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Infants attribute false beliefs to a toy crane

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Abstract

The mentalistic view of early theory of mind posits that infants possess a robust and sophisticated understanding of false belief that is masked by the demands of traditional explicit tasks. Much of the evidence supporting this mentalistic view comes from infants' looking time at events that violate their expectations about the beliefs of a human agent. We conducted a replication of the violation-of-expectation procedure, except that the human agent was replaced by an inanimate agent. Infants watched a toy crane repeatedly move toward a box containing an object. In the absence of the crane, the object changed location. When the crane returned, 16-month-old infants looked longer when it turned toward the object's new location, consistent with the attribution of a false belief to the crane. These results suggest that infants spontaneously attribute false beliefs to inanimate agents. A video abstract of this article can be viewed at https://youtu.be/qqEPPhd9FDo

KEYWORDS
agency, false belief, infancy, theory of mind, violation-of-expectation

1 | INTRODUCTION

The ability to understand and reason about one's own and others' mental states, also known as Theory of Mind (ToM), is a foundational cognitive ability (Wellman, 2017). Among mental states, false belief understanding—originally reported to develop around the age of four years—is considered to be the marker of a fully developed ToM (Wimmer & Perner, 1983). A decade ago, this conceptual shift was challenged in a landmark study reporting false belief understanding in 15-month-old infants using the violation-of-expectation (VOE) paradigm (Onishi & Baillargeon, 2005). This striking finding led to the conclusion that 'infants already attribute false beliefs to agents, calling into question the conclusion that false-belief understanding is not achieved until about 4 years of age' (page 238) and that 'false-belief understanding emerges early in life and is *robust* and *sophisticated*' (Scott & Baillargeon, 2017, page 246). This mentalistic account posits that this ability is masked by the high task demands of the standard false belief task, which requires well-developed executive functioning abilities and verbal skills (Baillargeon, Scott, & He, 2010; Scott, 2017). Over the past decade, a large number of experiments have replicated and extended the original findings using a range of procedures all based on spontaneous responses, including anticipatory looking and prompted helping (see Scott & Baillargeon, 2017 for a review). However, a number of recent studies have failed to replicate the original VOE findings with human infants, calling into question the *robustness* of false belief understanding in infancy. Most studies conducted conceptual, rather than strict, replications as they incorporated minor or major procedural changes to the original design (Dörrenberg, Rakoczy, & Liszkowski, 2018; Poulin-Dubois, Polonia, & Yott, 2013; Powell, Hobbs, Bardis, Carey, & Saxe, 2018; Yott & Poulin-Dubois, 2016). Yet, the fact that methodological changes, such as the duration of infant-directed pauses or within-versus between-subjects design, could impact the findings provides some evidence for the lack of robustness of false belief understanding in infancy as measured with this paradigm.

Other paradigms have been developed to test false belief understanding in infancy (e.g. anticipatory looking, helping) but they have also proven difficult to replicate (Burnside, Ruel, Azar, & Poulin-Dubois, 2018; Crivello & Poulin-Dubois, 2018; Priewasser, Rafetseder, Gargitter, & Perner, 2018; Schuwerk, Priewasser, Sodian, & Perner, 2018). Additionally, there appears to be a lack of convergence in performance when the same infants are administered pairs of non-traditional false belief tasks (e.g. anticipatory looking and VOE) (Dörrenberg et al., 2018; Poulin-Dubois & Yott, 2018; Powell et al., 2018). Finally, when adults are presented with false belief scenarios identical to those shown to infants in the VOE paradigm, they only refer to the protagonist's mental states when instructed to do so, casting doubt on rich interpretations of infants' mentalizing abilities (Low & Edwards, 2018). Nevertheless, it is important to note that some researchers have reported successful replications of the original results with the VOE paradigm (e.g. Kovács, Téglás, & Endress, 2010; Luo, 2011; Surian, Caldi, & Sperber, 2007; Träuble, Marinović, & Pauen, 2010; Yott & Poulin-Dubois, 2012). Some of these successful conceptual replications included methodological changes to the original paradigm, such as replacing the human agent with animate agents (e.g. caterpillar, Smurf). In sum, there are mixed findings regarding the construct validity of this task.

Research Highlights

- An inanimate object, a toy crane, acted as the agent in the false belief task based on the violation-of-expectation paradigm.
- 16-month-old infants showed the same looking pattern observed with a human agent.
- These results provide critical information regarding the debate about the depth of infants' theory of mind.

In contrast to the mentalistic account, leaner views have been proposed to explain the behaviors observed in procedures based on looking patterns or prompted actions (Ruffman, 2014). For instance, it has been argued that infants' responses in the VOE task can be explained by infants' learning of stimulus-response behavioral rules, such as 'people look for an object at the last place they saw it' (Ruffman & Perner, 2005). Another lean account suggests that infants may solve implicit false belief tasks by submentalizing, a behavior that appears as if it is controlled by reasoning about mental states, but it is not (Heyes, 2014a). According to this view, rather than tracking the agent's false belief, infants encode the shallow visual properties of the stimuli—such as colors, shapes, and movements—during the familiarization trials and respond to the novelty of their configurations at the test trial. Thus, infants look longer during the incongruent test event than during the congruent test event because they witness a more perceptually novel event than that in the congruent condition (Heyes, 2014b). In order to determine whether there is a rich false belief understanding that is stable from infancy to childhood, the sophistication of such reasoning must be further examined. To investigate this issue, one recent suggestion was to replace the agent with an inanimate object in a task measuring false belief in infancy (Heyes, 2014a). Thus, this was the main goal of the present study, in which an inanimate agent (mechanical crane) replaced the human agent in the VOE procedure.

Although anthropomorphism is observed even in adults in certain contexts, sophisticated psychological reasoning entails reserving mental states to humans and animals (Abell, Happé, & Frith, 2000; Epley, Waytz, & Cacioppo, 2007; Oatley & Yuill, 1985). Thus, it has been proposed that inanimate objects should elicit different looking patterns than is the case when a human agent is involved (Heyes, 2014a). By preschool age, children deny mental states to inanimate agents (Opfer, 2002; Poulin-Dubois & Héroux, 1994). For example, Opfer (2002) asked 4-, 5-, 7-, 10-year-olds, and adults a series of questions after showing them an irregularly shaped dark dot moving in a goal-directed or non-goal-directed way. Specifically, the questions were addressing whether the participants ascribed biological, cognitive, and physiological properties to the inanimate agent. Although older children and adults considered the object that moved in a goal-directed way as alive, even 5-year-old children did not attribute mental states (e.g. does it think?) to this inanimate agent (Opfer, 2002; Poulin-Dubois & Héroux, 1994). A stimulus is considered agentive when it displays animacy cues (e.g. morphology, goal-directed action, internal control, etc.), while an agent is considered sentient when it shows psychological reasoning abilities (e.g. thinking, remembering). Interestingly, a number of studies have examined infants' attribution of motivational states (e.g. goals) to goal-directed inanimate agents. For example, by 5 or 6 months, infants attribute goals to a human but not to an inanimate agent such as a mechanical claw (Woodward, 1998). However, when unambiguous agency cues are provided (e.g. initiate motion in plain view), infants as young as 3 months detect the change of goals of inanimate agents such as a self-propelled box and can anticipate the goal of a mechanical claw by 11 months of age (Adam, Reitenbach, & Elsner, 2017; Luo & Baillargeon, 2010). This type of evidence has been interpreted as supporting the hypothesis that there exists an innate specialized psychological reasoning system that is activated whenever infants process the actions of individuals.

To our knowledge, only a handful of studies have been conducted on infants' attribution of *epistemic* states to inanimate agents. Surian and Geraci (2012) used animated geometric shapes in anticipatory looking false and true belief tasks. Infants watched two familiarization trials where a triangle followed a disc in a Y-shaped tunnel and entered a box at the end of one of the tunnels. In the true belief test trial, once the disc entered a box at the end of the Y-shaped tunnel, it changed location while the triangle was present. The triangle then entered the tunnel and infants' anticipatory looks to one of the two tunnel exits were recorded. In the false belief test trial, the triangle was absent from the scene during this change of location. Infants aged 17 months, but not 11-month-olds, attributed both true and false belief to the triangle, that is, they anticipated the disk would come out of the Y-shaped tunnel on the side that was consistent with the triangle's 'beliefs'. The authors concluded that by 17 months infants can attribute beliefs to aself-moving, interacting object lacking agent-like morphological features. More recently, Tauzin and Gergely (2018) showed that 13-month-olds attribute knowledge to geometric agents who display two agentive cues: goal-directed action and turn-taking, contingent communication. In this task, a blob appeared to have the goal to find a ball hidden in one of two boxes—a second blob was also present throughout the sequence of events. During the task, a ball hid in one location unbeknownst to the first agent (i.e. naïve agent), while the second agent 'knew' the location of the ball. They found that only when the agents engaged in unpredictable/variable contingent exchanges (i.e. communication) did the infants expect the naïve agent to find the object. Thus, there is evidence that ToM abilities play a role in communicative contexts, even in infancy. According to relevance theory, communicative utterances provide ostensive cues to observers (Sperber & Wilson, 1995). Results from Song and Baillargeon (2008) demonstrated that infants expect that an agent's false belief would be corrected after being informed of the actual location of an object. Further, Tauzin and Gergely's (2018) results indicated that infants recognize that animated agents can communicate information about the location of an object. These findings are in line with relevance theory and in conflict with Heyes's (2014b) lean view (Scott & Baillargeon, 2014). Finally, one recent study tested apes with a design in which the human agent was replaced with an inanimate agent to test false belief (i.e. moving geometric shape), and the pattern of anticipatory looking initially observed with a human agent was not replicated (Kano, Krupenye, Hirata, Call, & Tomasello, 2017). This was a follow-up to a previous study reporting that apes anticipated where a person would look for an object after the apes witnessed a change of location in her absence (Krupenye, Kano, Hirata, Call, & Tomasello, 2016). Given that apes only correctly anticipated the person's actions it was concluded that submentalizing cannot be responsible for apes' anticipatory looks in a false belief task.

The goal of the present study was to modify the design of the VOE task in order to answer the following question 'does the VOE task measure mentalizing abilities or submentalizing?' This question has been previously addressed by Santiesteban, Catmur, Hopkins, Bird, and Heyes (2014), with adults performing the dot perspective task. We extend these findings by investigating infants' reasoning about inanimate objects using Onishi and Baillargeon's (2005) VOE task. To our knowledge, no study has investigated whether human infants' responses in the VOE false belief paradigm are different when the agent is an inanimate object instead of a person. A remote-controlled mechanical crane performed the same movements as the human agent in the original false belief VOE task (Onishi & Baillargeon, 2005). The crane lacked many predictive cues of agency, including human-like morphology (e.g. eyes, human-shaped body), biological motion, texture (e.g. skin, fur), as well as contingent interaction with another object. However, the exact replication of the original design required the toy crane to display other agency cues (goal-direction, self-propulsion). Although self-propulsion is insufficient to attribute agency, the perception of internal control, that is, an entity having a goal, tends to generate the attribution of agency (Baillargeon, Scott, & Bian, 2016). Two experiments were conducted: 1) the original implicit paradigm with infant participants and 2) an explicit version of the same task with adults. If infants have a sophisticated false belief understanding akin to the one tapped by traditional false belief tasks, then they should not attribute a false belief to an inanimate agent. Specifically, they should expect the crane to behave at test as it had behaved in the familiarization trials—they should look longer at the event in which the crane moves to a different location than in the familiarization trials (i.e. congruent test event). In contrast, if infants' looking patterns from the original study are replicated when using an inanimate object, then this would provide evidence that infants might be mentalizing but are overattributing mental states to all types of agents (i.e. sentient and non-sentient). Such pattern of results could also signal that infants might be submentalizing when reacting to changes in the test events, creating associations between boxes, objects, and hands or shapes. Finally, if, as expected, adults have a sophisticated false belief understanding, and therefore understand that cranes do not have mental states, then they should anticipate that the crane will repeat the same movements as seen during the familiarization trials. In contrast, if adults attribute beliefs to inanimate agents, then they should predict that the crane will turn in a belief-congruent way, that is, they will anticipate the crane to turn to the empty box.

2 | METHOD

2.1 | Experiment 1

2.1.1 | Participants

Participants comprised of fifty-three infants (29 boys and 24 girls, M_{age} = 16.51 months, range = 15.60–17.87 months). Each infant was randomly assigned to one of two conditions: congruent (n = 28) or incongruent (n = 25). Fourteen additional infants were tested and excluded from the analyses due to fussiness preventing completion of the study (n = 6), lack of attention during the procedure (n = 3), parental interference (n = 2), or experimental error (n = 3). Parents were asked to report if their child was previously exposed to a remote-controlled toy at home or at daycare. Given that the toy crane was activated using a remote control, all infants with prior exposure to remote-controlled toys were excluded from further analyses (n = 17). Therefore, the final sample was comprised of 18 infants in the congruent group and 18 infants in the incongruent group.

2.1.2 | Procedure and materials

A warm-up session preceded the administration of the tasks to ensure that the infants were comfortable with the primary experimenter. During this time, parents were asked to complete a short demographic questionnaire, including a question about their child's exposure to remote-controlled toys. At the end of the session, infants received a gift and a certificate of merit for their participation. Parents received $20 as compensation.

2.1.3 | VOE false belief task

In order to conduct a strict replication of the original task, a detailed script of the task was approved by one of the original authors (Baillargeon, personal communication, October 9th, 2017). The task was administered on a stage-like apparatus (107 cm × 97 cm × 104 cm). A yellow box and a green box (14 cm × 14 cm × 14 cm each) were placed 37 cm apart at each end of the stage. The boxes had a 14 cm × 14 cm opening on the

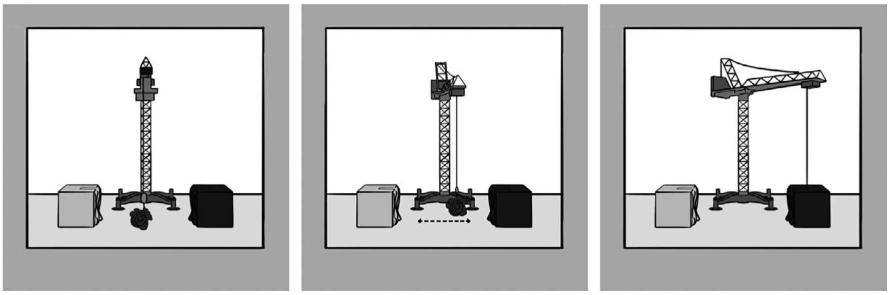

FIGURE 1 Depiction of actions during the first familiarization trial, where the light grey box is the yellow box and the dark grey box is the green box

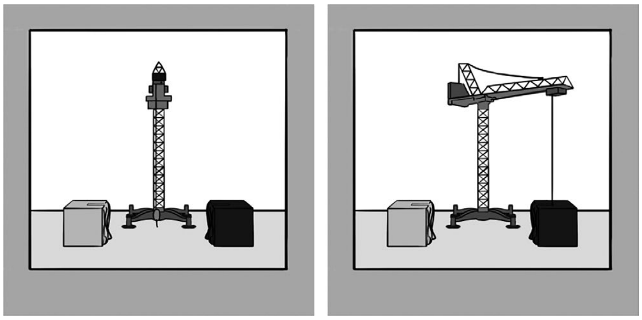

FIGURE 2 Depiction of actions during the second and third familiarization trials

side, covered with fabric. The boxes were placed such that the openings faced each other (see Figure 1). A yellow remote-controlled Playmobil™ toy crane (77 cm × 32 cm × 32 cm) was positioned at the center of the stage, exactly in the middle of the two boxes. The crane's arm extended 45 cm from the crane's body. A white board (110 cm × 52 cm) was used in the belief induction trial to block the crane from the participant's view. An orange cup (4.5 cm × 9 cm × 3 cm) covered in stickers with a magnet inside was used as the toy being manipulated by the crane. Another magnet was placed underneath the stage, such that the experimenter could slide the cup across the stage. A Panasonic™ camera was also located beneath the stage and was focused on the infant's face, which was displayed on an LCD monitor. An iMac 2011 running OSX Yosemite 10.10.5 was used to live-code infants' looking behavior using the Habit 2000 program (University of Texas).

Infants were seated on a highchair 110 cm from the stage. The parent sat 180 cm behind the infant. If infants refused to sit in the highchair, they were seated on their parent's lap (congruent: $n = 3$, incongruent: $n = 6$) and parents were asked to wear a sleep mask to cover their eyes. Infants viewed three familiarization trials, one belief induction trial, and one test trial. Each trial was followed by an infant-directed pause, which ended when the infants either (a) looked away from the scene for two consecutive seconds after looking at it for a minimum of two cumulative seconds, or (b) looked at the scene for 30 cumulative seconds. Between each trial, an attention getter sound accompanied the rising and lowering of the screen.

In the first familiarization trial, lasting a maximum of 12 s, the screen was raised, revealing a crane positioned between two boxes (a yellow box and a green box) and a small cup hanging from the crane's hook. The crane's arm moved slightly from side-to-side for 8 s, to mimic playing with the toy. The crane then rotated and placed the cup inside the green box. The crane paused in this position until the end of the infant-directed pause (Figure 1). In the second and

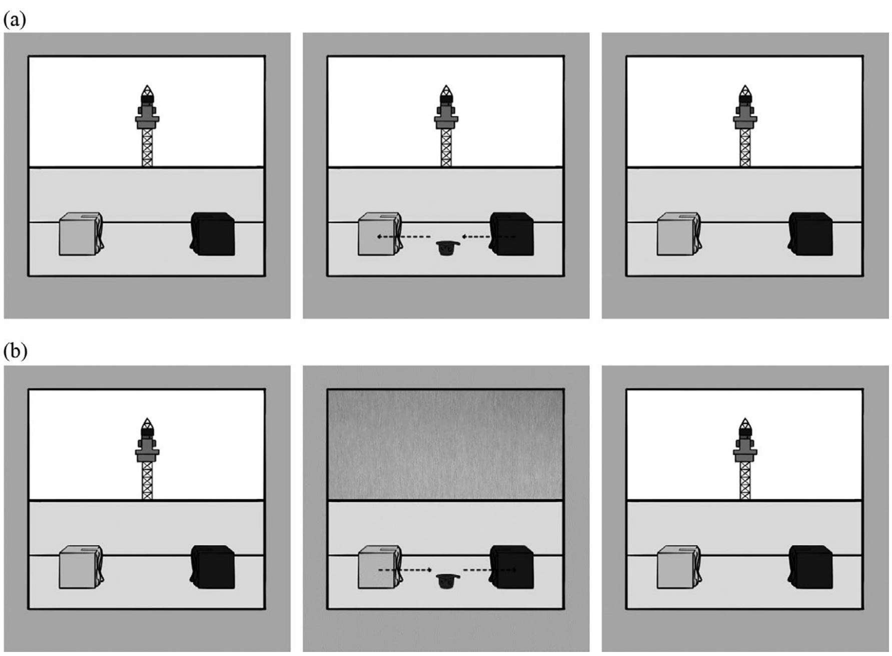

FIGURE 3 Depiction of actions during the first location-change (a) and the second location-change (b) of the false belief induction trial, equivalent to the FB-yellow condition in the original study (Onishi & Baillargeon, 2005)

third familiarization trials, lasting a maximum of 6 s each, the crane's arm rotated towards the inside of the green box (i.e. where the cup was hidden) and paused in this position until the end of the infant-directed pause (Figure 2). The goal of these familiarization trials was to show that the crane, like the human actor in the original experiment, reached for the cup in the green box.

In the false belief induction trial, lasting a maximum of 24 s, the screen was raised, revealing the crane oriented straight between the two boxes with a white board covering the lower portion of the crane. At the start of the trial, an experimenter hidden below the stage used a magnet to move the cup from the green box to the yellow box (Figure 3a). Following this, the upper half of the board was lifted, such that the crane disappeared from the scene. Using the magnet, the cup was then moved back into the green box (Figure 3b). This change of location is typically labeled as a false belief induction trial because the human agent in the original study held a false belief that the toy was in the yellow box. An infant-directed pause started once the cup entered the green box.

Infants then viewed one of two test trials, lasting a maximum of 6 s (Figure 4). For the congruent group, the crane was rotated toward the yellow box (i.e. empty box). For the incongruent group, the crane was rotated toward the green box (i.e. where the cup was located). For both groups, the crane's arm was paused in this position until the end of the infant-directed pause. Infants' total looking time (in seconds) at the scene during the infant-directed test pause was recorded by another experimenter. If infants do not ascribe mental states to a mechanical crane, then they were expected to look longer at the test event that shows the crane moving toward the box that is different from the box where it went to during the familiarization trials (i.e. infants should look longer if they viewed the yellow box [belief-congruent] test event). Thus, unlike the case with the human agent, infants should not consider the change of location of the object during the induction phase as having an impact on the crane's behavior during the test event. Three experimenters were needed to administer this task. One experimenter sat behind a wall (out of view of the infant), and activated the crane using a remote control and moved the cup with the magnet during the induction trial. A second experimenter, hidden by the puppet theater wall (also out of view of the infant), raised the curtain at the start of the trials and lowered the curtain at the end of the trials. The third experimenter sat behind the puppet theater wall at the computer and live-coded the infant's looking time at the scene in order to transition to the next trial after the infant-directed pauses. During the entire administration of this task, no experimenter was visible from where the infant was sitting.

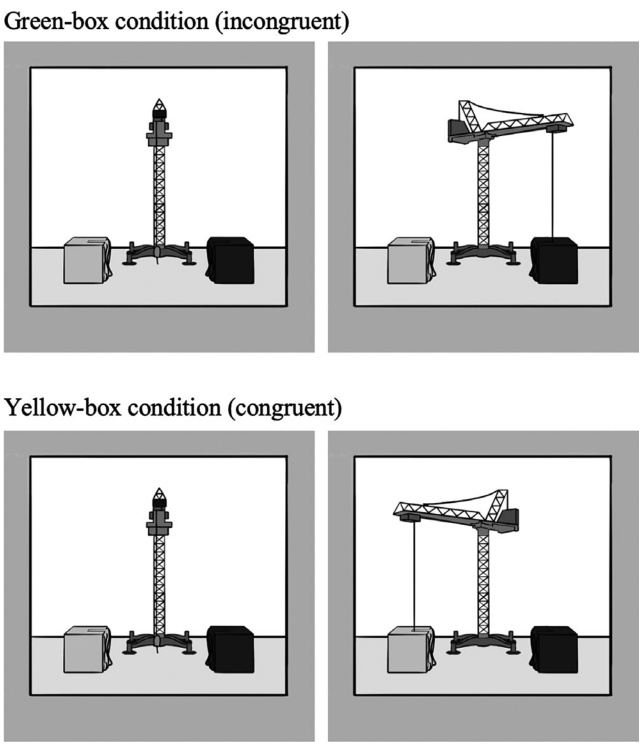

FIGURE 4 Depiction of actions during the test trial for both conditions

2.1.4 | Coding and reliability

Looking time during the infant-directed pauses was live-coded using Habit 2000 (University of Texas) as part of the procedure. To obtain a more precise measurement, infants' looking time was re-coded offline using INTERACT 8.0 (Mangold, 2010). To assess reliability, a second coder who was blind to the hypothesis of the study coded 25% of the video recordings. Cohen's kappa reliability was 0.83.

2.2 | Experiment 2

2.2.1 | Participants

Thirty students (11 males and 19 females, M_{age} = 24.49 years, range = 20.08–35.67 years) were recruited to participate in a manipulation check of the procedure administered to the infants. They were asked to make predictions while watching a pre-recorded video of the VOE paradigm. Participants were students enrolled in Psychology (*n* = 13), Natural Sciences (*n* = 9), Exercise Science (*n* = 2), Engineering (*n* = 2), Business/Finance (*n* = 2), and Other (*n* = 3) in a large Canadian university.

2.2.2 | Procedure and materials

Participants were asked to complete a short demographic questionnaire, including their field of study. Participants were entered in a draw to win one of two $20 prizes. The VOE false belief task viewed by the infant participants in Experiment 1 was filmed. Prior to watching the video, adults were instructed to carefully watch the short video and were told that they would be asked two short questions after the video ended. Adults viewed the three familiarization trials and induction trial—the video ended when the curtain was lifted at the start of the test trial, revealing the crane centered between the two boxes. Participants were then asked to answer 'do you think the crane will go into the yellow box or the green box?' on a sheet and were asked to explain why.

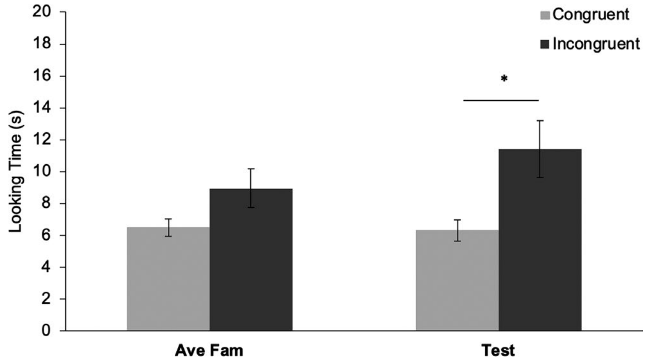

FIGURE 5 Infants' average looking time across the three familiarization trials and at test for both conditions

3 | RESULTS

3.1 | Experiment 1

Using z-scores with cut-offs of ±3.0, one participant's response in the test trial of the congruent condition was identified as an outlier. This score was replaced with the next highest value within three standard deviations of the condition mean. In their review of how to analyze looking-time data, Csibra, Hernik, Mascaro, Tatone, and Lengyel (2016) suggested that raw looking-time scores should be transformed using the logarithmic formula. As such, all analyses were conducted on transformed data, but the raw looking times are reported in text for comparison purposes.

On average, infants in the congruent group looked at the scene for 6.48 s (SD = 2.26) during the infant-directed pauses of the familiarization trials. During these same trials, infants in the incongruent group looked at the scene for 8.97 s (SD = 5.16). To determine if the two groups differed in their attention to the scene, infants' looking time during the infant-directed pauses of the three familiarization trials was analyzed in a 3 (trials) × 2 (group) repeated measures ANOVA. A main effect of trial was observed ($F(2, 68) = 6.42$, $p = .003$, $\eta^2 = 0.16$), and there were no main effect of group or interaction. Post-hoc analyses revealed that infants looked longer during the first familiarization trial (M = 9.61 s, SD = 5.88) than during the second familiarization trial (M = 6.87 s, SD = 4.50, $t(35) = 2.57$, $p = .02$, $d = 0.52$). Infants also looked longer during the first familiarization trial than during the third familiarization trial (M = 6.70 s, SD = 1.13, $t(35) = 2.44$, $p = .02$, $d = 0.46$). Infants' looking time during the second familiarization trial did not differ from their looking time during the third familiarization trial ($t(35) = 0.14$, $p = .89$, $d = 0.03$). Additionally, infants' average looking time during the three familiarization trials did not differ between the congruent group and the incongruent group ($t(34) = 1.47$, $p = .15$, $d = 0.63$). Since the two groups' performance did not differ during the familiarization trials, infants' looking time during the test trial was compared between the two groups. The infants in the incongruent group looked longer (M = 11.43 s, SD = 7.54) than those in the congruent group (M = 6.52 s, SD = 3.38, $t(34) = 2.44$, $p = .02$, $d = 0.89$; see Figure 5). This longer looking indicates that the infants were surprised when the crane turned to the green box (i.e. where the toy cup was actually located) compared to when the crane turned to the yellow box.

3.2 | Experiment 2

Overall, 77% (23/30) of adults predicted that the crane would turn to the green box (binomial p = .005). When asked to justify their predictions, 61% of adults (14/23) said that the crane would turn to the green box because that was where the crane always turned in the familiarization trials. Six (26%) adults responded that the crane's movements were linked to the cup's current location and three (13%) adults provided other answers (e.g. 'it didn't see it go back to the green box').

4 | DISCUSSION

The main goal of the present study was to investigate whether infants behave similarly when an inanimate object replaces a human agent in the false belief VOE task. It was expected that if infants possess a sophisticated psychological reasoning system, similar to that of older children and adults, then they would behave differently across the two conditions, and thus only attribute false belief to human agents. They should therefore not attribute a false belief to an inanimate agent, or display the same looking patterns as in the original task, given that the only animacy cues the toy crane displayed were self-propulsion and goal-directedness—cues that have been found to be sufficient to categorize an agent as alive, but not as sentient. In the present study, infants behaved similarly as in the original experiment with a human agent. In contrast, adults' testimony revealed that they expected the crane to turn to the green box given that this was the only movement the crane had previously exhibited. In other words, adults used a simple associative rule to predict the crane's movements and did not expect it to be guided by a belief about the location of the object following the belief induction phase. This is likely a result of their sophisticated false belief understanding and their advanced understanding of mechanical agents. However, it is important to acknowledge key methodological differences between the VOE task administered to the infants (i.e. implicit with a continuous variable) and to the adults (i.e. explicit with a dichotomous variable)—these two types of tasks do not have the same demands. Future studies should examine adults' spontaneous looking behaviors on this modified VOE task and compare them to infants' responses. To our knowledge, only one study has administered VOE false belief tasks to adults (Low & Edwards, 2018). After being exposed to the agent's actions, adults were either assigned to a mental-state tracking group (i.e. explain motives, beliefs, or perspectives), an object-tracking group (i.e. explain location), or a neutral group (i.e. explain events). Only the adults in the mind-tracking group provided explicit references to mental states. These results indicate that adults did not implicitly process the VOE task as a mental-state task—it was only when they were instructed to do so that they referred to mental states in their narratives. It would be interesting for future research to replicate and extend this procedure by replacing the human agent with the mechanical crane. Further, Santiesteban et al. (2014) investigated adults' mental state attribution with a Dot Perspective Task. In this task, adults were asked to report how many dots they could see (self-task) and how many dots the avatar could see (other task). This task included consistent (i.e. same number of dots visible to the participant and to the avatar) and inconsistent trials (i.e. the participant can see more dots than the avatar can). Santiesteban et al. (2014) compared a condition with a human avatar to a condition with an inanimate object (i.e. an arrow). Adults' performance did not differ across the two conditions—adults were slower in the inconsistent trials for both conditions. The authors suggested that the results yielded in these tasks might reflect submentalizing. However, the toy crane used in the present study, unlike arrows, possessed agentive features (i.e. similar to the Heider and Simmel (1944) geometric figures). As such, the self-propulsion and goal-directedness exhibited by the toy crane may explain why infants attributed mental states to this inanimate agent.

The main contribution of the present study was to demonstrate that infants' looking pattern in Onishi and Baillargeon's (2005) VOE false belief task was replicated using an inanimate agent. The 16-month-old infants did not expect the crane to turn towards the green box as it had done in the familiarization trials and were surprised when the crane turned towards the new location of the toy cup in the test trial. These results are in line with Surian and Geraci's (2012) findings using an anticipatory looking task with animated geometrical shapes that showed agency cues of goal-directed and interactive behaviors. An important difference between our toy crane and Surian and Geraci's (2012) blobs is that the crane only displayed self-propulsion and goal-directed action, while the blobs displayed goal-directed action and contingent communication with another agent. As previously mentioned, communication is an important aspect of ToM attribution in explaining Surian and Geraci's (2012) results, as well as Tauzin and Gergely's (2018) findings, which are in line with the relevance theory (Sperber & Wilson, 1995). The VOE task in the present study did not involve such communicative feature. There is evidence that infants reason about the actions of inanimate agents, such as boxes and geometric shapes, by attributing goals to such agents (Baillargeon et al., 2016). Such overattribution of motivational states has been previously reported in an experiment demonstrating that even 3-month-olds attribute goal-directed actions to a self-propelled box (Luo & Baillargeon, 2010).

One interpretation of the current results is that infants attribute false belief to any object that displays agentive features—in the present case, an object that appears to be capable of autonomous movement and that acts in a 'goal-directed' manner (Luo & Baillargeon, 2005). This interpretation is compatible with System 1 of Apperly and Butterfill's (2009) two-system theory. System 1 is inflexible because it is 'efficient, evolutionarily and ontogenetically ancient, operates quickly, and is largely automatic and independent of central cognitive resources' (Low, Apperly, Butterfill, & Rakoczy, 2016, page 185). We argue that our results are in line with this inflexible system as infants automatically attribute mental states to all agents. It is only later, by preschool years that they employ the flexible system (i.e. System 2) and only attribute mental states to sentient agents (Low et al., 2016; Opfer, 2002; Poulin-Dubois & Héroux, 1994; Wellman, Cross, & Watson, 2001). It has recently been proposed that key processes in constructing a flexible understanding of belief are social and mental coordination with other persons and their (sometimes conflicting) perspectives (Tomasello, 2018). False belief understanding requires engaging in social and mental coordination and involves shared intentionality (developed joint attention, linguistic communication) as well as well-developed executive functioning skills that permit such coordination. According to this shared intentionality account, in implicit tasks, infants are tracking simple epistemic states (e.g. knowledge). Knowledge attribution is a simpler ToM construct that is typically mastered earlier in infancy (Moll, Koring, Carpenter, & Tomasello, 2006; Moll & Tomasello, 2007; Tomasello & Haberl, 2003). Our findings are compatible with such a leaner mentalistic view but specify that infants are less selective than older children and track the epistemic states of all agents indiscriminately. One would expect that rich social experience would allow children to gradually narrow the scope of attribution of mental states to the animate agents with which they interact such as people, and animals. However, this account should be tested across the lifespan to investigate the context in which System 1 operates in adulthood, as well as the context when System 2 overrides System 1 (e.g. Low & Edwards, 2018; Silva, Ten Hope, & Tucker, 2014 for methodological suggestions). If there is developmental stability in false belief understanding (from implicit to explicit mentalizing) as some longitudinal studies have suggested (Thoermer, Sodian, Vuori, Perst, & Kristen, 2012; Sodian et al., 2016; but see Burnside, Azar, & Poulin-Dubois, 2018), then one would expect that infants would deny mental states to inanimate agents when tested with non-traditional false belief tasks based on spontaneous responses.

Another interpretation that is also compatible with the current findings is the perceptual novelty account that posits that infants simply analyze the perceptual, shallow properties of the scene and compare these across the familiarization and test trials. According to this submentalizing account, the last time infants saw the crane (during the first part of the induction trial) it was associated with the object located in the yellow box, so the incongruent test event is the one that differed most from the last 'crane event' encoded (Heyes, 2014b). Such novelty effect most probably did not impact the reasoning of adults, as they instead used their conceptual knowledge to infer that toys do not mentalize. Thus, they ignored the belief induction trial and used a simple rule, such as 'the crane always turns to the green box'. Unfortunately, the design of the current study does not allow us to tease apart the various accounts that explain infants' looking behaviors in the VOE paradigm. Therefore, the current results cannot conclusively demonstrate whether infants operate with submentalizing or some form of mentalizing abilities in such task—more research is needed to determine which mechanisms underlie infants' behaviors in the VOE task. Future research is also needed to determine how infants interpret the crane (i.e. as an agent or as an inanimate object) by testing infants' responses to the crane in contexts that require, for example, gaze following or communication.

In order to control for experience with self-propelled inanimate agents, we selected infants with no exposure to any type of remote-controlled toys. Future research should directly compare infants with previous exposure to a remote-controlled toy to 'naïve' infants. If a better understanding of mechanical agents does in fact affect individuals' performance, then one would expect a difference in performance between these two groups. Unfortunately, the current sample was not large enough to adequately compare and interpret these two groups' performances. It would also be interesting to use a within-subjects comparison where infants would be administered a task with a human agent and a task with an inanimate agent to directly investigate if the same infants behave differently across agents. We also recommend future research that would adopt the same design with other implicit tasks that are commonly used to assess false belief in infancy in order to determine whether the same patterns of results are replicated when using a nonhuman agent.

To conclude, the purpose of the current study was to examine whether infants attribute false beliefs to inanimate agents in the VOE paradigm given that most studies investigating false belief attribution to inanimate agents were conducted using the anticipatory looking task (e.g. Kano et al., 2017; Surian & Geraci, 2012); only a single study used a looking time task (e.g. Tauzin & Gergely, 2018). These studies yielded conflicting findings. When the anticipatory looking paradigm was used with apes, they behaved differently when a geometric shape performed the actions in the change of location task, that is, they did not anticipate an arrow to act as knowing the new location of a displaced object. In contrast, by 17 months, infants attributed false belief to a simple animated shape (Surian & Geraci, 2012). It is possible that adult apes may possess a different concept of false belief than human infants (see Heyes, 2017 for critical comments on the original findings) or that the anticipatory looking procedure is a more conservative test of false belief. More likely, the presence of contingent interactions between the stimuli in Surian and Geraci's (2012) study might have been sufficient to trigger their psychological reasoning system given that the communication of ostensive cues is critical in ToM understanding. It is possible, as some researchers have suggested, that infants process the visual elements of the scene in the VOE task rather than interpret the storyline with regards to the agent's beliefs. If this is the case, then the properties of the agent are irrelevant as infants submentalize when exposed to such scenarios. In the present case, infants appear to be able to generate rapid, online predictions of agents' actions toward objects based on their prior actions. Nonetheless, these submentalizing or 'overmentalizing' abilities might provide the building blocks for the development of a sophisticated ToM. With the development of language and executive functions, paired with experience interacting with others, infants will gradually narrow down their concept of a sentient agent. Some outstanding questions are: which mechanism underlies infants' behaviors during implicit tasks (i.e. overmentalizing, submentalizing, simple behavioral rules) and under what conditions (i.e. which agents) do infants display these behaviors? Much remains to be done to better understand how infants' ability to reason about others' mental states improves with age.

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