properties.

The infants in Experiment 1 were assigned to a false-belief or an ignorance-control condition. The infants in the false-belief condition first viewed a familiarization trial in which a female agent (A1) sat at a table (see Figure 1). In front of her were two cylindrical objects, two lids, and a tray holding six marbles. A1 placed three marbles in each object, closed each with a lid, and then repeatedly shook each object in turn, demonstrating that both objects produced a rattling sound. In the second familiarization trial, A1 was absent; a male agent (A2) now sat to the right of the table with a tray beside him. A2 removed the lid from one of the objects, emptied the marbles onto his tray, and replaced the lid. A2 then repeatedly shook each object in turn, demonstrating that one object still rattled while the other was silent. Finally, infants viewed one of two test trials in which A2 and his tray were absent and A1 again sat at the table (see Figure

2). A1 shook each object and displayed surprise at either the silent object (consistent trial) or the rattling object (inconsistent trial).

If the infants in the false-belief condition attributed to A1 the belief that both objects rattled and recognized that agents should express surprise specifically when they discover that they are mistaken, then they should expect A1 to display surprise when she shook the silent object and discovered that her belief about this object was false and they should expect her not to display surprise when she shook the rattling object. The infants should find it unexpected if A1 instead displayed the opposite pattern of reactions. Thus, the infants who received the inconsistent trial should look reliably longer than those who received the consistent trial.

The ignorance-control condition was designed to rule out several alternative interpretations of positive results in the false-belief condition. First, it could be suggested that the infants in the false-belief condition might look longer if they received the inconsistent trial because A1's reaction to the rattling object in this trial (surprised expression) deviated from her reaction to the rattling objects in the first familiarization trial (neutral expression) and thus the inconsistent trial was more perceptually novel than was the consistent trial. Second, Heyes (2014) recently proposed that when an agent is absent for a portion of a false-belief task, the agent's sudden return causes retroactive interference, disrupting infants' memory of recent events. If true, this raises the possibility that the infants' responses in the false-belief condition might be the product of retroactive interference caused by A1's reappearance in the test trial. For instance, if A1's return caused infants to forget A2's actions in the second familiarization trial, then they themselves might find the silent object surprising (because they remembered it rattling in the first familiarization trial but not its alteration in the second) and respond with increased attention when A1 did not share this reaction.

In order to address these possibilities, the infants in the ignorance-control condition saw trials that were identical to those in the false-belief condition except that when A2 emptied the object in the second familiarization trial, he placed the marbles back on the tray in the center of the table (i.e. where they were at the start of the experiment). When A1 returned in the test trial she could see that marbles had been removed from one of the objects, but she was ignorant about which object had been altered. Note that A1 produced the same emotional displays and left and returned at the same time points in both conditions. If the infants' responses in the false-belief condition were due to perceptual novelty and/or retroactive interference, then the results of the ignorance-control condition should be identical to those of the false-belief condition.

However, if the infants were reasoning about the relationship between A1's expectations about the objects and her subsequent emotional display, then infants in the ignorance-control condition should respond differently from those in the false-belief condition. Specifically, the infants in the ignorance-control condition might reason about A1's reactions in one of two ways. If they realize that agents express surprise when overturning a false belief rather than alleviating ignorance, then they should expect A1 not to express surprise at either object. Alternatively, if infants this age possess an immature expectation that agents express surprise when they discover things that they did not know (e.g., Ruffman & Keenan, 1996), then the infants should expect A1 to express surprise at both objects (we return to these two possibilities in Experiment 2). In both cases, in each trial one of A1's expressions should violate the infants' expectations. Thus, if infants were reasoning about the causal antecedents of surprised expressions, then the infants in the ignorance-control condition should look equally long, regardless of whether they received the consistent or the inconsistent trial.

Finally, this experiment was designed to address an additional potential low-level

interpretation of infants' responses. It is possible that infants might respond with increased attention or arousal when an object produces a rattling sound or when they see an agent display surprise. Because all the infants in this experiment saw A1 shake both objects and produce a surprised expression, such an increase in arousal would produce equally long looking times across both conditions and trial types. If the infants instead exhibited differential responses depending on their condition and the trial that they received, this would rule out this arousal-based explanation.

2.1. Method

2.1.1. Participants

Participants were 28 healthy infants, 14 male and 14 female, ranging in age from 18 months, 17 days to 21 months, 26 days ($M = 20$ months, 19 days). Six additional infants were tested but excluded because they looked the maximum time allotted on every trial (2), because of parental interference (2), or because of experimenter error (2; see Section 2.1.4). Half the infants were randomly assigned to the false-belief condition ($M = 20$ months, 21 days), and half to the ignorance-control condition ($M = 20$ months, 17 days).

The infants' names in this and following experiments were obtained from birth records provided by the California Department of Public Health, as well as from a database of parents who had previously expressed interest in participating in research studies with their children. The parents gave written informed consent for their child's participation. Parents were offered reimbursement for their transportation expenses and their infant was given a small gift (book or t-shirt) for participating.

The racial composition of the infants tested in this and the following experiments was 54% Caucasian, 4% Asian, 2% African American, 2% American Indian or Alaska Native, and

1% Hawaiian or Pacific Islander; an additional 17% chose ‘other race’, 8% selected more than one race, and 12% chose not to respond. 56% of the sample identified as Hispanic or Latino, 36% identified as Not Hispanic or Latino, and 8% chose not to respond. In lieu of income information, we recorded the highest level of education reported by either parent: 7% completed less than high school, 45% completed high school, 8% completed a 2-year degree, 16% completed a Bachelor’s degree, 13% completed a Master’s degree, 10% completed a doctoral degree, and 1% chose not to respond.

2.1.2. Stimuli

Stimuli consisted of digitized high definition video recordings of two actors performing a series of actions. Video stimuli were used in order to ensure that the emotional displays shown in the test trial were consistent across participants. Prior to filming the experimental stimuli, the actress who played A1 was shown several example expressions and was instructed on the key aspects of a surprised expression (raised eyebrows, wide eyes, open mouth). The actress then practiced this expression until it closely matched the examples provided.

All infants saw two familiarization trials and one test trial. A separate video was played for each trial. In the following descriptions of the videos played in each trial, the numbers in parentheses indicate the number of seconds the actors took to perform the actions described.

2.1.2.1. False-belief condition familiarization trials.

Each familiarization trial consisted of an initial phase followed by a final phase. The duration of the initial phase was fixed and identical for all participants. The duration of the final phase was infant-controlled.

At the start of the first familiarization trial, A1 sat centered behind a table (see Figure 1). Two cylindrical objects, one red and one green, stood on the table in front of A1, 23 cm apart;

the red object stood to the right and the green object to the left. These objects were plastic cups (each 9 cm tall, 7.5 cm in diameter at the top, and 6 cm in diameter at the base) that could be closed with screw-on lids. A gray lid sat in front of the red object, and a green lid sat in front of the green object; each lid was 7.5 cm in diameter. Centered between the lids was a blue tray (13.5 cm long X 10 cm wide X 1.5 cm high) holding six orange marbles (1.5 cm in diameter).

During the 15-s initial phase of the trial, A1 grasped the red object with one hand (1 s), picked up three marbles with the other hand (1 s), and then dropped the marbles into the red object (1 s). She then grasped the gray lid (1 s) and screwed it onto the red object (3 s). A1 then repeated this process with the green object (7 s): she placed three marbles inside and closed the object with the green lid. A1 then placed her hands on the table and paused (1 s). During the final phase, A1 demonstrated that both objects now rattled: she grasped the red object (1 s), shook it twice per second for 3 s, set it back on the table (1 s), and then repeated this with the green object (5 s). A1 repeated these actions, shaking each object in turn to demonstrate the rattling sound, until the trial ended (see Section 2.1.3 for specific criteria used to end trials). A1 maintained a neutral facial expression throughout the entire familiarization trial.

In the second familiarization trial, A1 was no longer present. Instead, a male agent (A2) sat to the right of the table (Figure 1). A white tray (13 cm long X 9.5 cm wide X 2.5 cm high) sat next to A2 on the front right corner of the table. During the 10-s initial phase of the trial, A2 grasped the red object (1 s), unscrewed the lid (1 s), and placed the lid on the table (1 s). He poured the marbles into his left hand (1 s), placed the object back on the table (1 s), and then placed the marbles into his white tray (2 s). He screwed the lid back on the red object (3 s). During the final phase, A2 grasped the red object (1 s), shook it twice per second for 3 s (the object made no sound), set it back on the table (1 s), and then repeated this with the green object

(which rattled; 5 s). A2 repeated these actions, demonstrating that the green object rattled but the red object did not, until the trial ended.

The object that A2 emptied in the second familiarization trial was counterbalanced within each condition. For ease of exposition, the familiarization and test trials are described from the perspective of the infants who saw A2 empty the red object.

2.1.2.2. False-belief condition test trials

The infants received either a consistent or an inconsistent test trial. Unlike the familiarization trials, the test trial had only a single phase, the duration of which was infant-controlled. At the start of each test trial, A1 again sat centered behind the table; A2 and his white tray were no longer present (see Figure 2). In the *consistent* test trial, A1 grasped the red object (1 s), shook it twice (1 s; the object did not rattle), and displayed surprise while looking at the object (1 s). She shook the object again while continuing to express surprise (1 s). She then set the object back on the table as her face returned to a neutral expression (1 s). Next, she grasped the green object (1 s), shook it twice (1 s; the object rattled), and looked at the object with a slight satisfied expression (1 s). She shook the object again (1 s), continuing to look satisfied, and then set the object back on the table (1 s). A1 then repeated these actions, shaking each object and producing the appropriate expressions, until the trial ended. The *inconsistent* trial was identical except that the pairings of objects and expressions was reversed: A1 produced a satisfied expression at the silent object, and a surprised expression at the rattling object. The order in which A1 shook the objects (silent first vs. rattling first) was counterbalanced across condition and trial type.

We contrasted a surprised expression with a satisfied expression so that A1 always reacted after she shook an object (as opposed to maintaining a neutral expression). This ensured

that infants' responses to the test trials were driven by whether or not A1's emotional displays were appropriate, rather than whether she reacted at all. We used a satisfied expression because it was close to a neutral expression and could reasonably be viewed as an appropriate response to confirming one's true belief or alleviating one's ignorance about an object's properties.

2.1.2.3. Ignorance-control condition familiarization and test trials

The trials in the ignorance-control condition were identical to those in the false-belief condition with three exceptions. First, the white tray was not present during the second familiarization trial. Second, when A2 emptied the object in the second familiarization trial, he placed the marbles on the blue tray in the center of the table. Third, at the start of the test trial, three orange marbles were visible on the blue tray in the center of the table. Thus, when A1 returned in the test trial, she could see that marbles had been removed from one of the two objects, although she was ignorant as to which object had been emptied.

2.1.3 Apparatus and procedure

Infants sat on their parent's lap 91.5 cm in front of a large television screen (122 cm x 68.5 cm). The room was dimly lit. A camera hidden at the base of the television (centered, 89 cm above the floor) recorded the infant's face during the experiment. Parents were instructed to close their eyes or look down to avoid biasing their infant's responses.

The television was connected to a Macintosh computer located to the left of the infant behind a sound-dampening room divider. This computer controlled the presentation of the experimental stimuli using custom software written in Python (Peirce, 2007). The software selected the correct version of each trial based on the infant's condition and presented the video in the center of the television screen (each video measured 64 cm x 37 cm on screen). The software also controlled the duration of each trial. An experimenter observed the infant on a

monitor and pressed a button on the keyboard whenever the infant attended to the video. The software separately computed looking times for the fixed-duration and infant-controlled portions of each trial; looking times during the infant-controlled portion of the trial were used to determine when each trial ended. In between trials, an attention-getter (a yellow smiley face measuring 28 cm x 20 cm) was displayed on the screen for 4 seconds and a brief tone was played to attract the infant's attention back to the television screen.

At the start of the experiment, the attention-getter was presented in the center of the television screen. When the infant attended to the screen, the experimenter initiated the presentation of the stimuli on the television. Infants first viewed the two familiarization trials appropriate for their condition. Each familiarization trial ended when the infant either (1) looked away for 2 consecutive seconds after having looked for at least 10 cumulative seconds (the time it took the agent to shake both objects once) or (2) looked for 60 cumulative seconds without looking away for at least 2 consecutive seconds.

Finally, infants viewed a test trial that was appropriate for their condition; half the infants in each condition saw the consistent trial and half saw the inconsistent trial. This trial ended when infants (1) looked away for 2 consecutive seconds after having looked for at least 15 cumulative seconds or (2) looked for 50 cumulative seconds without looking away for at least 2 consecutive seconds. The longer minimum looking time was chosen to ensure that infants observed A1's reaction to each object at least once. Although both reactions were shown during the first ten seconds, A1 produced each emotional display only briefly. If infants happened to glance away, it would be possible for them to reach a ten second minimum look without having viewed both emotional displays. This was less likely to occur with a 15-second minimum look.

2.1.4. Coding and analysis

Although the experimenter did not know whether the infant was assigned to the false-belief or ignorance-control condition, the experimenter could hear sound cues from the television and thus was not completely blind to the contents of the stimulus videos. Therefore, all infants were coded offline from silent video by a trained coder who was naïve to the condition and test trial that the infant received; the looking times resulting from this offline coding were used in all analyses³. For each trial, the coder indicated the infant's direction of gaze (at the stimuli or away) for each frame of the video. For the infant-controlled portions of each trial, the offline coder used the same trial-ending criteria as described above.

All infants were also coded offline by a second naïve coder; the two offline coders agreed on the children's direction of gaze for 97% of coded video frames. For two infants (one in each condition), the offline coders agreed that the experimenter had terminated the test trial prematurely; these infants were eliminated and replaced.

Preliminary analyses indicated that infants were highly attentive during the initial phase of both the first and second familiarization trials, attending, on average, for 96% and 98% of the initial phases, respectively. Preliminary analyses of the test data indicated no significant interactions of condition and trial with sex, which object was silent (red vs. green), which color object A1 shook first in the test trial (red vs. green), whether A1 shook the rattling or silent object first in the test trial, or whether the infant's age was above or below the median, all F s < 1.27, all p s > .27. The data were therefore collapsed across these factors in subsequent analyses.

2.2. Results and discussion

The infants' looking times during the test trial (see Figure 3) were analyzed using an

³ The online coding for one infant was lost due to experimenter error. For the remaining 83 infants in this report, the looking times recorded by the experimenter and the primary offline coder during the infant-controlled portion of the trials were highly correlated, $r(249) = .97, p < .001$ across all trials, indicating strong agreement between the two coders.

analysis of variance (ANOVA) with condition (false-belief, ignorance-control) and trial (consistent, inconsistent) as between-subjects factors. The analysis yielded a significant interaction of condition and trial, $F(1, 24) = 5.36, p = .029$. There were no main effects of condition or trial, both $F_s < 1$. Planned comparisons revealed that in the false-belief condition, the infants who received the inconsistent trial ($M = 46.6, SD = 7.6$) looked reliably longer than those who received the consistent trial ($M = 34.1, SD = 11.9$), $F(1, 24) = 5.43, p = .029$, Cohen's $d = 1.25$. In the ignorance-control condition, the infants looked about equally long whether they received the inconsistent ($M = 41.2, SD = 11.7$) or the consistent ($M = 46.3, SD = 8.1$) trial, $F < 1$. An analysis of covariance (ANCOVA) using as covariates infants' averaged looking times during the final phases of the familiarization trials again revealed a significant condition by trial interaction, $F(1, 23) = 4.59, p = .043$, and planned comparisons yielded equivalent results.

As predicted, the infants in the false-belief condition looked reliably longer if they received the inconsistent trial than they did if they received the consistent trial. These results could not have stemmed from an increase in attention or arousal caused by hearing a rattling sound or viewing a surprised expression, as this would have resulted in equally long looking times to both trial types. Similarly, if the infants had only a general expectation that A1 should express surprise because something occurred in her absence, then they should have looked equally at both trials. The results of the false-belief condition instead suggest that the infants attributed to A1 the false belief that both objects rattled, expected her to display surprise when she shook the silent object and not when she shook the rattling object, and hence looked longer if she produced the opposite pattern of reactions.

However, because A1's emotional displays were confounded with one another (i.e. she produced two appropriate displays or two inappropriate displays), it is possible that infants'

looking times were driven by one of these displays and not the other: they might have expected A1 to display surprise when she discovered her false belief and looked longer when she failed to do so, or they might have expected A1 not to display surprise when she confirmed her false belief and looked longer when she did so. Although the results of the false-belief condition indicate that infants possess at least one of these expectations, it remains unclear whether they possess *both* expectations. To address this issue, in the subsequent experiments we examined each of these expectations separately.

In contrast to the infants in the false-belief condition, the infants in the ignorance-control condition looked equally, regardless of which trial they received. This suggests that they attributed to A1 ignorance about which of the objects had been altered (and, correspondingly, which still rattled), and either expected A1 to express surprise at neither object (because they realized that surprise results from discovering a false belief rather than alleviating ignorance) or expected her to express surprise at both objects (because they incorrectly view surprise as resulting from discovering something one does not know). In Experiment 2, we clarify which of these expectations infants possess. Regardless, the test trials in the ignorance-control condition differed from those in the false-belief condition in only a subtle way: whether three marbles were visible on the tray between the two objects. These two conditions nevertheless produced reliably different results, thereby ruling out the possibility that the infants' responses were simply driven by perceptual novelty or retroactive interference.

3. Experiment 2

The results of Experiment 1 suggest that infants possess some understanding of the circumstances under which an agent should or should not display surprise. In Experiment 2, we sought to clarify the nature of this understanding in two ways. First, we sought to confirm that

infants expect agents to express surprise when they discover that they are mistaken. Second, we asked whether infants realize that agents should not express surprise when alleviating their ignorance about a situation.

In order to address these questions, we focused specifically on infants' expectations for how A1 should respond to the silent object. The infants were assigned to either a false-belief or an ignorance-control condition; in both conditions, the familiarization trials were identical to those in the corresponding conditions of Experiment 1. In the test trial, all infants saw A1 grasp the silent object, shake it, and then produce either a surprised expression (surprise trial) or a satisfied expression (satisfied trial). The scene then paused with A1 holding this expression.

As in Experiment 1, the infants in the false-belief condition should attribute to A1 the belief that both objects rattled. If the responses of infants in the false-belief condition in Experiment 1 were driven solely by A1's reaction to the rattling object, then the infants in the false-belief condition of Experiment 2 should have no expectations for how A1 should respond to the silent object and hence should look equally, regardless of which trial they received. If, however, infants understand that agents should display surprise when they discover that they are mistaken, then the infants in the false-belief condition should expect A1 to display surprise when she shook the silent object and discovered that she was mistaken about this object, and they should look longer if she produced a satisfied expression instead. The infants who received the satisfied trial should thus look reliably longer than those who received the surprise trial.

In contrast, the infants in the ignorance-control condition should attribute to A1 ignorance about the properties of both objects. If infants incorrectly think that agents display surprise when they discover something that they do not know, then the infants in the ignorance-control condition should expect A1 to express surprise when she shook the silent object and

alleviated her ignorance about its properties, and they should look longer if she produced a satisfied expression instead. If, however, infants realize that agents display surprise when overturning a false belief rather than merely alleviating their ignorance, then they should expect A1 not to express surprise when she shakes the silent object and they should look longer if she does so. The infants who received the surprise trial should therefore look longer than those who received the satisfied trial. Thus, if infants correctly link displays of surprise to false belief and not to ignorance, then the two conditions should yield opposite patterns of results.

3.1. Method

3.1.1. Participants

Participants were 28 healthy infants, 13 male and 15 female, ranging in age from 18 months, 20 days to 21 months, 27 days ($M = 20$ months, 3 days). Two additional infants were tested but excluded because they were fussy (1) or had a test looking time over 2.5 SD away from the mean of their condition (1). Half the infants were randomly assigned to the false-belief condition ($M = 20$ months, 6 days), and half to the ignorance-control condition ($M = 20$ months, 0 days).

3.1.2. Stimuli, apparatus, and procedure

The apparatus and the videos used in the familiarization and test trials were identical to those used in Experiment 1. The procedure was also identical to Experiment 1 with three exceptions. First, in the test trial, all infants saw A1 shake the silent object (color counterbalanced). After shaking the object, A1 produced either a surprised (surprise trial) or satisfied (satisfied trial) expression. Second, the test trial paused with A1 holding this facial expression; infants viewed this paused scene until the trial ended. Third, because A1 did not interact with both objects in the test trial (the scene paused after she responded to the silent

object), the minimum looking time was shortened: the test trial ended when infants (1) looked away for 2 consecutive seconds after having looked for at least 5 cumulative seconds or (2) looked for 50 cumulative seconds without looking away for at least 2 consecutive seconds.

3.1.3. Coding and analyses

All infants were coded offline from silent video by two trained coders who were naïve to the condition and test trial that the infants received; the two offline coders agreed on the infants' direction of gaze for 96% of coded video frames. Preliminary analyses indicated that the infants were highly attentive during the initial phase of both the first and second familiarization trials, attending, on average, for 97% and 98% of the initial phases respectively. Preliminary analyses of the test data indicated no significant interactions of condition and trial with sex, which object was silent (red vs. green), or whether the infant's age was above or below the median, all F s < 1. The data were therefore collapsed across these factors in subsequent analyses.

3.2. Results and discussion

The infants' looking times during the test trial (Figure 3) were analyzed using an analysis of variance (ANOVA) with condition (false-belief, ignorance-control) and trial (surprise, satisfied) as between-subjects factors. The analysis yielded a significant interaction of condition and trial, $F(1, 24) = 16.48, p < .001$. There were no main effects of condition, $F(1, 24) = 1.55, p = .23$, or trial, $F < 1$. Planned comparisons revealed that in the false-belief condition, the infants who received the satisfied trial ($M = 27.0, SD = 7.2$) looked reliably longer than those who received the surprise trial ($M = 14.8, SD = 6.7$), $F(1, 24) = 8.81, p = .007, d = 1.75$. In the ignorance-control condition, the infants who received the surprise trial ($M = 22.9, SD = 10.0$) looked reliably longer than those who received the satisfied trial ($M = 11.6, SD = 6.2$), $F(1, 24) = 7.68, p = .01, d = 1.36$. An analysis of covariance (ANCOVA) using as covariates infants'

averaged looking times during the final phases of the familiarization trials again revealed a significant condition by trial interaction, $F(1, 23) = 14.67$, $p = .001$, and planned comparisons yielded equivalent results.

The positive result of the false-belief condition indicates that the responses of infants in the false-belief condition of Experiment 1 were not driven solely by expectations for how A1 should react to the rattling object. Rather, this finding suggests that in both Experiments 1 and 2, the infants in the false-belief condition attributed to A1 the belief that both objects rattled, expected her to display surprise when she shook the silent object and discovered that this was not the case, and looked longer when she produced a satisfied expression instead. In contrast, the infants in the ignorance-control condition displayed the opposite pattern of responses: the infants who received the surprise trial looked reliably longer than those who received the satisfied trial. Thus, the infants attributed to A1 ignorance about the properties of the objects, recognized that because she was ignorant she had no reason to express surprise at the silent object, and looked reliably longer when she did so. This result suggests that infants do not view surprise displays as arising from ignorance.

Together with the results of Experiment 1, these results demonstrate that by 20 months of age, infants expect agents to display surprise when they discover that they are mistaken, but not when they merely alleviate their ignorance, about a situation.

Could these results reflect expectations about when agents should express satisfaction rather than when they should express surprise? Because all infants saw A1 shake the silent object and discover that it no longer rattled, these results cannot be explained by a general expectation that A1 would not display satisfaction when she discovered the object's properties, as this would have produced identical patterns of responses across conditions. However, it might be suggested

that these results could still be explained by assuming that infants possess two distinct expectations regarding the expression of satisfaction. First, infants might expect agents not to express satisfaction when they discover that they are mistaken and therefore infants in the false-belief condition looked longer when A1 did so. Second, infants might expect agents to express satisfaction when they alleviate their ignorance and hence infants in the ignorance-control condition looked longer when A1 expressed surprise instead.

Although the results of Experiment 2 are technically consistent with this suggestion, we nevertheless find it unlikely. Consider the lunchbox scenario in Section 1. If Sarah falsely believes that her lunchbox contains an apple, then when she discovers the banana she could express surprise and satisfaction (if she likes bananas) or surprise and disappointment (if she dislikes bananas). Similarly, if she is ignorant about which fruit is present, she should not express surprise, but she could still express either satisfaction or disappointment depending on her preferences. As this example illustrates, the expression of satisfaction is not systematically related to belief or to ignorance. It is therefore not clear how or why infants would come to possess the expectations described above. We therefore find it more plausible that the present results reflect expectations about when agents should express surprise rather than expectations about when agents should express satisfaction. Whether infants also possess expectations about the expression of satisfaction remains a question for future research.

4. Experiment 3

Experiment 3 had four goals. The first was to replicate the key finding from Experiments 1 and 2 that infants expect an agent to display surprise when she discovers that she holds a false belief. The second goal was to extend this finding to a different belief-inducing situation: whereas Experiments 1 and 2 focused on an agent who held a false belief about the non-obvious

properties of an object, Experiment 3 involved a false belief about the contents of an object. Third, we sought to verify that infants expect agents not to display surprise when their beliefs are confirmed. Fourth, the results of Experiment 1 suggested that infants do not possess an immature expectation that agents display surprise at desirable outcomes. In the first familiarization trial of that experiment, A1 deliberately created rattling objects and shook them repeatedly to produce a rattling sound, thereby indicating that rattling was a desirable property. If the infants viewed surprised expressions as tied to desirable outcomes, then they should have expected A1 to express surprise at the rattling object and looked longer when she did not do so. Infants in neither condition produced this pattern of responses, suggesting that they did not expect A1 to express surprise at the desirable object. However, it could be argued that because A1 remained neutral throughout the first familiarization trial, the infants in Experiment 1 were uncertain whether rattling was a desirable property. To address this issue, in Experiment 3 we examined whether infants expected an agent to express surprise at an object that she had previously indicated was desirable by emoting positively towards it.

The infants in Experiment 3 were assigned to either an empty-container or a full-container condition. All the infants first viewed a familiarization trial in which a female agent (A1) sat a table behind two lidded containers (see Figure 4). A stuffed bear sat in front of each container. A1 briefly played with one bear while smiling happily and then placed the bear in one of the containers; she then repeated this process with the other bear. A1 clearly expressed happiness as she interacted with each bear, thereby suggesting that she found them desirable. In the second familiarization trial, A1 was absent. A different female agent (A2) entered, removed one of the bears, and left with it. The infants then received one of two test trials. In the empty-container condition, A1 was again seated at the table (see Figure 5). A1 opened the container that

was now empty, looked inside, and displayed either surprise (surprise trial) or happiness (happiness trial). The scene then paused with A1 holding this expression. In the full-container condition, A1 instead opened the full container that still held a bear, looked inside, and then displayed either surprise or happiness.

Note that in the prior experiments, when A1 interacted with an object in the test trial, she either expressed surprise or satisfaction. In the present experiment, however, A1 displayed happiness at both objects during the first familiarization trial. Given this display, it seemed likely that the infants in the full-container condition would find it odd if A1 merely looked satisfied when she opened the full container and saw the bear. For this reason, in Experiment 3, we contrasted a surprised expression with a happy expression, an expression that is appropriate when obtaining something desirable.

Based on the prior experiments, we predicted that the infants in the empty-container condition would attribute to A1 the belief that both containers held a bear, expect her to express surprise when she opened the empty container and discovered that she was mistaken about its contents, and look longer if she expressed happiness instead. The infants in the empty-container condition should thus look longer if they received the happiness trial than if they received the surprise trial. If infants realize that agents should not express surprise when their beliefs are confirmed, even when they obtain something desirable, then the infants in the full-container condition should exhibit the opposite pattern of responses: they should expect A1 not to express surprise when she opens the full container and confirms her belief that a bear is present, and they should look longer if she does so. Together with the prior experiments, such results would suggest that infants expect agents to express surprise if, and only if, they discover that they hold a false belief about a situation.

4.1. Method

4.1.1. Participants

Participants were 28 healthy infants, 14 male and 14 female, ranging in age from 18 months, 25 days to 21 months, 26 days ($M = 20$ months, 12 days). Ten additional infants were tested but excluded because they were inattentive (1), failed to complete the task (3), had a test looking time over 2.5 standard deviations from the mean of their condition (3), because of parental interference (1), or because of experimenter error (2; see Section 4.1.4). Half the infants were randomly assigned to the empty-container condition ($M = 20$ months, 18 days), and half to the full-container condition ($M = 20$ months, 6 days).

4.1.2. Stimuli

As in Experiment 1, the actress who played A1 was trained on the production of both surprised and happy expressions prior to filming the experimental stimuli. The infants saw two familiarization trials and one test trial. A separate video was played for each trial.

4.1.2.1. Familiarization trials

Each familiarization trial consisted of an initial phase followed by a final phase. The duration of the initial phase was fixed and identical for all participants, while the duration of the final phase was infant-controlled.

At the start of the first familiarization trial, a female agent (A1) sat centered behind a table (Figure 4). Two lidded containers (each 15 cm high and 14.5 cm in diameter) stood centered in front of A1, 26 cm apart. Each container was made of cardboard and covered in purple contact paper; each lid had a wooden spherical knob, 3 cm in diameter, affixed to its center. A pink, stuffed bear (each 15 cm tall X 11.5 cm wide X 6.5 cm deep at its largest points) sat in front of each container. During the 35-s initial phase of the trial, A1 grasped the bear on

the left (2 s), brought it in front of her (1 s), and then made the bear dance in the air (5 s) while she smiled happily. She then set the bear down in between the containers (1 s), grasped the container on the left (1 s), and removed the lid (2 s). A1 picked the bear back up (1 s), placed the bear in the left container (2 s), and closed the container with the lid (2 s). A1 then repeated this sequence with the bear on the right (17 s): she picked up the bear, made it dance while smiling at it happily, placed it into the container on the right, and then closed the container with the lid. A1 then placed her hands in her lap and paused (1 s). During the final phase of the trial, infants viewed this paused scene until the trial ended.

In the second familiarization trial, A1 was absent. During the 18-s initial phase, a second female agent (A2) entered the scene from the right (1 s), grasped the container on the right (1 s), and removed the lid (2 s). She then removed the bear from the right container (1 s) and inspected it (2 s) before putting it back into the container (1 s) and replacing the lid (2 s). She then grasped the left container (1 s), removed the lid (2 s), and took out the bear (1 s). She placed the lid back on the left container (2 s), and exited the scene to the right, taking the bear with her (2 s). During the final phase, the infants viewed the paused scene with the two containers until the trial ended.

A2 always removed the bear from the second container that she opened; the order in which A2 opened the containers, and therefore which container was empty, was counterbalanced within each condition. Because A2 acted on both bears and containers in the second familiarization trial, any differences in looking time in the test trial could not be due to the fact that one container had been manipulated more than the other during the familiarization trials.

4.1.2.2. Test trials

The infants received either the surprise or happiness trial that was appropriate for their condition. Each trial consisted of an initial and a final phase. In the empty-container condition, at

the start of the trial A1 was again seated behind the table (Figure 5). During the 5-s initial phase, A1 grasped the empty container (1 s), removed the lid (2 s), looked inside (1 s), and then produced either a surprised (surprise trial) or happy (happiness trial) expression (1 s). The scene then paused with A1 holding this expression. During the final phase, infants viewed this paused scene until the trial ended. The test trials in the full-container condition were identical to those in the empty-container condition except that A1 opened and looked into the full container.

4.1.3. Apparatus and procedure

The apparatus and presentation of the experimental stimuli was identical to that used in Experiments 1 and 2. All infants first viewed the two familiarization trials appropriate for their condition. Each trial ended when infants (1) looked away for 2 consecutive seconds after having looked for at least 5 cumulative seconds or (2) looked for 60 cumulative seconds without looking away for at least 2 consecutive seconds. The infants then viewed a test trial that was appropriate for their condition; half the infants in each condition saw a surprise trial and half saw a happiness trial. This trial ended when infants (1) looked away for 2 consecutive seconds after having looked for at least 5 cumulative seconds or (2) looked for 50 cumulative seconds without looking away for at least 2 consecutive seconds.

4.1.4. Coding and analyses

As in the prior experiments, all infants were coded offline from silent video by two trained coders who were naïve to the condition and test trial that the infants received; the two offline coders agreed on the infants' direction of gaze for 96% of coded video frames. For two infants (one in each condition), the offline coders agreed that the experimenter had terminated the test trial prematurely; these infants were eliminated and replaced.

Preliminary analyses indicated that infants were highly attentive during the initial phase

of both the first and second familiarization trials, attending, on average, for 96% and 97% of the initial phases, respectively. Infants were also attentive during the initial phase of the test trial, attending, on average, for 99% of the initial phase. Preliminary analyses of the test data indicated no significant interactions of condition and trial with sex, the side A1 reached towards in the test trial, or whether the infant's age was above or below the median, all $F_s < 1.01$, $p_s > .32$; the data were therefore collapsed across these factors in subsequent analyses.

4.2. Results and discussion

The infants' looking times during the test trial (Figure 3) were analyzed using an analysis of variance (ANOVA) with condition (empty-container, full-container) and trial (surprise, happiness) as between-subjects factors. The analysis yielded a significant condition by trial interaction, $F(1, 24) = 13.06$, $p = .001$. There were no effects of condition or trial, both $F_s < 1$. Planned comparisons revealed that in the empty-container condition, the infants who received the happiness trial ($M = 24.9$, $SD = 10.9$) looked reliably longer than those who received the surprise trial ($M = 14.1$, $SD = 5.4$), $F(1, 24) = 4.31$, $p = .049$, $d = 1.25$. In contrast, in the full-container condition, the infants who received the surprise trial ($M = 29.6$, $SD = 14.1$) looked reliably longer than those who received the happiness trial ($M = 13.8$, $SD = 5.5$), $F(1, 24) = 9.21$, $p = .006$, $d = 1.47$. An analysis of covariance (ANCOVA) using as covariates infants' averaged looking times during the final phases of the familiarization trials again revealed a significant condition by trial interaction $F(1, 23) = 7.11$, $p = .014$, and planned comparisons yielded equivalent results.

The infants in the empty-container condition attributed to A1 the belief that there was a bear in both containers, expected her to express surprise when she opened the empty container and discovered that the bear was gone, and looked longer if she expressed happiness instead.

This result confirms and extends the results of the false-belief conditions in Experiments 1 and 2: infants again demonstrated the understanding that agents should display surprise when they discover that they are mistaken, and they did so in a different belief-inducing situation. In contrast, the infants in the full-container condition expected A1 not to express surprise when she opened the full container and saw the desirable object that she had placed there and they looked longer if she did so. This demonstrates that infants understand that agents should not express surprise when their beliefs are confirmed, and that they do not view surprise as resulting from desirable outcomes.

4.3. Combined analyses of Experiments 2 and 3

The present results suggest that infants expect agents to express surprise when they discover that they are mistaken. In contrast, they find it unexpected if agents express surprise when they confirm their true belief or alleviate their ignorance about a situation. One might wonder, however, whether these latter two scenarios are somewhat different from one another. Perhaps displaying surprise is more acceptable when one is ignorant and thus somewhat uncertain about a situation than it is when one holds an accurate belief. Although intuitively plausible, research on the causal antecedents of emotions suggests that surprise does not arise from uncertainty, even when that uncertainty is extreme (e.g., Roseman et al., 1996; Roseman, Spindel, & Jose, 1990). Instead, only events that violate one's expectations elicit surprise. Consistent with these findings, older children expect mistaken, but not ignorant agents, to feel and display surprise (e.g., Ruffman & Keenan, 1996). Thus, with regards to the expression of surprise, infants should treat knowledgeable and ignorant agents similarly: they should find it equally unexpected for an agent to express surprise when confirming her true belief or alleviating her ignorance about an object.

In order to test this prediction, in a final set of analyses we combined the data from Experiments 2 and 3 and examined the infants' responses to A1 expressing surprise (surprise trials) or non-surprise (satisfied and happiness trials) in situations in which she discovered that she was mistaken (false-belief and empty-container conditions, $n = 28$) to those in which she did not discover that she was mistaken (ignorance-control and full-container conditions, $n = 28$). The data were analyzed using an ANOVA with Experiment (2, 3), condition (mistaken, not-mistaken), and expression (surprise, non-surprise) as between-subjects factors. This analysis yielded a significant condition by expression interaction, $F(1, 48) = 28.65, p < .001$. No other effects were significant (Experiment by condition interaction: $F(1, 48) = 1.54, p = .22$; all other $F_s < 1$). Critically, the absence of a three-way interaction of Experiment, condition, and expression indicates that there were no differences between the two non-mistaken conditions in how infants responded to the facial expressions. This suggests that the infants did indeed find it equally unexpected when an agent displayed surprise after alleviating her ignorance or confirming her true belief about an object.

Planned comparisons confirmed the results of the individual experiments: the infants in the combined mistaken condition looked reliably longer if given the non-surprise trial ($M = 25.9, SD = 9.0$) as opposed to the surprise trial ($M = 14.5, p = 5.8$), $F(1, 48) = 9.81, p = .003, d = 1.52$, whereas the infants in the combined non-mistaken condition looked reliably longer if they received the surprise trial ($M = 26.3, SD = 12.2$) as opposed to the non-surprise trial ($M = 12.7, SD = 5.8$), $F(1, 48) = 13.68, p < .001, d = 1.42$. We also compared the infants' responses to each emotional expression across conditions. A planned comparison focusing on the surprise trial revealed that the infants in the non-mistaken condition looked reliably longer than did those in the mistaken condition, $F(1, 48) = 10.51, p = .002, d = 1.23$. In contrast, a planned comparison

focusing on the non-surprise trial indicated that the infants in the mistaken condition looked reliably longer than did those in the non-mistaken condition, $F(1, 48) = 13.19, p < .001, d = 1.76$. Taken together, these results demonstrate that infants expect agents to express surprise if, and only if, they discover that they hold a false belief.

5. General Discussion

The present results provide the first empirical demonstration that infants in the second year of life understand belief-based emotional displays. In the false-belief condition of Experiment 1, 20-month-olds first watched an agent repeatedly shake two rattling objects; in her absence, one of the objects was altered so that it no longer rattled. When the agent returned, she shook both objects and reacted to one of the objects with surprise. The results indicated that infants attributed to the agent the belief that both objects rattled, expected her to express surprise when she shook the silent object and discovered that her belief about this object was false, and they looked longer if the agent instead expressed surprise at the rattling object. In contrast, when the agent was ignorant about which object rattled and which did not (ignorance-control condition), infants looked equally regardless of whether the agent expressed surprise at the silent or the rattling object. In Experiment 2, the infants were tested in false-belief and ignorance-control conditions similar to those in Experiment 1 except that when the agent returned, she always shook the silent object and reacted with surprise or satisfaction. The infants in the false-belief condition again expected the agent to express surprise when she shook the silent object and discovered that she was mistaken about its properties, and they looked reliably longer if she instead produced a satisfied expression. In contrast, the infants in the ignorance-control condition did not expect the agent to express surprise when she alleviated her ignorance about the silent object's properties and they looked reliably longer if she did so.

Finally, in Experiment 3 infants watched an agent happily play with two bears, placing each into a separate container; one of the bears was then removed in the agent's absence. When the agent returned, she opened one of the containers, looked inside, and produced either a surprised or happy expression. Results suggested that the infants attributed to the agent the belief that there was a bear in both containers, expected her to be surprised when she opened the empty container and discovered that she was mistaken, and looked longer if she expressed happiness at the empty container instead. When the agent opened the full container, the infants did not expect her to express surprise when she saw the desirable object that she had previously placed inside, and they looked longer if she did so.

Together, these results demonstrate that by 20 months of age, infants understand the causal relationship between false belief and the expression of surprise. As shown in all three experiments, infants expect agents to express surprise when they discover that they are mistaken about a situation. Moreover, this expectation is specific to situations in which an agent discovers a false belief: infants do not expect agents to express surprise when (1) they are merely ignorant and discover something that they did not previously know, (2) when their beliefs are confirmed, or (3) when they obtain something desirable.

Might infants instead view surprised expressions as resulting from something *undesirable*? Across all three experiments, the object that was unexpected was also arguably undesirable because it lacked a desirable non-obvious property (Experiments 1 and 2) or desirable contents (Experiment 3). The infants might have expected the agent to express surprise at these objects because they were undesirable rather than because they were unexpected. If that were the case, however, then the infants in the ignorance-control condition of Experiment 2 should also have expected A1 to express surprise when she shook the undesirable silent object.

Contrary to this prediction, the infants in the ignorance-control condition expected A1 not to express surprise and looked longer if she did so, suggesting that infants do not expect agents to display surprise at undesirable outcomes. It is possible that infants expect expressions of surprise to result from situations that are *both* unexpected and undesirable, as in the false-belief conditions (Experiments 1 and 2) and empty-container condition (Experiment 3). Given that there is no evidence that older children ever link surprise with undesirable outcomes (e.g., MacLaren & Olsen, 1993; Ruffman & Keenan, 1996), we find it more plausible that infants possess the simpler expectation that agents will express surprise when they discover something unexpected.

However, as mentioned in the introduction, the expectation that agents should express surprise when they discover something unexpected could arise in one of two ways. It could be that by 20 months of age, infants understand that discovering one's false belief causes one to experience an internal emotional state of surprise, which in turn causes one to produce a corresponding external emotional display of surprise. Alternatively, infants might understand that discovering one's false belief causes one to produce a surprised expression without necessarily understanding that this expression corresponds to an internal affective state. Because either understanding could have produced the present results, we cannot say for certain which understanding 20-month-olds possess.

That said, several sets of findings suggest that infants this age could be capable of reasoning about an agent's internal experience of surprise. Considerable evidence indicates that by the second year of life, infants can attribute to agents a rich array of internal states including goals, dispositions, knowledge, and beliefs (for a review, see Baillargeon et al., 2015). If infants can attribute these internal states to agents, then it seems plausible that they can attribute internal

emotional states to agents as well. Evidence from studies of infants' behavioral responses to emotional displays supports this possibility (for a review, see Walle & Campos, 2012). For instance, 18-month-olds who witnessed an adult express anger at another adult's action were less likely to imitate that action if the emoter was watching them with a neutral expression than if she was looking away or had her eyes closed (Repacholi, Meltzoff, & Olsen, 2008). This suggests that the infants anticipated that the emoter would be angry with them if she saw them perform the offending action. Further support comes from recent work by Walle and Campos (2014) demonstrating that 19-month-olds distinguish between authentic and inauthentic emotional displays. In one experiment, infants saw a parent express pain after either hitting or missing her hand with a toy hammer. If the parent hit her hand, the infants responded with concern; if she had missed her hand they responded with increased positive affect and aggressive or playful behaviors. This suggests that infants interpreted the same emotional display as reflecting different internal emotional states depending on the context in which it occurred.

Together, these various findings suggest that by 18 months, infants can attribute a variety of internal states, including emotional states, to agents. We therefore think it likely that the infants in the present experiments were reasoning not only about A1's external emotional display but also her internal affective state: they expected her to *feel* surprised, and hence display surprise, if and only if she discovered that she was mistaken. Additional research is needed to directly test this possibility.

The results of these experiments contribute to our understanding of early false-belief reasoning in several ways. First, they confirm prior findings that by the second year of life, infants can attribute false beliefs to agents (e.g., Buttelmann et al., 2009; Kovács et al., 2010; Luo, 2011; Onishi & Baillargeon, 2005; Scott et al., 2015; Senju et al., 2011; Träuble et al.,

2010). Second, these results extend these findings to a novel belief-based response: infants can reason not only about which location a mistaken agent will act on, but also about how her false belief will affect her subsequent emotional displays. Together with other recent findings, these results suggest that by 20 months of age, infants appreciate how an agent's goals, desires, and beliefs can interact to produce physical actions, verbal behaviors, and affective displays such as surprise. Thus, like older children, infants appear to possess a robust understanding of belief that they can flexibly apply to a range of belief-inducing situations and belief-based responses. This growing body of evidence casts doubt on the notion that infants' successful performance in false-belief tasks is the result of primitive abilities that apply to only a limited range of situations and behaviors. Such findings instead support recent mentalistic accounts, which propose that infants make sense of agents' behavior by reasoning about their motivational, epistemic, and counterfactual states (e.g., Baillargeon, Scott, & Bian, 2016; Baillargeon et al., 2010; Barrett et al., 2013; Buttelmann et al., 2009; Carruthers, 2013; Kovács et al., 2010; Luo, 2011; Scott et al., 2010; Southgate et al., 2007; Surian et al., 2007).

In particular, the present results bear on the minimalist account proposed by Apperly and colleagues (e.g., Apperly & Butterfill, 2009; Butterfill & Apperly, 2013; Low, Drummond, Walmsley, & Wang, 2014; Low & Watts, 2013). According to this account, two distinct systems underlie human psychological reasoning. The late-developing system that emerges around age 4 is capable of attributing false beliefs to agents, thereby enabling success on traditional elicited-response false-belief tasks. In contrast, the early-developing system that is present in infancy cannot attribute false beliefs to agents. This system instead tracks simpler, belief-like states called registrations. A registration is a relation between an agent and a specific object: when an agent encounters an object, the agent registers that object's location and properties. The early-

developing system treats registrations as enabling conditions for actions, allowing infants to predict simple goal-directed actions such as where an agent will reach for an object. For instance, imagine that an agent encounters an object in one of two locations and then the object is moved in the agent's absence (e.g., Onishi & Baillargeon, 2005). By tracking where the agent last registered the object, the early-developing system can predict that the agent will reach for the object in its original location. The early-developing system is thus able to explain the results of many prior false-belief tasks with infants (for exceptions, see Scott et al., 2015).

It is less clear, however, whether the early-developing system could produce the present results. In the current experiments, the agent formed two relevant registrations during the first familiarization trial: in Experiments 1 and 2 she registered that the green object rattled and that the red object rattled, and in Experiment 3 she registered a bear in the left container and a bear in the right container. Given these registrations, it was plausible for the agent to reach to either object in the test trial in order to producing a rattling sound (Experiments 1 and 2) or to obtain a bear (Experiment 3). Thus, regardless of whether infants tracked the agent's registrations or beliefs, they could not succeed in the present experiments by focusing solely on where the agent should direct her actions in the test trial. Instead, infants needed to use the agent's belief to predict the emotional display that the agent should produce after she acted on a particular object. It is not immediately apparent how a system that treats "registrations as informing basic object-directed actions" (p. 1521, Low et al., 2014) might predict an agent's emotional display.

Moreover, if the present results reflect a capacity to reason about internal emotional states, as we suggested above, then this would mean that infants understood the causal interaction between the agent's belief and her subsequent emotions. Does such causal reasoning fall within the purview of the early-developing system? According to the minimalist account, this

system cannot handle arbitrarily complex interactions amongst registrations and other psychological states (e.g., Butterfill & Apperly, 2013). This suggests that there should be limits on the number of mental states that the early-developing system can integrate. However, it does not preclude the possibility that this system can handle *some* interactions amongst mental states. Without further specification of the types of causal interactions that this system can entertain, we cannot rule out the possibility that the early-developing system could have produced the present results. Indeed, it would be difficult for any individual study alone to demonstrate that there are no arbitrary limits on infants' ability to reason about causal interactions amongst mental states. Rather, the present study adds to a growing body of evidence that infants can reason about causal interactions amongst mental states (e.g., Scott & Baillargeon, 2009; Scott et al., 2015). As such evidence accumulates, the existence of arbitrary limits on infants' false-belief understanding become less plausible. The present results also demarcate a clear lower bound for the early-developing system: if infants possess this system, it must be capable of handling interactions as least as complex as those involved here – an interaction amongst an agent's goal, registration, goal-directed action, and subsequent emotional response.

More generally, our results reveal a new dimension of early false-belief understanding that may play an important role in early development. The purpose of psychological reasoning is not to succeed in arbitrary experimental tasks, but to facilitate everyday social interactions. While the agents in many experiments on infants' psychological reasoning display neutral affect, in real life agents respond to situations with a myriad of emotions. Effectively interacting with others thus requires the ability to predict, interpret, respond to, and in some cases manipulate an agent's emotional reactions (e.g., Moll et al., 2016; Reschke, Walle, & Dukes, under review). Our results add to a small body of research on infants' understanding of the causal antecedents of

emotion (e.g., Chiarella & Poulin-Dubois, 2013; Skerry & Spelke, 2014; Walle & Campos, 2014) by demonstrating that by 20 months of age, infants grasp how an agent's beliefs could give rise to surprised responses. Future research should continue to explore infants' understanding of this affective dimension of belief, including whether infants use this understanding to guide their social interactions.

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Figure Captions

Figure 1. Events shown in the familiarization trials of the false-belief condition in

Experiment 1. Infants in the ignorance-control condition saw identical familiarization trials except that in the second familiarization trial, the white tray was absent and A2 emptied the marbles onto the blue tray in the center of the table. Which object A2 emptied was counterbalanced within condition.

Figure 2. Events presented in the test trials of the false-belief condition in Experiment 1.

Infants in the ignorance-control condition saw identical test trials except that three orange marbles were visible on the blue tray in the center of the table. Which object A1 shook first was counterbalanced across condition and trial type.

Figure 3. Results from Experiments 1-3. Mean looking time (sec) of the infants during the test trial as a function of condition and trial. Error bars represent standard errors, and an asterisk denotes a significant difference between the trials within a condition ($p < .05$).

Figure 4. Events presented in the familiarization trials of Experiment 3. The bear that A2 removed in the second familiarization trial was counterbalanced within condition.

Figure 5. Events presented in the test trials of Experiment 3.

False-belief Condition

Familiarization Trial 1

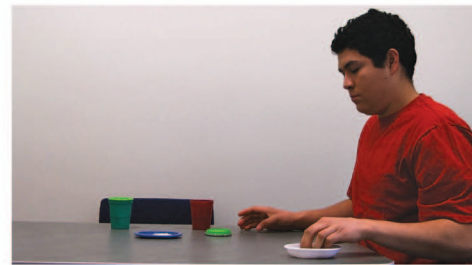
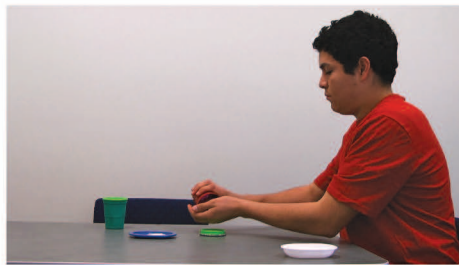


(rattling noise)

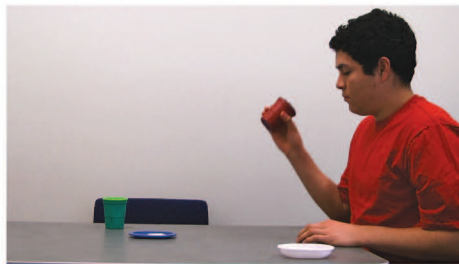


(rattling noise)

Familiarization Trial 2



(no noise)



(rattling noise)



False-belief Condition

Inconsistent Test Trial



(no noise)



(rattling noise)

Consistent Test Trial



(no noise)

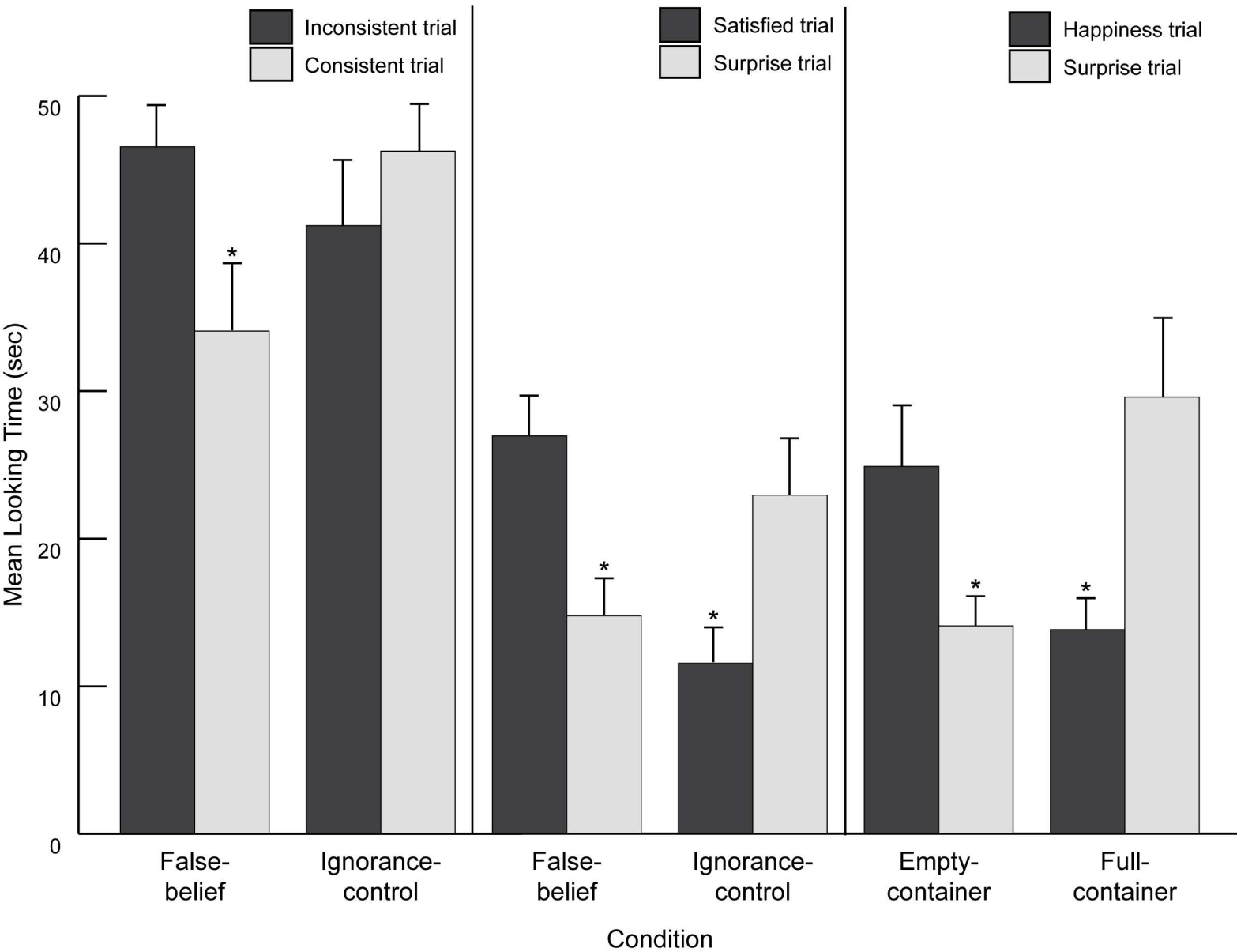


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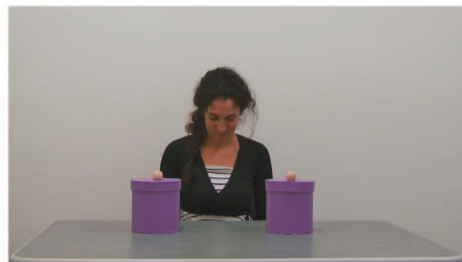
Experiment 1

Experiment 2

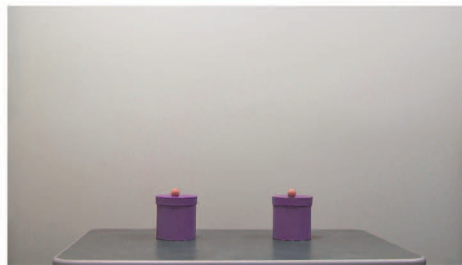
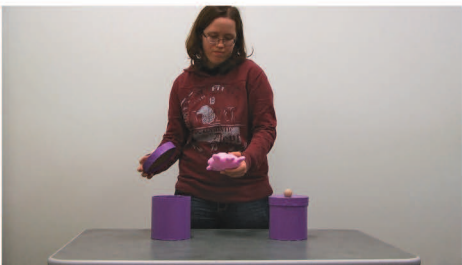
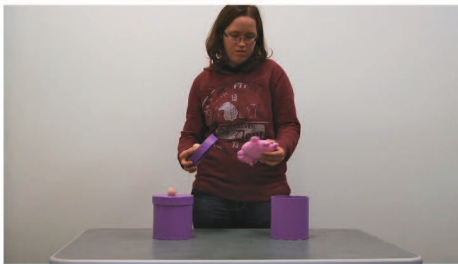
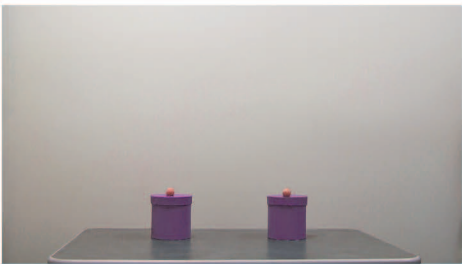
Experiment 3



Familiarization Trial 1



Familiarization Trial 2



Empty-container Condition

Surprise Trial



Happiness Trial



Full-container Condition

Surprise Trial



Happiness Trial

