COGNITIVE SCIENCE
A Multidisciplinary Journal

Cognitive Science 46 (2022) e13087

ISSN: 1551-6709 online
DOI: 10.1111/cogs.13087

Infants' Attributions of Insides and Animacy in Causal Interactions

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Received 19 March 2021; received in revised form 7 December 2021; accepted 15 December 2021

Abstract

Past work has found that infants show more interest when an object that has at least two properties of animate beings, such as engaging in self-generated motion and having fur, is shown to be hollow than when an object with none or one of these properties is revealed to be hollow. When an object is grabbed by a hand and moved to a new place, by 7 months of age, infants explain the motion of the object as due to the hand, and thus do not interpret this object as capable of self-generated motion. This constant application of force is called an "entraining" event. Other work has found that 6-month-old infants are sensitive to the reversals of causal roles in "launching" events (billiard-ball-like collisions), but not entraining events. Here, we examine whether 10-month-old infants explain the motion of the patient in a launching event as being due to the contact with the launching agent. Experiment 1 replicates past work, showing that infants look longer when a self-propelled object with animate features (fur or feathers) is shown to be hollow, compared to a similar object undergoing spatiotemporally identical motion entrained by a human agent. Experiment 2 finds that infants look equally at the agent and patient, both covered by fur or feathers, of a launching event when each is revealed to be hollow. Experiment 3 shows that infants look longer when a fur-covered causal patient is shown to be hollow compared to a plain-box causal agent, indicating that 10-month-old infants do not explain the motion of the causal patient of a launching event as due to the agent, even though they do so for an entraining event. This dissociation suggests the existence of multiple independent causal representations in the first year of life.

Keywords: Cognitive development; Causality; Animacy; Agency; Infant

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1. Introduction

Early in life, infants are sensitive to causal interactions within events. By 3 months, infants distinguish between interactions with and without contact, showing surprise if the interaction results in a state change in an object approached intentionally by a human without contact (Liu, Brooks, & Spelke, 2019), and by 6 months, they have a rich understanding of contact causality in which one object hitting another causes the latter to go into motion (Kominsky et al., 2017; Leslie & Keeble, 1987; Cohen & Amsel, 1998; for review, see Saxe & Carey, 2006).

Infants' representation of causality is deeply connected to their early-developing ability to distinguish between animate agents and inert objects. This distinction supports myriad inferences and expectations about events in the world. Infants have different expectations regarding agents and inert objects with respect to intentionality, interpreting the actions of animate agents as goal-directed (e.g., Woodward, 1998) and having communicative intent (e.g., Johnson, Slaughter, & Carey, 1998). Furthermore, very young infants use many different surface features to identify animate agents, such as presence of eyes, faces, body covering, animal-like locomotion, body parts, and the capacity for self-generated motion (Adam, Reitenbach, & Elsner, 2017; Di Giorgio, Lunghi, Simion, & Vallortigara, 2016; Frankenhuis, House, Barrett, & Johnson, 2013; Kuhlmeier, Bloom, & Wynn, 2004; Spelke, Phillips, & Woodward, 1996; Surian & Caldi, 2010; Woodward, Phillips, & Spelke, 1993).

Many have argued that infants' early understanding of causality and their understanding of animate agency are one and the same. On this theory, infants initially understand causality only within the context of animate agents acting on their environment (Hohenberger et al., 2012; Meltzoff, Waismeyer, & Gopnik, 2012; Piaget, 1930; Piaget & Garcia, 1977). The interconnection between infants' attributions of causality in a particular situation and their representations of animate agency has been established in many paradigms. For instance, by 7–10 months of age, infants infer unseen animate agentive causes for the motion of inanimate objects. If they see an inanimate object fly out from behind an occluder, they expect to find a hand, but not another inanimate object, behind that occluder. However, they have no such expectations when the flying object has the features of a dispositionally animate agent (fur, eyes, and legs), indicating that they expect that it could have propelled itself from behind the occluder (Saxe, Tenenbaum, & Carey, 2005; Saxe, Tzelnic, & Carey, 2007).

Consistent with a close relationship between the representations of causality and animacy, infants seem to have no trouble "explaining" the motion of an object if that movement occurs while it is in continuous contact with an obvious dispositionally animate agent, like a human hand (Setoh, Wu, Baillargeon, & Gelman, 2013; Träuble & Pauen, 2011). Events such as these are called "entraining," and for adults, such events are seen as causal even if the agent is not unambiguously animate (Michotte, 1946/1963). In fact, Michotte offered an account of the origin of causality in which representations of animate agency play no role. He proposed an innate, modular (Fodor, 1983) input analyzer that identifies events in which the movement of one object is completely determined by a physical collision with another object, such as the entraining event shown in Fig. 1a or the launching event shown in Fig. 1b. According to Michotte's view, this perceptual representation of causality is the precursor to causal

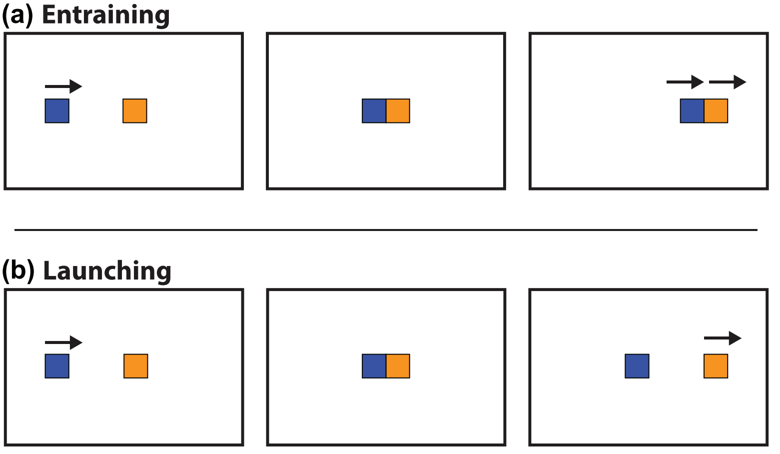

Fig 1. Schematics of classic Michottean "entraining" (a) and "launching" (b) events. In entraining, one object moves until it makes contact with the other, at which point they remain in contact and move together. In launching, the first object stops at the point of contact, while the second object immediately begins moving in the same direction.

representations of other kinds of causal interactions that do not involve motion or collision, which are subsequently constructed by analogy to launching/entraining.

The literature following Michotte has delved deeper into this phenomenon of "causal perception." The vast majority of studies in this literature have focused on a specific type of perceived causal interaction: the launching event (Michotte, 1946/1963; Scholl & Tremoulet, 2000). In a launching event, an object A initiates its own motion and moves toward a stationary object B until they are adjacent, at which point object A stops and object B begins to move in the same direction and roughly the same speed. This event is shown in Fig. 1b, and both of these events can be found animated at https://www.jfkominsky.com/demos.html. Readers are encouraged to view these events in animated form, to appreciate the irresistible impression that object A causes object B to move, and that the motion of object B can be completely explained by the collision with object A. Michotte (1946/1963) considered both launching and entraining events equally to fall under an innate schema in which the motion of the causal patient is completely caused by the motion of the situational causal agent upon contact.

Launching has been studied much more in infancy than has entraining. In adults, the perception of causality in launching events depends on a strict set of spatiotemporal constraints (e.g., Choi & Scholl, 2006a; Michotte, 1946/1963). Infants distinguish causal launching events from events that violate those same constraints starting at 6 months of age (Cohen & Amsel, 1998; Newman, Choi, Wynn, & Scholl, 2008). Put simply, infants distinguish causal launching events from events in which the movement of object B occurs at the wrong time (either before or after contact), or events in which the objects do not come into contact at all. Both infants and adults are even sensitive to the real-world Newtonian constraints that apply to these sorts of elastic collision events, but *only* when the collision has the spatiotemporal parameters of causal launching (Kominsky & Carey, 2018; Kominsky et al., 2017). Infants also seem to be sensitive to *situational* causal roles in launching events, that is, if they are habituated to square A launching square B, they will dishabituate strongly to B launching A, but they will not dishabituate to the reversal of a non-causal event (Leslie & Keeble, 1987; Bélanger & Desrochers, 2001).

While infants very clearly represent launching as causal in at least these respects, the literature presents contradictory evidence on whether they understand entraining as the same kind of causality, as Michotte's (1946/1963) account of the origins of causal representations would predict. One early signature of launching causality, sensitivity to Newtonian constraints, cannot be applied to entraining in the first place, as there are no analogous universal Newtonian constraints that apply to entraining events where the two objects remain in contact (requiring either a very inelastic interaction or a constant application of force). Six-month-old infants are unable to track situational causal roles in entraining events between arbitrary objects, as they are able to do with launching (Bélanger & Desrochers, 2001). There is convergent evidence from psychophysics work with adults for a distinction between representations of launching and entraining within perceptual processing. Experiments reveal retinotopically specific visual adaptation to the causality of launching events (Rolfs, Dambacher, & Cavanagh, 2013). Kominsky and Scholl (2020) showed adaptation transfer between different causal launching events (e.g., an event in which A does not fully stop at contact but continues forward at reduced speed will adapt standard launching), but adapting to entraining events has no effect on the perception of launching. That is, at this early, retinotopically mapped stage of visual processing, entraining and launching are not the same kind of "cause."

To be clear, there is evidence that infants do understand entraining events as causal, particularly when the causal agent is a hand. When infants see a hand and an ambiguous agent (a fur-covered object with eyes) moving together in an entraining event, they attribute the motion to the hand, but when they see an ambiguous agent and a clear artifact (a ball) moving together, they attribute the motion to the ambiguous agent (Träuble & Pauen, 2011). Notably, this is a different kind of measure than most of the studies of launching discussed above. Rather than examining infants' reactions to changes in the parameters of the event itself, this study examined infants' attributions about the source of motion of the objects in the event, and their inferences about the dispositional or intrinsic properties of the objects (i.e., which ones are animate agents; see also Setoh et al., 2013).

While infants explain the motion of the causal patient in an entraining event as due to the motion of the causal agent, it is unclear whether they do the same for the patient of a launching event. In principle, one would think they should. In the classic launching event, object A initiates its own motion, that is, is self-propelled, while the movement of object B can be completely explained by the collision with object A. Thus, one would think, infants should treat object A as the source of motion for both objects, and treat it as a dispositional animate agent and object B as a dispositional inert object, just as they do in cases where a hand grabs and moves an object around. One study has provided evidence that launching innately supports attributions of animacy, at least in chickens (Mascalzoni, Regolin, & Vallortigara, 2010). In this work, chicks are raised in an environment in which their visual input is carefully controlled. In particular, chicks in this experiment saw a launching event between two objects of different colors, with one color consistently the situational agent and the other the situational patient. Importantly, the motion of each object was strictly equated: each went from rest to motion and then stopped abruptly after travelling the same distance. Mascalzoni et al. reported that the chicks imprinted on the causal agent of the launching event, that is, they spent more time with an object the color of the agent than one the color of the patient, when given access to the two objects, suggesting that they used its role in the launching event to identify it as more likely to be "Mom." However, while this provides indirect evidence that chicks explain the motion of the causal patient as due to that of the launching agent, this result has failed to replicate (Wood & Wood, 2019). Further, the nature of the evidence gives little insight into whether human infants would make the same attributions. Even if replicable, this finding may reflect a specific adaptation within the imprinting mechanism of chicks.

As for our own species, there is evidence that human infants may explain the motion of causal patients in some launching events, when the causal agent is a human being. Luo, Kaufman, and Baillargeon (2009) found that 5-month-old infants expect that an object launched *by a hand* will not be able to change direction of its own accord, that is, is not capable of self-propelled movement. Infants in this study were shown an object move behind an occluder and then return, after being launched by a human hand. Infants looked longer when the occluder was dropped and they were shown the launched object changing direction spontaneously in order to return, rather than bouncing off a wall. Notably, this apparent expectation that a launched object is inert was reported at 5 months of age, which is before infants seem to understand launching between geometric objects as causal (Cohen & Amsel, 1998; Desrochers, 1999), making it difficult to determine whether this event was truly understood by these infants as "launching" at all.

In short, there is only tenuous evidence that infants explain the movement of a causal patient in a launching event as caused by the motion of the launching agent, or that they regard the situational agent as a dispositionally animate agent and the patient as dispositionally inert. Furthermore, there is some direct evidence that infants do not make these dispositional attributions in launching events, at least in the first year of life. Cicchino, Aslin, and Rakison (2011) found that 10-month-old infants look equally long when the situational agent and situational patient of a launching event are subsequently shown to be self-propelled. By 14 months, infants show a violation of expectancy effect if the causal patient moves in a self-propelled manner, but not if the causal agent does so. These findings suggest that 10-month-old infants do not explain the motion of the causal patient as due to the collision with the causal agent, but that by 14 months of age, children do so.

How can it be that infants so readily explain the motion of a causal patient and make dispositional attributions in entraining events, but may not do so in launching events at the same (or even older) age? This apparent contradiction relies on an implicit assumption, which we make explicit and call into question: that the causality of launching events and the causality of entraining events are the same underlying "causality" in the infant mind. If there is an integrated causal representation that is shared by both events, then infants should be able to make the same causal inferences from each event they recognize as causal. However, if not, then inferences supported by one kind of causal event might not be supported by the other, even if there is reason to think that each one is represented as a cause-and-effect interaction in other ways. Specifically, entraining may be represented in a way that supports attributions about the dispositional properties of an object based on whether it is or is not the source of motion, while launching may be represented in terms of the physical dynamics of the event itself, supporting sensitivity to situational roles and Newtonian constraints.

1.1. The current experiments

Here, we seek to test whether infants make different dispositional attributions to entities within launching and entraining events based on the entities' causal roles. To do this, we use a paradigm first employed by Setoh et al. (2013) to study a different question: whether infants expect animate agents to have something inside them. Setoh and colleagues found that 8-month-old infants expected an object that had *at least two* cues to being a biological animate agent was expected to have something inside it, and showed a violation of expectancy effect if it was revealed to be hollow. They tested three cues in different combinations. One cue was whether the object had the surface features of real-world biological agents, in particular whether the object was covered in fur. A second cue was whether the object had a contingent interaction with a human experimenter, that is, whether a human interacted with it like a social agent. A third cue was whether the object engaged in self-propelled motion. They contrasted puppets that had two of these cues to puppets that had one or zero of these cues, and found that infants looked longer when the puppets with two cues to animate agency were revealed to be hollow.

The way Setoh et al. (2013) manipulated the cue of self-propelled motion is of particular interest for our purposes. In their Experiment 3, they contrasted a fur-covered puppet with a puppet that had no fur. One group of infants saw both puppets moving in an apparently self-propelled manner (spontaneously going from rest to motion and changing direction) back and forth across a stage, and then both were shown to be hollow. In this case, infants looked longer when the fur-covered puppet was shown to be hollow than when the furless puppet was shown to be hollow, indicating that self-propelled motion and fur together made up two cues to animate agency. Another group of infants saw both puppets being moved back and forth across the stage in the exact same way, while in constant contact with the hand of a human experimenter. While Setoh et al. (2013) did not label it as such, this is a clear example of an entraining event, and infants were expected to explain the motion of the puppet (the causal patient) as being produced by the human actor. Therefore, the puppets in this condition were not seen as self-propelled, and infants looked equally when both puppets were shown to be hollow, showing that fur alone was not sufficient to support this "insides" attribution.

Using the basic paradigm of Setoh et al. (2013)'s Experiment 3, we test whether 10-month-old infants make this dispositional "insides" attribution based on entraining events and launching events and in particular whether they explain the motion of a situational causal patient in each event as produced by the causal agent. Alternatively, infants may be unable to make such dispositional attributions in launching events despite both making these dispositional attributions on the basis of causal roles in entraining events at 8 months of age (Setoh et al., 2013), and in spite of showing clear sensitivity to causal launching at 6 months of age (Cohen & Amsel, 1998; Leslie & Keeble, 1987).

In Experiment 1, we conducted a conceptual replication of Setoh et al. (2013)'s Experiment 3, but testing a within-subjects comparison that was absent from the original paper. We showed 10-month-old infants two puppets with features of biological agents (one covered in fur and one covered in feathers), one of which was shown to be self-propelled, while the other was entrained by a human actor (which was manipulated between-subjects in the Setoh et al.'s experiment, and within-subjects here). We predicted that infants would look longer when the self-propelled puppet, which has two cues to animate agency, was revealed to be hollow, compared to the entrained puppet, which only had one. The goal of this experiment was to validate that infants would make distinct dispositional attributions based entirely on whether a puppet's motion was explained by an entraining agent's motion.

In Experiments 2 and 3, we tested whether the motion of the causal patient of a launching event is similarly explained as caused by the launching agent. If so, infants should not regard the causal patient as self-propelled, and should look longer when the causal agent (which shows a spontaneous motion onset) is revealed to be hollow than when the causal patient is.

2. Experiment 1

Experiment 1 had two goals. First, we sought to provide a conceptual replication of Setoh et al. (2013), to provide convergent evidence that infants are surprised when an object construed as an animate agent is hollow. Second, we tested a direct contrast that was absent from Setoh et al. (2013). The within-subjects contrast in Setoh et al. (2013) was always between a fur-covered object and a plain box, with both objects exhibiting the same behavior (either both self-propelled or both entrained, between-subjects). In this experiment, the within-subjects contrast directly examined causal status as a cue: Both objects had visual features of animate agents (fur or feathers), but one initiated its own motion and changed directions without any outside intervention (i.e., appeared self-propelled), while the other was entrained by a human actor. Under Setoh et al.'s analysis, the self-propelled object has two cues to animate agency (self-propelled motion and surface features). In contrast, if the motion of the entrained patient is explained by the motion of the entraining agent, then the patient object has only one cue to animacy (surface features). As reviewed in the introduction, Setoh et al. found that infants expected only objects with *at least two* cues to animate agency to have internal sources of motion. Thus, infants should show greater interest when the self-propelled object is shown to be hollow, compared to when the entrained object is shown to be hollow.

2.1. Methods

2.1.1. Participants

Based on the results of a pilot experiment, we preregistered (https://osf.io/xu4gn) and recruited 16 9.5- to 11.5-month-old infants (9 boys; mean age 10 months 4 days; range 9 months 21 days to 11 months 3 days) from the greater Boston area through publicly available birth records. Families were contacted by an initial mailing and could then sign up to

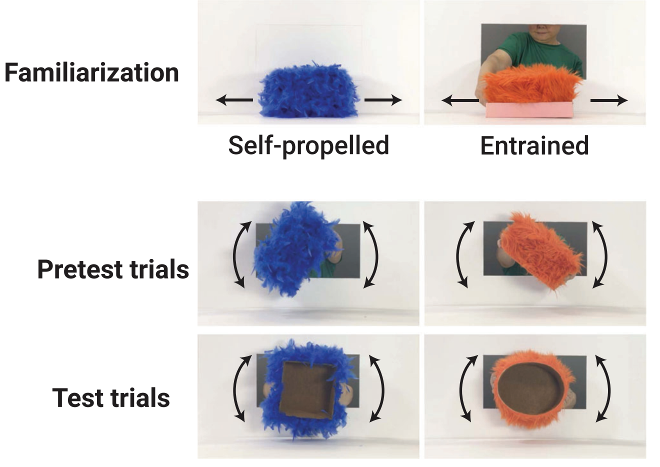

Fig 2. Stimuli used in Experiment 1. All videos were presented sequentially. Half of the participants saw the blue object moving in a self-propelled manner and the orange object being entrained, as shown here, while the other half saw orange object move in a self-propelled manner and the blue object being entrained.

be contacted for research studies. This yielded a generally middle-class population with two college-educated parents, often with higher degrees. Families received $5 for travel reimbursement and their choice of a toy as compensation. An additional four infants participated but were excluded due to fussiness ($n = 2$), procedural errors ($n = 1$), or reliability coding based on pre-registered exclusion criteria ($n = 1$; see below).

2.1.2. Stimuli

Stimuli consisted of video-recordings of two puppets moving and interacting with an actor on a stage. The stage consisted of a white foam board floor and a white foam board back wall, and all videos were shot such that only these areas were visible (Fig. 2). The back wall (55 cm high × 94 cm wide) had a window cut in it (25 cm × 48 cm) that could be closed by an identical piece of foam board, or open with an actor visible. The floor of the stage had a track (3.5 cm wide × 48cm long) running parallel to the back wall, 15 cm away from it. There were two puppets. One was a rectangular box (15 cm high × 22 cm long × 22 cm wide) covered with blue feathers. The other puppet was an elliptical cylinder (13 cm high × 26 cm longer diameter × 24 cm shorter diameter) covered with bright orange fur. Both puppets' interiors were lined with identical tan felt.

We filmed four videos for each puppet (eight videos total, of which each participant saw four, see below): A "self-propelled" familiarization, an "entrained" familiarization, a pre-test trial, and a test trial (see Fig. 2; All stimuli can be found at https://osf.io/xu4gn). In the self-propelled familiarization video, the puppet was shown starting at rest in the center of the stage for 1.5 s, at which point it began moving to the left at 4.5 cm/s. On reaching the end of the stage, it immediately began moving in the other direction at the same speed. In the full video, it goes from center to left, and then from left to right and back twice, before ending up in the center. The whole sequence took 39 s. In the entrained familiarization video, the puppet was seen resting in a pink tray (7 cm high × 29 cm long × 33 cm wide), and the stage window was open, showing an actor in a green shirt whose eyes were not visible (see Fig. 2).

The actor reached through the window and grabbed the side of the tray, and then proceeded to move the object at the same speed and in the same manner as the movement as the self-propelled familiarization video, for the same amount of time.

In the pre-test videos, the actor reached through the window with both hands and picked up each puppet, and then tilted it to the left and right several times, but never showed the underside of the puppet. The actor then put the puppet down. Each video was 14 s long, but was presented in a loop until the infant lost interest (see procedure). The goal of presenting each of these videos until the infant lost interest was to show the infant the actor interacting with each puppet, since at this point in the procedure, they had not seen the actor on-screen with the self-propelled puppet. Thus, these trials ensure that infants' responses to the test trial were not just a result of the human interacting with the self-propelled puppet for the first time. All infants met the look-away criterion before they proceeded to the test trials.

The test trial videos were identical to the pre-test videos, except that immediately after picking the puppet up, the actor rotated the puppet to show its interior, which was always empty. The added rotation made the test trial videos slightly longer, at 16 s. The test-trial videos were also looped until the infant looked away.

2.1.3. Apparatus and procedure

The experiment was presented and data recorded with PyHab (Kominsky, 2019), an add-on for PsychoPy (Peirce et al., 2019). The PyHab experiment folder can be found at https://osf.io/xu4gn. Participants sat on their caregiver's lap approximately 135 cm from a 68 cm × 38 cm LCD screen embedded in a black panel, surrounded by curtains. A hidden camera was located under the screen. The experimenter sat behind the screen and observed the infants' behavior from the camera feed on one screen, while controlling the experiment on an adjacent computer. The experimenter pressed a key to present an attention getter at the start of each trial (a looming and rotating yellow rectangle accompanied by a rising chime), and then held down a key while the infant was looking at the screen, and released the key whenever the infant was not looking at the screen. PyHab controlled when each trial ended, and an experimenter window on the computer (invisible to the participant) informed the experimenter that the trial had ended so that they could present the attention getter for the next trial. Notably, the experimenter could not see the stimulus display, and was blinded to the counterbalancing (see below), so at no point did the experimenter know which video the infant was watching on any given trial.

All stimuli were presented sequentially, so no more than one video was presented at any given time. Participants first saw two familiarization trials in which one of the puppets was shown to be self-propelled and the other entrained. For each familiarization trial, the 36-s video was played from start to end once, regardless of infants' looking behavior, and then a still image of the last frame was presented on the screen until the infant either (a) looked away for two consecutive s or (b) 60 s had passed, whichever came first. Which puppet was self-propelled versus entrained, and the order of presentation, was counterbalanced between participants, and which participant saw which of these counterbalanced presentations was randomized prior to the start of data collection.

After the familiarization trials, participants saw the two pre-test trials, followed by the two test trials. The order of the pre-test and test trials was matched to the order in which the puppets had been presented, for example, if the orange puppet was shown first during familiarization, it was also shown first during pre-test and test. The videos for both the pre-test and test trials were looped until the trial ended. The pre-test and test trials ended when the infant either (a) looked away for two consecutive seconds after looking at the display for five cumulative seconds or (b) 60 s had passed from the start of the trial. Notably, this meant that in each pre-test and test trial, the video for that trial was presented on a loop for up to 60 s or until the infant lost interest.

2.1.4. Reliability coding

To verify the accuracy of the live coding, all videos were coded independently by a second coder, also blind to condition. We pre-registered criteria for exclusions on the basis of unreliable coding as follows: if there was a difference in looking duration of greater than 10% between the two codings for a test trial, that participant would be excluded from analyses and replaced. The 10% threshold was defined as 10% of whichever looking time was longer, for example, if the one coder recorded a test trial looking time of 15 s, and the other coder recorded a looking time of 13.6 s for the same trial, that would not lead to an exclusion (difference of 1.4 s and a threshold of 1.5 s), but if the difference was between 15 and 13.2, it would lead to an exclusion. Looking times to the familiarization and pre-test trials were not considered in determining exclusions. One participant was excluded from analyses and replaced based on these criteria in this experiment.

2.2. Results

2.2.1. Pre-test trials

A two-tailed paired-samples t-test examined whether infants looked longer when the agent picked up the self-propelled object and rotated in from side to side than when she did so to the entrained object. There was a small but non-significant effect, $t(15) = 2.10$, $p = .053$, Cohen's $d = .43$. Looking times to the self-propelled object ($M = 34.32$ s, $SD = 14.63$) were qualitatively, but not quantitatively, longer than to the entrained object ($M = 27.55$, $SD = 16.77$). All infants had met the look away criterion before moving on to the test trials, suggesting that the pre-test trial served the intended purpose of making infants equally familiar with the agent picking up the self-propelled and entrained objects.

2.2.2. Test trials

The results of the main analysis can be found in the leftmost column of Fig. 3. The pre-registered (https://osf.io/xu4gn) primary analysis was a straightforward two-tailed paired-samples t-test comparing how long infants looked at the test trial for the self-propelled object and the test trial for the entrained object, collapsing across order and object identity. In spite having become equally bored by an agent interacting with these objects during the

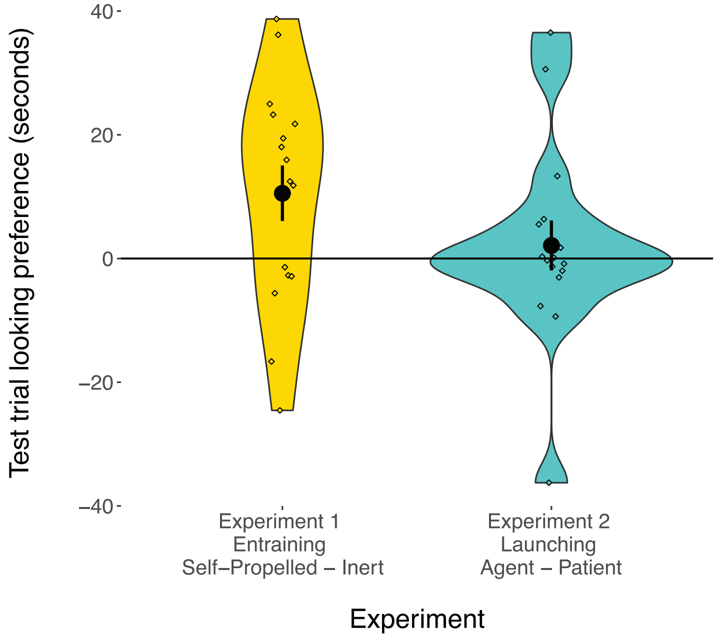

Fig 3. Difference in test trial looking times when objects were revealed to be hollow in Experiments 1 and 2. For Experiment 1, the difference score is: looking time at the object that had been self-propelled during familiarization minus the looking time at the object that had been inert. For Experiments 2 and 3, the difference score is: looking time at the object that had been the agent during familiarization minus looking time at the object that had been the patient. Large dots represent group means, and error bars are ± 1 SEM. Small diamonds are individual participants.

pre-test trials, infants looked significantly longer at the self-propelled puppet when it was revealed to be hollow (M = 33.84 s, SD = 13.91) than the entrained puppet was (M = 23.29s, SD = 13.03), $t(15) = 2.35$, $p = .033$, Cohen's $d = .59$. Pre-registered secondary analyses adding trial order (self-propelled first vs. entrained first) and puppet identity (blue self-propelled vs. orange self-propelled) as between-subjects factors in a linear mixed-model analysis (conducted using R's afex package [Singmann et al., 2019]) preserved the main effect of self-propelled versus entrained test trial, $t(11.99) = 2.41$, $p = .033$, and found no significant interactions, with the interaction between blue test first versus orange test first and self-propelled versus entrained test trial reaching $p = .085$, and all other interactions at $p > .5$.

In short, infants looked significantly longer when a self-propelled puppet was revealed to be hollow, compared to a puppet that was the patient of an entraining event with a human agent. This suggests that they identified the motion of the self-propelled puppet as a cue to animate agency, while explaining the (identical) motion of the entrained puppet as due to the motion of the agent. This both provides a conceptual replication of Setoh et al. (2013) and the first direct test of whether infants make distinct attributions about the insides of a self-propelled object versus an entrained object that are otherwise matched for cues to animate agency.

3. Experiment 2

In both entraining events and launching events, the situational patient goes from a state of rest to motion. Experiment 1 found that 10-month-old infants explain the motion of the patient of an entraining event as being produced by the causal agent, confirming Setoh et al.'s (2013) findings that they are not surprised if the patient of an entraining event is hollow. The new question in this project is whether 10-month-olds would similarly explain the motion of the patient of a launching event as being caused by contact with the moving situational agent. As reviewed in the introduction, some previous work (e.g., Cicchino et al., 2011) would suggest that they would not do so while others (e.g., Mascalzoni et al., 2010) would suggest they should.

Experiment 2 explores this issue using the same paradigm, puppets, and test trials as Experiment 1, but with a launching event as our familiarization. Instead of contrasting a fully self-propelled object with an entrained object, this experiment contrasted a fully self-propelled situational causal agent with a situational causal patient. Infants saw the causal agent spontaneously goes from rest to motion. Of course, they also saw the causal patient goes from rest to motion, but only when contacted by the causal agent. Both objects had the surface features of animate agents (fur or feathers). The question was whether the motion onset of the causal patient would be explained by the contact by the moving launching agent, in which case the patient only has one cue to animate agency. Alternatively, the transition from rest to motion, if not explained by contact by the agent, constitutes a second cue to animate agency and would lead infants to be surprised if the causal patient was revealed to be hollow as well. On the first hypothesis, infants should look longer when the causal agent is revealed to be hollow, compared to when the causal patient is revealed to be hollow, but on the second hypothesis, they should look equally when each object is revealed to be hollow.

3.1. Methods

3.1.1. Participants

We recruited a new group of sixteen 9.5-11.5-month-old infants (6 boys; mean age 10 months 24 days; range 9 months 19 day to 11 months 14 days) who had not participated in Experiment 1. Eight additional infants participated but were excluded from the final sample due to fussiness ($n = 3$) and unreliable coding ($n = 5$), according to the same exclusion criteria as Experiment 1.

3.1.2. Stimuli and procedure

Stimuli, apparatus, and procedure were identical to Experiment 1 with the following modifications: Rather than the two familiarization trials, infants saw only one familiarization trial, consisting of a launching event between the two objects (see Fig. 4, top panel). The video showed both objects at rest for 1 s, at which point the agent object moved toward the patient object at a constant speed for 1 s until they came into contact, at which point the agent object immediately stopped and the patient continued forward at the same constant speed for another second, with the video fading to black before the offset of the causal patient's motion

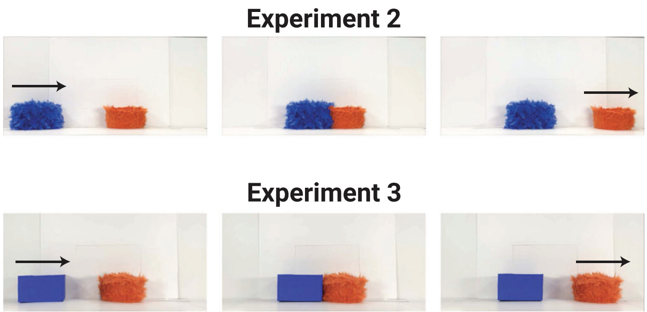

Fig 4. Familiarization sequences used in Experiments 2 and 3. In Experiment 2, which object was the causal agent and which was the causal patient was counterbalanced between participants. In Experiment 3, there were two conditions, but the primary condition of interest involved a plain box launching a fur-covered situational patient, as shown here.

(to prevent the appearance that it was stopping itself). This familiarization video was played on a continuous loop until (a) the participant looked away from the screen for two consecutive seconds after looking for 20 cumulative seconds or (b) 80 s had passed, whichever came first. Which puppet was the causal agent in the launching event, and the order of pre-test and test trials was counterbalanced between participants in the same manner as Experiment 1.

The pre-test and test trials were identical to those of Experiment 1 (Fig. 1), and were looped as in Experiment 1. The infants had not seen the human agent during the launching familiarization and so the pre-trials ensured that infants were familiarized with the agent picking up and rotating each object before the test trials in which the hollowness of each was revealed.

3.2. Results

3.2.1. Pre-test trials

In this experiment, there was no detectable difference in how long infants looked at the pre-test trials for the agent and patient objects, $t(15) = .16$, $p = .87$.

3.2.2. Test trials

The results can be found in Fig. 3, second column, and pre-registered analysis plans at plans at https://osf.io/xu4gn. The primary comparison was causal agent test trial versus causal patient test trial, again analyzed with a paired-samples *t*-test. This analysis found no significant difference in looking times, with infants looking for a similar amount of time when the causal agent was revealed to be hollow ($M = 30.68$ s, $SD = 16.22$) compared to the causal patient ($M = 28.62$ s, $SD = 17.23$), $t(15) = .51$, $p = .62$. Exploratory analyses that included causal agent identity (blue vs. orange) and order of test trials (orange first vs. blue first) found a significant interaction between order of presentation and agent versus patient test trial, $t(44) = 3.37$, $p = .002$. This interaction yields no interpretable effects, as it shows an effect on agent versus patient test trial that changed based on which *color* puppet was presented first at test, regardless of the causal role of that puppet. A post-hoc analysis that recoded the between-subjects factors into a single factor of "agent test first" versus "patient test first," ignoring object identity, found no significant interactions or main effects, *p*s $\geq$ .11.

In short, this experiment found no evidence that infants looked longer when the agent was revealed to be hollow compared to the patient. The results of Experiment 2 converge with the findings of Cicchino et al. (2011) that 10-month-olds do not explain the motion of a causal patient in a launching event as being caused by the situational agent, and find no support for the theory put forward by Mascalzoni et al. (2010). Furthermore, the failure to explain the movement of the causal patient as due to contact by the situational agent in Experiment 2 contrasts sharply with the results of a few previous studies that found that infants *do* seem to explain the motion of the patient of an entraining event as due to the motion of the agent (Setoh et al., 2013; Träuble & Pauen, 2011; the present Experiment 1).

There are two possible interpretations for equal looking at the situational agent and the situational patient when each was revealed to be hollow. First, infants may have had an expectation that *both* objects had insides, based on the fact that each has two cues of animate agency, namely, that each has the visual features of animate agents and each was seen going from rest to motion (as we have suggested), or second that the evidence that the causal *agent* was self-propelled was insufficient in the launching events, and so, they expected *neither* object to have insides (as each would only have had one cue to being an animate agent). In Experiment 1, infants were provided with more evidence for self-propelledness than in Experiment 2. In Experiment 1, the self-propelled object visibly went from rest to motion on its own, *and spontaneously* changed direction. In Experiment 2, only the motion onset cue was available. Experiment 3 seeks to decide between these two interpretations of the results of Experiment 2.

4. Experiment 3

The goal of this experiment was to more definitively test whether infants explained the motion for the causal patient of a launching event to the causal agent, and thus not expect the causal patient to have insides. To do this, we introduced a second contrast already shown to be related to the "insides" attribution, namely, the presence or absence of surface features of animate agents (fur or feathers). We created a new set of events involving a plain box, which infants do not expect to have an insides even when fully self-propelled (Setoh et al., 2013), and familiarized infants with events in which it either launched or was launched by a fur-covered puppet.

The two hypotheses as to why infants might not have differentiated the agent object from the patient object in Experiment 2 make conflicting predictions for the outcome of Experiment 3 (diagrammed in Fig. 5). First, if infants do not attribute the causal patient's motion to the collision with the causal agent, then they should simply look longer when the fur-covered object is revealed to be hollow regardless of whether it is the agent or patient of the launching event, since in both cases, it is a fur-covered object going from rest to motion. Under this hypothesis, there are two cues to animate agency for the fur covered object (fur and going from rest to motion) and only one for the plain box (going from rest to motion; Fig. 5, left panel). Second, if merely going from rest to motion, and being the causal agent of a launching

Fig 5. Predicted patterns of mean difference in looking time to the fur-object test trial and the plain-box test trial in Experiment 3, for three different hypotheses (see text). The left dot in each panel is the predicted fur test trial minus box test trial difference in the condition where the box is the causal agent and the fur object is the causal patient, and the right dot in each panel is the predicted difference in the condition where the fur object is the causal agent and the box is the causal patient.

event, is insufficient evidence for self-propelled motion, then there should be no difference in looking times when either object is shown to be hollow because neither has two cues to animate agency. Rather, on this hypothesis, the only cue to animate agency in this launching event is the presence of fur on one of the objects (Fig. 5, middle panel).

Of course, there is also a third possibility, which is that we fail to replicate Experiment 2, and infants explain the motion of the causal patient in this launching event as being caused by the agent. Under this hypothesis, the transition from rest to motion of a fur-covered causal patient is *not* a cue to animate agency because that motion is explained by the launching collision. Thus, on this hypothesis, only the fur-covered *causal agent* has two cues to animate agency, and infants should look longer when the fur-covered object is revealed to be hollow only in the case where the fur-covered puppet launches the plain box (Fig. 5, right panel).

4.1. *Methods*

4.1.1. *Participants*

We recruited a new group of 32 9.5–11.5-month-old infants (18 boys; mean age 10 months 12 days; range 9 months 19 days to 11 months 15 days) who had not participated in previous experiments. Three additional infants participated but were excluded from the final sample due to fussiness ($n = 1$) and unreliable coding ($n = 2$), according to the same pre-registered exclusion criteria used in Experiments 1 and 2. In addition, we ran one further participant to replace an outlier. One of the participants in the fur-agent condition showed a difference in looking times greater than 2.5 standard deviations from the group mean for that condition on the test trials. No such outlier existed in Experiments 1 or 2, or in the box-agent condition of Experiment 3. We elected to replace the outlier with a new participant, though this decision was not pre-registered. An analysis including the outlier can be found in the Supporting Information.

4.1.2. Stimuli, apparatus, and procedure

This experiment was identical to Experiment 2, but with a new set of videos. Participants were randomly assigned to one of two conditions. In the "box agent" condition, the familiarization video consisted of a plain blue box, the same dimensions as the feather-covered box, launching the fur-covered ellipsoid from the previous experiments (see Fig. 4, bottom panel). In the "fur agent" condition, the familiarization trial consisted of the fur-covered ellipsoid launching the blue box. The speeds and timing were matched to Experiment 2's familiarization videos. The pre-test and test trials were also re-recorded with the new objects, following the timing of the videos used in previous experiments. The launching familiarization videos, the pre-test videos, and the test videos were all looped, repeating the events until the infants looked away.

4.2. Results

We pre-registered (https://osf.io/ur4pn) an analysis that collapsed across causal role and examined the effect of puppet alone, that is, how long infants looked when the fur-covered puppet was revealed to be hollow compared to when the plain box was revealed to be hollow, regardless of their causal roles.

4.2.1. Pre-test trials

There was no detectable difference between the fur-covered and plain object pre-test trials, $t(31) = .32$, $p = .75$. All infants met the look-away criterion before proceeding to the test trials.

4.2.2. Test trials

Fig. 6 depicts the results of the test trials. A two-tailed paired-samples t-test found that infants overall looked longer when the fur object was revealed to be hollow ($M = 22.70$ s, $SD = 11.47$) than when the plain object was revealed to be hollow ($M = 16.98$ s, $SD = 10.83$), $t(31) = 2.72$, $p = .01$, $d = .48$. This finding decisively rules out the second hypothesis that going from rest to motion in these events is insufficient evidence that an object is self-propelled. It is clear that infants understood the motion of the fur-covered object as self-propelled, providing a second cue to animate agency for this object, and inferred the presence of insides.

This main effect of fur versus plain could be driven by the fur-agent condition, and indeed if infants in the fur-agent condition showed a stronger preference for the fur-covered agent than those in the box-agent condition showed for the fur-covered patient, it would indicate that they are, in fact, sensitive to causal role. This would be detectable as an interaction between trial (fur puppet test trial vs. plain puppet test trial) and causal agent identity (fur vs. plain; Fig. 5, right panel). As seen in Fig. 6, this was not the case. An exploratory mixed-model analysis explored the effects of puppet (fur vs. plain) and situational causal role during familiarization (agent vs. patent) on test-trial looking time. This analysis preserved the main effect

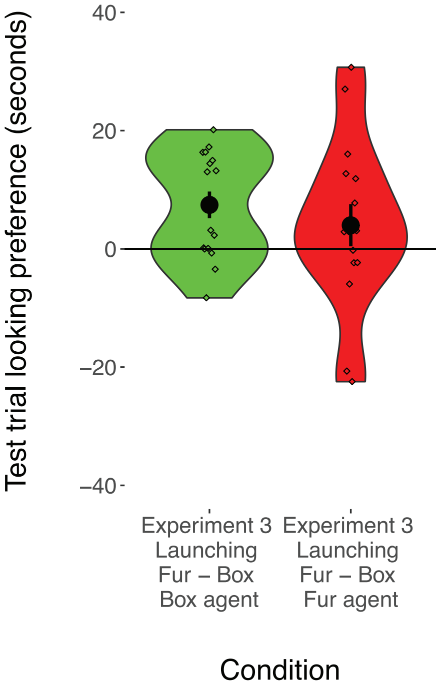

Fig 6. Difference in test trial looking times in Experiments 3 between the fur-object test trial and the plain-box test trial, in each condition. Large dots represent group means, and error bars are ± 1 SEM. Small diamonds are individual participants.

of puppet, $t(30) = 2.71$, $p = .01$, and found no significant effect of situational causal role and no interaction, $ps > .4$. This suggests that infants truly looked longer when the fur-covered object was revealed to be hollow *regardless* of whether it was the causal agent or the causal patient. Indeed, in Fig. 6, one can see that, in the box-agent condition, infants looked longer when the fur-covered causal *patient* was revealed to be hollow than when the plain box agent was. That is, the overall looking preference for the fur-covered box was not driven by the condition in what that box had been the situational agent. The observed pattern of looking times is that predicted by Hypothesis 1 (Fig. 5, left panel).

In conclusion, Experiment 3 provides a second replication of Setoh et al.'s (2013) finding; when an object exhibits two cues to animate agency (in this case fur and being seen going from rest to motion), infants are surprised when this object is seen to be hollow. This is consistent with their interpretation that infants attribute insides to self-propelled objects with an additional cue to animate agency. For present purposes, Experiment 3 shows that situational causal role in a launching event does not provide the infant with any evidence with respect to animacy, converging with the results of Cicchino et al. (2011). Ten-month-old infants did not attribute the motion of the causal patient to the causal agent in a launching event. That is, they did not explain the transition from rest to motion of the patient as resulting from the interaction with the agent.

5. General discussion

The present experiments yielded three main results. First, we replicated Setoh et al. (2013) in demonstrating that an object's providing two cues to animate agency (in this case being self-propelled and having either fur or features) leads infants to be surprised if that object is subsequently revealed to be hollow (Experiments 1 and 3). Second, we replicate Setoh et al. in demonstrating that the observed motion of an entrained object is *not* taken as evidence for that object's being self-propelled, and thus is not taken as a cue to animate agency (Experiment 1). Third, we show that the same inference is not made for the motion of a launched object; infants do not explain the motion of a patient in a launching event as being generated by the agent as they do the motion of an entrained object (Experiments 2 and 3).

Besides providing data that converge with those of Setoh et al. (2013), these data converge with those from Träuble and Pauen (2011) concerning the interrelations between representations of animate agency and representations of entraining events. Träuble and Pauen familiarized 7-month-old infants with an ambiguous entraining event. A fur-covered snake/tail wrapped around a ball went into random motion. In fact, the source of motion was in the ball, but the fur-covered object had two cues to animate agency (fur and the pattern of motion), whereas the ball had only one (the pattern of motion). After this motion had been observed, the objects were separated and placed side by side. Seven-month-old infants looked at the fur covered object, consistent with the interpretation that they construed it as the animate agent, and expected that it might do something further. Although this inference is indirect, it is consistent with the present findings, as well as Setoh et al.'s (2013) findings that the motion of entrained objects is not taken as evidence for that object's being self-propelled.

The present results also converge with Cicchino et al.'s (2011) conclusion that 10-month-old infants do not explain the observed motion of the patient in a launching event as being generated by the actions of the agent. They habituated infants to a launching event in which A entered the scene in motion and hit B, upon which B went from rest to motion. They then showed infants A moving by itself and B moving by itself. While the paradigms are different, both Cicchino et al. (2011) and Träuble and Pauen (2011) tested whether infants attribute the capacity for self-propelled motion to an object based on its causal role. However, Cicchino et al. (2011) found that at 10 months, unlike at 14 months, infants were not surprised when B, a launched object, moved by itself in the test events, whereas Träuble and Pauen (2011) found that, even at 7 months, infants infer which object is a dispositional animate agent in an entraining event. The present study generalizes these findings to a new dependent variable (expectations concerning having something inside) and by comparing the same objects in the roles of agent/patient in entraining and launching events.

The "insides" attribution that is the dependent variable in the current studies is itself somewhat mysterious. Setoh et al. (2013) suggested that infants believed that these puppets were alive, and they expect living things to have insides. We are agnostic to this conclusion. It is clear that infants are surprised to see nothing when one of these self-propelled fur-covered puppets is shown to be hollow, but that does not tell us what they expect to see. Past work has found that children have intuitions about what might be inside biological and mechanical entities that they are familiar with beginning around 4 years of age, but even these expectations are somewhat tenuous (Simons & Keil, 1995). We cannot say with certainty whether infants are surprised that the puppets are hollow because they think that they are biological entities and therefore should have biological insides, or if they expect there to be a hand inside (see Saxe et al., 2005; Saxe et al., 2007) or an artificial mechanism that allows the object to move. Recent work based on the present paradigm (Kominsky, Shafto, & Bonawitz, 2021) found that pre-schoolers, like infants, expect fur-covered self-propelled entities to have insides, but have no clear expectations concerning whether those insides are guts or gears. If pre-schoolers do not have any specific expectations about what might be inside one of these agents, then it seems unlikely that infants would have such expectations. In fact, Setoh et al.'s (2013) Experiment 2 found that infants looked longer at a hollow agent than an agent that simply had a cover on its underside, giving no indication as to whether it was hollow or not, which further supports the idea that infants merely expect there to be something and not nothing, and showing them a hollow puppet gives them specific evidence that there is nothing.

Why might infants explain the motion of the patient of an entraining event as being generated by the situational agent, but not that of a patient of a launching event? It is possible that the differences we observed between Experiment 1, on the one hand, and Experiments 2 and 3, on the other, did not derive from differences between entraining and launching, per se. The agent in the entraining event was a canonical animate agent—a person; the agent of the launching event was a fur covered or a plain box. Infants do not need additional evidence (like self-propelled motion) to treat a human being as an animate agent, but they do require such evidence for puppets, even those with animate features (e.g., Träuble & Pauen, 2011). Furthermore, the entrained motion was much more extensive (back and forth across the stage) than the launched motion (although the launching video was looped so infants watched it until they were bored). Future studies, under development in our lab, should equate the agents and degree of motion across the entraining and launching events. To give just one example: one could compare two events in which the agent is a human, and the patient is a fur-covered box in one event and feather-covered box in the other event, and the motion of the boxes back and forth across the stage is equated across familiarization events. The entraining event could be identical to that of Experiment 1, and the launching event could involve a human with both hands on the stage floor, launching the object in one direction, then another, in alternation. As in the current paper, the DV would be how long infants looked when the entrained and launched objects were subsequently revealed to be hollow. This would clarify whether the use of a human agent for the entraining event made it easier for infants to identify the patient as an inanimate object, relative to the launching event we deployed in Experiments 2 and 3.

However, there are two reasons to believe that this alternative explanation cannot be the whole story. The first is that Träuble and Pauen (2011) demonstrated that infants can simultaneously identify a *novel object* as an animate agent and appreciate its causal role in an entraining event, based on its features. In particular, when infants in their experiment saw the fur-covered tail and ball move together (an ambiguous entraining event) without the hand touching them, they identified the tail as the source of motion, based entirely on the fact that (a) it moved and (b) between the tail and the ball, the tail had more features of an animate agent. It therefore seems unlikely that the fact that the situational agent in the entraining event used here was a human can fully explain our results, though it may have contributed.

The other reason is that there is ample evidence in the existing literature that, contrary to Michotte's (1946/1963) analyses, entraining events are represented in very different ways from launching events. Both in studies of early vision, and in the infant literature, there are signatures of causal representations for launching events that are not observed for entraining events, and there are different signatures of causal representations of entraining events that are not observed for launching events. Indeed, the present study, subject to the caveat addressed above, completes a double dissociation between launching and entraining in the literature.

With respect to signatures of causal representations observed for launching and not for entraining in infancy, infants respond to situational role reversals in launching events at 6 months of age (Leslie & Keeble, 1987), but infants do not respond to situational role reversals in entraining events at the same age, and it is not yet known when they do so (Bélanger & Desrochers, 2001). Furthermore, while infants distinguish launching from non-causal events with delays or spatial gaps by 6 months of age (Cohen & Amsel, 1998), they are not as sensitive to a lack of contact in an entraining event unless the agent is a hand (Leslie, 1986).

With respect to causal representations early in visual processing, adaptation to hundreds of launching events makes ambiguous launching events, events in which A and B overlap to some degree, look less like launching and more like non-causal passing, but only when the adaptation stream and the test events are presented to the same retinotopic location (Rolfs et al., 2013). This retinotopically specific visual adaptation unambiguously shows that there is some *perceptual* representation of launching at a relatively early point in visual processing (early enough that the visual system still uses a retinotopic frame of reference). The property of launching that is adapted in these experiments is also found in a similar event called "triggering," in which B moves much faster than A, and in cases where A slows but does not stop after collision with B, as shown by the finding that adaptation to triggering events has the same effect on the perception of ambiguous launching displays. However, visual adaptation to entraining does not affect the perception of these ambiguous launching events (Kominsky & Scholl, 2020), showing that it lacks the same underlying perceptual representation. These findings show that some signatures of launching representation are not found for entraining—a single dissociation.

At the same time, infants' understanding of entraining depends on and supports the attributions of dispositional agency in the first year of life (Setoh et al., 2013; Träuble & Pauen, 2011; Experiment 1), but the very limited evidence on whether infants made dispositional attributions based on launching events did not directly contrast launching and entraining events (Cicchino et al., 2011), and so, a direct comparison has not been possible. Here, we have shown that 10-month-old infants make no such inferences from launching events using the same paradigm to test attributions of agency in both events (in this case, the "insides" attribution), with the same objects used as the patients of the events, thereby completing the double dissociation.

One possible explanation for this pattern is that Michotte (1946/1963) was correct in identifying *launching* causality as an innate perceptual schema, but entraining is not part of that schema. The psychophysical evidence around launching, particularly the retinotopic adaptation effect (Kominsky & Scholl, 2020; Rolfs et al., 2013), is very compelling on this point. However, there is no evidence as yet that there is a corresponding perceptual schema for entraining. This is in part because there has been little effort to look for one. It is possible that entraining does have an independent innate perceptual schema supporting it (e.g., Ullman, Harari, & Dorfman, 2012), but it is also possible that entraining causality is something else entirely.

5.1. What counts as a "causal" representation?

Two sorts of evidence warrant attributing causal content to some representations formed by non-verbal creatures, as well as to some non-verbal representations in human adults. First, the representational systems must distinguish causal events from closely matched non-causal events. Second, there must be evidence for causally relevant constraints on the formation of these representations, as well as on the inferences made from them. Michottean causal representations (especially launching and triggering) are clearly visuoperceptual language-independent phenomena, as they show automatic advantage effects in visual search paradigms and are subject to retinotopically specific adaptation (Kominsky et al., 2017; Kominsky & Scholl, 2020; Rolfs et al., 2013). Both of these phenomena occur at early states of visual processing. With respect to the first signature of warranting causal attribution, these phenomena are disrupted if the spatiotemporal evidence at collision do not specify causality (i.e., if there is a spatial or temporal gap between the offset of the motion of the candidate causal agent and the onset of the motion of the candidate patient). By 6 months of age, infants habituate to causal launching events, and treat both gap and delay events as equivalent (and different from launching; Cohen & Amsel, 1998).

With respect to the second signature, the representations of launching are subject to Newtonian constraints on elastic collisions, both in early vision and in infants as young as 7 months of age (Kominsky et al., 2017; Kominsky & Carey, 2018). Further, by 6 months of age, infants distinguish the agent and patient role in representations of launching, but do not distinguish which object moves first and which moves second in closely matched gap and delay events (Leslie & Keeble, 1987). This work provides very strong evidence for Michotte's characterization of launching as causal perception, with emphasis on both *causal* and *perception*. These findings also provide evidence that Michottean causal perception, specifically the launching schema, emerges early in infancy.

As mentioned above, the available data fail to support Michotte's view that entraining and launching are represented almost identically, as causal perceptual schema in which the motion of the patient is seen as a continuation of the motion of the agent. There is no evidence as of yet that entraining is a causal schema represented in early vision at all (Kominsky & Scholl, 2020), and the present results, together with previous results (Bélanger & Desrochers, 2001; Träuble & Pauen, 2011), show that entraining is represented very differently from launching in infancy. However, there is no doubt that even in infancy, entraining has causal content. The present experiments demonstrate the second signature of warranting causal attribution: inferences that follow from representations of cause. The motion of an entrained patient is fully attributed to the intentional agent entraining it. This inference goes above and beyond the event itself, and as we have seen, supports inferences not only about the source of motion but the internal properties and features of the objects involved.

5.2. *The ontogenetic origins of representations of* cause

In the literature, there are three broad theoretical proposals about the ontogenetic origins of causal thought in the human mind. Each one suggests that there is a single type of causal representation that emerges early in development and becomes the basis of adults' rich causal cognition, but they disagree as to what this single origin is.

One proposal is that causal representations originate from a perceptual module that detects a specific kind of motion-based relationship (Leslie, 1986; Michotte, 1963). In particular, Michotte suggested that the visual system innately possessed a schema for a type of relationship that he termed "ampliation." Ampliation is the impression that the movement of the causal patient is a continuation of the movement of the causal agent, and fully determined by the interaction with the causal agent. Michotte highlighted launching and entraining as two events that possessed particularly clear versions of this schema. As we have discussed, there is very good evidence that there is a launching schema present by 6 months of age (Cohen & Amsel, 1998; Leslie & Keeble, 1987) and in early visual processing (Rolfs et al., 2013), but there is also evidence that launching and entraining do not share this schema (Bélanger & Desrochers, 2001; Kominsky & Scholl, 2020), including the present results. Furthermore, there is ample evidence that an ampliation schema cannot be the *sole* origin of causal representations. As young as 3 to 8 months of age, infants represent state changes that do *not* involve the motion of the causal patient (Liu et al., 2019; Muentener & Carey, 2010), as early or earlier than we have any evidence for causal representations of either launching or entraining, and entraining and launching representations provide different signatures of causal content early in infancy. In short, individual aspects of Michotte's account have empirical support, but as a full account of the sole ontogenetic origins of causal representations, the evidence does not support it.

A second account also describes an early-developing schema, but one that involves intentional agents (particularly human beings) effecting state changes on their environment in pursuit of goals (Maine de Biran, 2016; Piaget, 1930; Ullman et al., 2012). Our findings clearly support the existence of some kind of agent-based causal schema in infants' representation of entraining events, as do previous studies (Setoh et al., 2013; Träuble & Pauen, 2011). There is also good evidence for such a schema in the representation of state change events that do not involve the motion of the causal patient (Muentener & Carey, 2010; Liu et al., 2019), and for expulsion events that do involve the motion of causal patient (Saxe et al., 2005; Saxe et al., 2007). However, our findings undercut the existence of such a schema in the representation of launching events at 10 months of age, even though, as we have discussed, launching is clearly a special category of interaction by 6 months of age. Once again, there is evidence to support individual aspects of this second account, but as a complete theory of the sole ontogenetic origin of causal representations, the evidence does not support it.

The third account of a sole ontogenetic origin to causal representations is that causality is a counterfactual-supporting dependence relation inferred from patterns of covariation (Chaput & Cohen, 2001). Such accounts are usually examined more in the context of adult causal reasoning (Cheng, 1997; Pearl, 2000) or causal learning in 2-4-year-old children (Benton, Rakison, & Sobel, 2021; Gopnik, Sobel, Schulz, & Glymour, 2001; Gopnik et al., 2004).

There is some evidence that 8-month-old infants are at least sensitive to the right kinds of patterns of covariation (Sobel & Kirkham, 2006). However, there is no evidence that infants represent *causality* in this latter case, only that they are able to predict the location of a forthcoming stimulus from previously observed patterns of covariation. Our findings do not bear directly on this account, but this account also fails to readily predict dissociations between entraining and launching, nor that infants should not make dispositional attributions from launching events.

Our findings are part of a growing body of recent evidence that leads us to pose the following question for future work: is there actually a *sole* ontogenetic origin to causal representation? An alternative proposal is that there may be distinct representational systems with causal content with innate support, or that emerge early in infancy, and the course of causal development involves, among other tasks, integration of these distinct systems. For example, there is no evidence for inference *across* representations of causality in launching and inferences of dispositional agency until 14 months, when infants infer that the patients of launching events are not self-propelled (Cicchino et al., 2011). There is unambiguous evidence in the adult literature for causal semantic content in the representation of launching events. For example, the dynamics of a launching event can shape our social and moral judgments that depend on causal attributions, even when we are not explicitly aware of its influence (De Freitas & Alvarez, 2018). While adults make rich causal inferences from launching as easily as they make them from other sorts of events or information, it is likely that the perceptual representation of launching remains encapsulated, which can sometimes lead adults to identify two contradictory causes for the same event (Schlottmann & Shanks, 1992).

Clearly, the proposal that there may be several independent, early developing, causal representations for specific events, which develop in parallel and may only be integrated later in development warrants further research (see also Muentener & Bonawitz, 2017). We eagerly look forward to future work that will ask whether there is one ontogenetic origin to causal representation, or independent "causal primitives" that are later integrated into a coherent concept of "cause."

Acknowledgments

This work was funded by NIH grant F32HD089595 to JFK. The authors would like to thank Teresa Li and Haihua Li for their assistance with stimulus creation for Experiments 1 and 2, Debbie Kwan and Jiayi Hu for their assistance with data collection and stimulus creation for Experiment 3, Evan Orticio for assistance with data collection, the members of the Harvard Lab for Developmental Studies for feedback throughout this project, and all of the participants and their families.

Notes

1 An alternative, and no less interesting, interpretation is that infants responded to the change in causal status for the self-propelled object: it went from being an agent during

familiarization to a patient during pre-test and test trials, and it is for this reason that infants looked longer at it in both the pre-test and test trials. This interpretation predicts a stronger effect in the pre-test trials, but what we found is an absence of evidence rather than evidence of absence. Experiments 2 and 3 do not have this alternative interpretation available, and nor does Setoh, Wu, Baillargeon, and Gelman's (2013) experiment 3, since they compared two self-propelled object. We therefore acknowledge this possibility and feel it would be an interesting finding in its own right, but at the same time much more convincing evidence would be needed to favor it over the current interpretation.

2 We also conducted a Bayesian analysis of this result, which revealed $BF_{01} = 3.49$, that is, that the data were 3.5 times more likely to occur if the null hypothesis were true (infants looked equally when the agent and patient were revealed to be hollow) than if the alternate hypothesis were true.

Open Research Badges

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