The Interaction Between Action Understanding and Causal Reasoning in Young Children

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Abstract

Previous research suggests that young children are sensitive to causal cues and are able to infer action goals at a young age. In this study, we asked whether these two variables interact by examining whether action understanding influences children's causal reasoning. Young children (1 to 3 years old) watched a video of two co-occurring potential causes that led to an outcome. Two actors simultaneously used an intentional and an unintentional action to press two identical buttons, activating a light-up toy. During the exploration phase, 2-year-olds selectively explored the intentionally pressed button. Children were more likely to act on both buttons with age, children's causal exploration increased over age, and predictive looking increased with age. In the control condition (Experiment 3), we showed that the 2-year-olds' preference for the intentional button was causally motivated and not a result of an inherent preference for intentional actions. These results suggest that children selectively imitate actions they think are causally efficacious. Limitations and further directions are discussed.

Keywords: causal reasoning, exploration, prediction, young children, action understanding

The Interaction Between Action Understanding and Causal Reasoning in Young Children

Causal reasoning is ubiquitous in our daily lives: from playing basketball to solving problems, we perform each action with a certain expectation for its outcome. For example, we throw an object to launch it, pet a cat to befriend it, and flick a switch to turn on some lights. At the most fundamental level, this expectation belies our ability to "bracket" groups of successive or simultaneous occurrences together so that we can perceive our environments as composed of meaningfully bounded events (Bullock, Gelman, & Baillargeon, 1982). Instead of experiencing all occurrences as independent, random events, we derive meaningful information by observing associations, inferring potential relationships between them, and applying causal inferences.

The impulse to derive meaning from our experiences and environments appears early in development, and may even be a cornerstone of human cognition (Muentener & Schulz, 2014). As mentioned in *The Developmental Psychology Of Time* (Bullock, Gelman, & Baillargeon, 1982), Bullock (1979) found that young children were unwilling to believe that events could happen without a cause. Further research supported Bullock's claims: Schulz and Sommerville (2006) presented evidence that 3- to 5-year-old children believe in causal determinism, and Muentener and Schulz (2014) found that 18- to 30-month-old toddlers selectively explored potential causes after watching an apparently spontaneous event. These studies present strong evidence that young children interpret their environment causally, inferring that outcomes must have underlying causes.

Although we observe countless combinations of occurrences in daily life, we do not apply causal inferences to all of them. Research with adults suggests that humans are sensitive to a set of basic cues and conditions that, when met, promote causal thinking: covariation, temporal contiguity, spatial contiguity, and knowledge (Bullock, Gelman, & Baillargeon, 1982). In other words, we are more likely to infer causality when a probable cause is followed by an immediate outcome, when the probable cause is physically close to the outcome, when we have observed consistent covariation between those events, or when we have information or prior experience with the subject matter. Sensitivity to these cues begins in early infancy, and becomes more sophisticated throughout development (Leslie & Keeble, 1987; Needham & Baillargeon, 1993; Oaks & Kannass, 1999). In toddlerhood and early childhood, children become capable of more complex judgments such as incorporating external information (Grotzer & Solis, 2015) and prioritizing certain cues over others (Wilde & Coker, 1978, as cited in *The Developmental Psychology of Time*).

One way in which causal reasoning develops may be through repeated experience (Bullock, Gelman, & Baillargeon, 1982), where young children learn associatively by observing covariation patterns and identifying predictive relations which are also causal (Gopnik & Schulz, 2004; Meltzoff, Waismeyer, & Gopnik, 2012; Sobel & Legare, 2014). In other words, children use temporal associations (e.g. learning that Event A is always closely followed by Event B) they see in daily life to infer causal relationships between them (e.g. that Event A causes Event B to occur) (Bullock, Gelman, & Baillargeon, 1982; Kuhn & Phelps, 1976). By age four, children use temporal and covariation information jointly: when asked to make judgements about the relationship between two variables, they inferred causal direction based on the variables' behavior over time (Rottman, Kominsky, & Keil, 2014). Despite this, the two factors are not simultaneously essential for causal reasoning to take place. Mendelson and Shultz (1976) reported that 4- to 7-year-old children attributed an outcome to a consistent but delayed (temporally non-contiguous) candidate cause when there was a physical rationale for the delay, but to the temporally contiguous but inconsistent candidate cause when no such rationale was given. Thus, temporal contiguity takes priority over covariation for children (Bullock, Gelman, & Baillargeon, 1982).

Spatial contiguity is another important causal cue, and often occurs concurrently with temporal contiguity. Infants become sensitive to spatial information within the first year of life and are able to apply them to causal relations; however, their causal reasoning is limited to simple physical events that involve direct contact. By four months old, infants expect objects to fall when their supports are removed (Needham & Baillargeon, 1993), and six-month-old infants perceive causal relationships in direct launching events (Leslie & Keeble, 1987). However, Oakes and Kannass (1999) found that 7- and 10-month-olds' causal understanding is limited to only simple and straightforward physical events such as rolling: they did not generalize their causal inferences to other patterns of movement such as bouncing. Further research found that children begin to use novel information in their causal inferences by preschool age, even if the information runs contrary to their spatial intuitions (Kushnir & Gopnik, 2007). Despite this, they remain more likely to be correct overall when the causes are spatially contiguous. The influence of spatial cues continues throughout childhood: as described in *The Developmental Psychology of Time*, Koslowski (1976) found that children considered more spatially contiguous potential causes to be more likely; another study found that even 6-year-olds did not give causal explanations for spatially non-contiguous causal events (Lesser, 1977).

Dependence on spatial contiguity cues, however, decreases with age (Lesser, 1977; Schlottmann, 1999). As children become more proficient at reasoning (Lesser, 1977) and amass more knowledge about mechanisms that underlie causal relationships (Schlottman, 1999; Grotzer & Solis, 2015), they improve at making causal inferences for spatially non-contiguous events.

Schlottmann (1999) found that older children (9 to 10 years old) were able to use mechanism information to choose a noncontiguous cause over a contiguous one while younger ones (5 to 7 years old) were not; Grotzer and Solis (2015) found that elementary-school children only provided distal (i.e. spatially removed) explanations when they possessed prior knowledge about their mechanisms. These results suggest that children use mechanism information to explain spatially non-contiguous causal relationships, and that the way children integrate what they see with their knowledge undergoes a developmental shift (Schlottmann, 1999). While younger children ignore mechanism information and rely on visual perception, older children recognize that mechanism is superordinate. As such, they rely less on contiguity cues, but integrate their knowledge into causal judgments.

Even if potentially causal events are temporally and spatially contiguous and fulfill probabilistic cues, children do not believe that they are causal unless they abide by the correct temporal order of cause and outcome. By 3 years old, children believe that causes must precede their outcomes. Bullock and Gelman (1979) showed 3- to 5-year-old children a sequence of three events in an A-B-A' structure and asked them which event (A or A') caused the intermediary event (B). The majority of children consistently chose the first event (A) across all three age groups; correct answers increased with age and reached ceiling by age 5. In a second experiment, they further demonstrated that temporal order overrides contiguity cues. Children saw a similar series of events; this time, the first event (A) was spatially disconnected from the outcome (B) while the following event was spatially connected (A'). Children chose the temporally correct but spatially disconnected cause (A), which suggests that the temporal order of events is more important than spatial contiguity.

Beyond these factors, young children are also sensitive to different types of potential causes. They discriminate between causal agents, and believe that some are more likely than others to cause outcomes. As described in *The Developmental Psychology Of Time* (Bullock, Gelman, & Baillargeon, 1982), Bullock (1979) found that children ages 3-5 believe that a rolling ball is more like to be the cause for a jack-in-the-box than a moving light. A recent study further suggests that children are sensitive to causal mechanisms beginning in their first year: Muentener and Pelliccione (2015) reported that 6- to 36-month-olds preferred a button over a block as the candidate cause for a light. These studies suggest that children impose constraints upon different types of causal agents and their scope of influence, and that children develop a schema for causal agents early in life. Inanimate objects aside, another category of causal agents may be actors, such as human beings. Unlike objects (such as buttons or balls), the movements of causal actors can be perceived in terms of goals and intentions (Woodward, 1998; Woodward, 1999; Buresh & Woodward, 2007); infants infer different things about the behavior of humans and inanimate objects, even if their actions are identical (Woodward, 1998).

Given that children believe certain entities are more likely than others to be causal, are they also sensitive to action goals and different types of actions? Research suggests that children are indeed able to distinguish intentional actions from non-intentional ones beginning from a very young age (Carpenter, Akhtar, & Tomasello, 1998; Woodward, 1999; Hamlin, Hallinan, & Woodward, 2008). Even young babies demonstrate understanding that human actions are motivated by goals, and this continues to develop throughout infancy. As early as 3 months, infants begin to form goal-based action representations; however, this preliminary understanding is contingent upon their personal experience with the actions (Sommerville, Woodward, & Needham, 2005; Gerson & Woodward, 2014). As infants accumulate more observations and experiences, they learn to categorize actions and outcomes by their goal-directedness: 5- and 9-month-olds are able to differentiate between intentional and non-intentional actions (Woodward, 1999), and they selectively imitate intentional ones by 7 months old (Hamlin, Hallinan, & Woodward, 2008). Nine-month-old infants not only attribute goals to actions, but also associate those goals with their specific actors (Buresh & Woodward, 2007). Between 10 and 12 months, infants begin to recognize that actions can be goal-directed and intentional regardless of whether they succeed or fail (Wellman & Brandone, 2009). One reason this meaning-making behavior emerges at such a young age may be because it is innate to how we cognitively represent events: episodic memory is organized around action goals and outcomes for both adults and children (Zacks & Tversky, 2001).

Like goal understanding, the goal-based structure of memory and cognition develops and matures throughout childhood. Compared to the memories of older children and adults, toddlers' and younger children's narratives and episodic memories are less aligned with the goal-based structure (Price & Goodman, 1990; Trabasso & Nickels, 1992; Fivush & Nelson, 2004; Keven, 2016). Beyond memory, however, humans also process information in terms of actions and goals. Adult readers understand sentences more quickly when the described action is well-aligned with the goal, even when the goal is implicit (Egidi & Gerrig, 2006). Taken together, these studies provide evidence that humans cognitively organize information in increasingly sophisticated ways, becoming better attuned to goal-directed behavior throughout the developmental years.

Recent research continues to provide evidence that infants' action understanding is strongly influenced by their own motor activation, action experience, and action control. In support of Sommerville, Woodward, and Needham's (2005) findings, researchers who used a similar paradigm with 1-year-olds found that those who completed a behavioral task (placing toys in a container) before watching another person perform the task paid more attention to the person's actions than infants who had observed the person before performing the task (Cannon, Woodward, Gredebäck, van Hofsten, & Turek, 2012). Loucks and Sommerville (2012) offer a plausible explanation: infants can only think of actions as goal-directed if they know their purposes, of which they learn by experiencing the actions. In their study, 10-month-old infants only showed understanding of different types of grasping motions and their purposes only if they were able to produce those grasps themselves. As infants become more capable of interacting with their environments throughout development, they become more likely to view actions as goal-oriented (Sommerville et. al., 2005; Cannon et. al., 2012).

Infants' action understanding is not only influenced by their own experience, but also causal efficacy. Event outcomes influence action understanding for infants, who do not only selectively imitate intentional actions (Hamlin, Hallinan, & Woodward, 2008), but also selectively imitate actions that produce clear outcomes on their objects. When Woodward's (1999) study was modified such that each action (grasping or back-of-hand) either physically moved a toy or did not, 8-month-old and ten-month-old infants no longer attributed intentionality solely to the grasping motion. Instead, they represented all toy-moving actions as intentional regardless of the specific motion used (Kiraly, Jovanovic, Prinz, Aschersleben, & Gergely, 2003). As Loucks and Sommerville (2012) suggest, the infants' attributions of intentionality in Woodward's (1999) study may reflect their limited notions of possible goals due to lack of experience: while infants grasp objects in daily life, they seldom reach to only touch objects with the back of their hands. In further support that causal outcomes affect infants' action understanding and goal attribution, studies found that 1-year-olds regard outcome-producing actions as intentional even if the action is shown in a video instead of by a live actor (Klein, Hauf,

& Aschersleben, 2006), or produced by a non-human agent such as a mechanical claw (Hofer, Hauf, & Aschersleben, 2005).

Given this, how can we know whether a toddler imitates an action for its intentionality alone or because they additionally understand its causal efficacy? Research shows that young children who observe a consistent causal relationship (e.g. Action A causes Event B) will not only imitate the action, but simultaneously look to the site of the outcome event in expectation (Bonawitz, Ferranti, Saxe, Gopnik, Meltzoff, Woodward, & Schulz, 2010). For 2-year-olds, predictive looking reflects causal reasoning that exceeds simple correlation learning and physical causation (Meltzoff, Waismeyer, & Gopnik, 2012). Given two identical objects that differed only in whether they produced an outcome, toddlers preferred to act on the outcome-producing object, and looked predictively to the outcome site.

In summary, previous research exploring the development of causal reasoning and action understanding in infants and toddlers has demonstrated that they comprehend causality early in infancy, exhibit bias for goal-oriented actions, and prefer outcome-producing actions. While some research has addressed the role of physical causality in action and goal understanding, it remains an open question whether action understanding affects young children's causal reasoning within the first few years of life. In other words, do young children believe that certain actions are more effective than others at causing events to happen? To evaluate this question, we examined their reasoning about two simultaneous candidate actions on a causal outcome. We showed children a video depicting a novel light-up toy, from which two buttons that differed only in color extended out on either side. Two actors simultaneously pressed the buttons using similar actions; however, one was intentional while the other was not. The light-up toy activated following the actor's button actions. After watching the video, children were offered the opportunity to play with the toy.

In a series of 3 experiments, we asked whether children believe that the intentional action is a better candidate cause for the causal event. To do this, we measured their first button action on the toy and whether it is accompanied by a predictive look. In Experiment 1, they were shown that the actions immediately activated the toy. In Experiment 2, the temporal order of the actions and the outcome were reversed. In Experiment 3, not only was the order of events reversed, the timings of the actions and outcome were further separated such that they became disjointed. Given young children's causal understanding and action preferences, we hypothesized that they would expect the intentional button action to be more likely than the non-intentional button action to cause the toy to activate. Since infants' causal reasoning develops rapidly throughout the first few years, we hypothesized that this expectation will increase with age.

Experiment 1

Method

Participants. Ninety-six children aged one (N=32, 15 boys 17 girls, mean = 19 months, range = 12-24 months), two (N=32, 16 boys 16 girls, mean = 28.8 months, range = 24-36 months), and three (N=32, 19 boys 13 girls, mean = 41.3 months, range = 36-47 months) were recruited from a children's museum. An additional 7 children were excluded from the final sample due to lack of interaction with the toy (2 year olds N = 4), becoming too agitated to continue (1 year olds N = 2), or parental interference (1 year olds N = 1). 4 children were run in Mandarin Chinese, of which the experimenter is a native speaker. Participants generally reflected the demographic of the museum's visitors, who are typically middle to upper-middle class families with parents that received a high school education.

Materials. A novel toy was constructed for the study (Figure 1): a light-up toy was attached to a large soda bottle to create a body (10 cm × 46 cm). Two identical button boxes (7.5 cm × 8 cm) that differed only in color (yellow and blue), each with an identical button on top, were arranged in front of the red body, 52 cm apart. Since physical connection encourages causal reasoning for young children (Kushnir & Gopnik, 2007), two identical red rods (18 cm) were placed so that they extended symmetrically from each side of the body and connected with the boxes. The toy was fixed on a piece of white Styrofoam board.

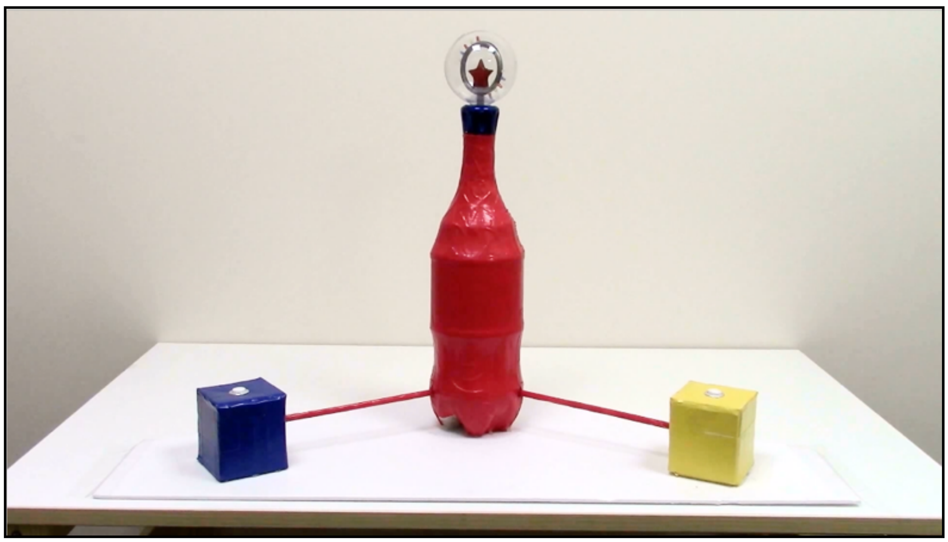

Figure 1. The novel light-up toy with identical rods and button boxes that differ only in color, protruding symmetrically from either side of the body.

A stimulus video was created where two actors pushed the buttons simultaneously with actions that differed in intentionality (Figure 2). As infants have been shown to consider grasping motions as goal-directed but not motions with the back of the hand (Hamlin, Hallinan, & Woodward, 2008; Woodward & Guajardo, 2004), intentional and non-intentional actions were operationalized as palm-down and palm-up respectively. In the video, a spinning star first appeared with a harp sound for 4 seconds to draw the children's attention (Figure 2a). Then, the toy appeared on the screen (Figure 2b), and the actors' hands entered the frame at 6 seconds to push the buttons (Figure 2c). Until the end of the video, the hands remained on the buttons as the toy lit up and emitted a high-pitched spinning sound (5 seconds in total) (Figure 2d). Throughout the video, only the actors' hands were shown.

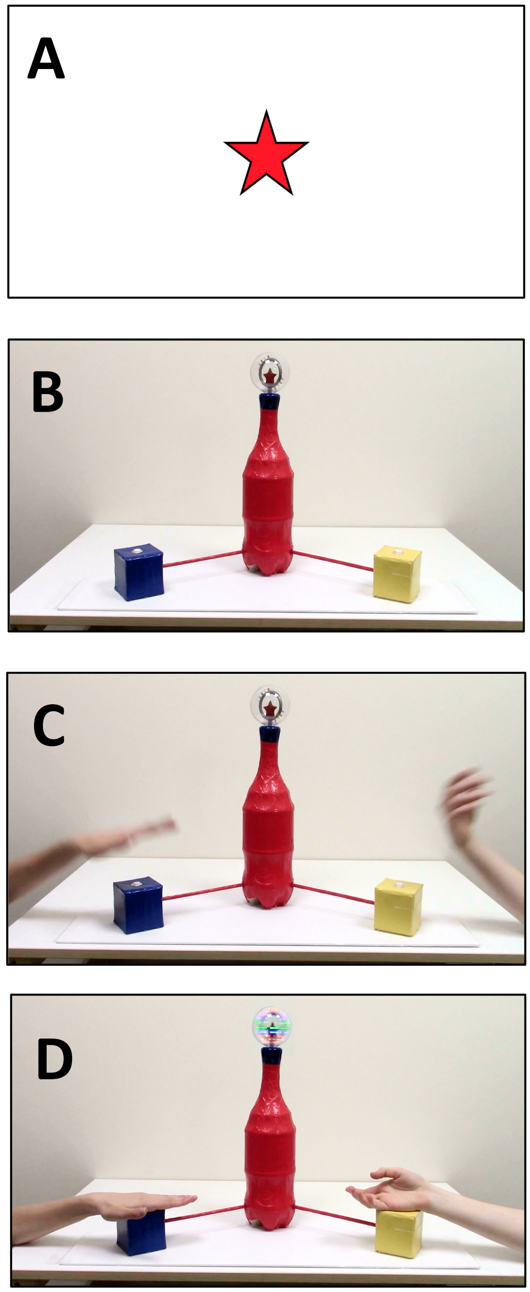

Figure 2. Description of video demonstration in Experiment 1. (a) A spinning star appears at the center of the screen, accompanied by a musical harp sound, to draw the children's attention. (b) Next, the inert novel light-up toy appears on the screen. (c) The actors' hands then enter the

frame to push the buttons with different actions, one intentional and one non-intentional. (d). Finally, the actors' hands remain on the buttons as the toy lights up and emits a high-pitched spinning sound, until the end of the video.

Procedure. The procedure was approved by the Tufts Institutional Review Board. Participants were tested either in a private testing room or in a hallway of the museum. Throughout the study, the child and the experimenter sat on opposite sides of a table while parents sat or stood behind or adjacent to their child. The camera was placed behind the experimenter, facing the child, so that their actions and gaze could be easily coded. Parents were allowed to encourage their child to explore the toy, but asked not to give any specific instructions during the study. The study was comprised of two parts: the presentation phase and the intervention phase.

Presentation Phase. In the presentation phase, children watched the stimulus video on a laptop. If the child stopped attending to the video, the experimenter gently tapped the top of the laptop screen and used non-specific attentional statements ("Look at this") to redirect their attention. When the video ended, the experimenter removed the laptop and told the child that they could play with the toy they saw (e.g. "Remember the toy you saw in the video? You can play with it too!"). Unbeknownst to the children, both buttons were inert on the toy.

Intervention Phase. In the intervention phase, the experimenter produced the light-up toy, placed it on the table, and pushed it towards the child for them to play with. The experimenter allowed each child to play for one minute or until they lost interest, defined as getting up and walking away from the experimenter. If the child did not play with the toy, the experimenter used generic statements to encourage them (e.g. "You can play with it" or "What can you do with it?").

Coding. Participants' actions and looking behavior were coded from the videotaped testing sessions. The primary measures were the children's first action on a button, and whether or not it was followed by a predictive look towards the light. If the participant's first action was not on the intentional button, we coded whether they ever pressed it; and if so, whether they made a predictive look then. Since the children had different levels of motor abilities across the age groups, we coded touching as a button press for children who did not demonstrate the ability to press the buttons fully or exactly throughout the session. A second independent coder who was blind to condition coded 40% of all sessions across Experiments 1, 2, and 3. Inter-coder reliability was high for the children's first button action ($\kappa > 0.7$), as well as their predictive looking after selecting the intentional button ($\kappa > 0.7$).

Results and Discussion

The primary outcome measure was whether children's first button choice was directed towards the button the experimenter interacted with in an intentional manner. Yet, preliminary analyses revealed that children's inference that only one button caused the toy to activate changed with age. A binary logistic regression indicated that age reliably predicted children's likelihood of preferring one button (either the intentional or unintentional button), (Wald's criterion, $p < 0.01$; chi square = 9.975, $p < 0.01$, df = 1). One-year-olds (93%, 30/32 children; Binomial test, $p < 0.01$) and 2-year-olds (66%, 21/32 children; Binomial test, $p < 0.05$) demonstrated a strong expectation for only one button to be sufficient for activating the toy, while three-year-olds' expectations were split between either one or both buttons (59%, 19/32 children, *ns*). See Figure 3.

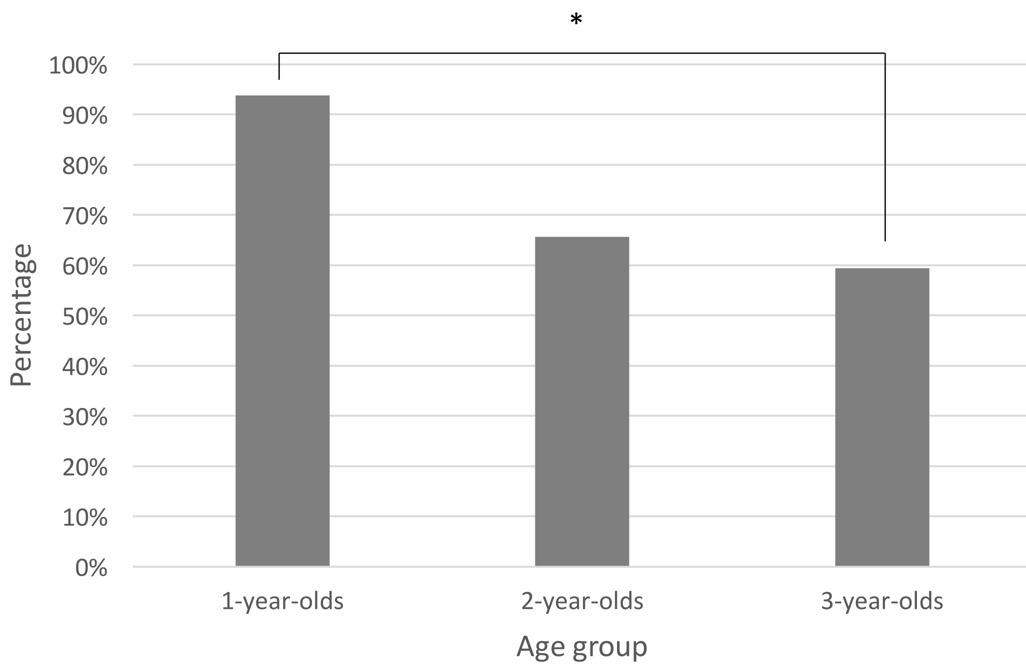

Figure 3. Children's preference for one button on their first button action.

Therefore, our first analysis focused on only the subset of children that directed their first action towards a single button. Two-year-olds who expected only one button to activate the toy demonstrated a strong preference for the intentional button (76%, 16/21 children; Binomial test, $p < 0.01$). However, 1-year-olds (50%, 15/30 children; *ns*) and 3-year-olds (63%, 12/19 children; *ns*) both performed at chance. A binary logistic regression did not find that age predicted children's likelihood of preferring the intentional button. See Figure 4.

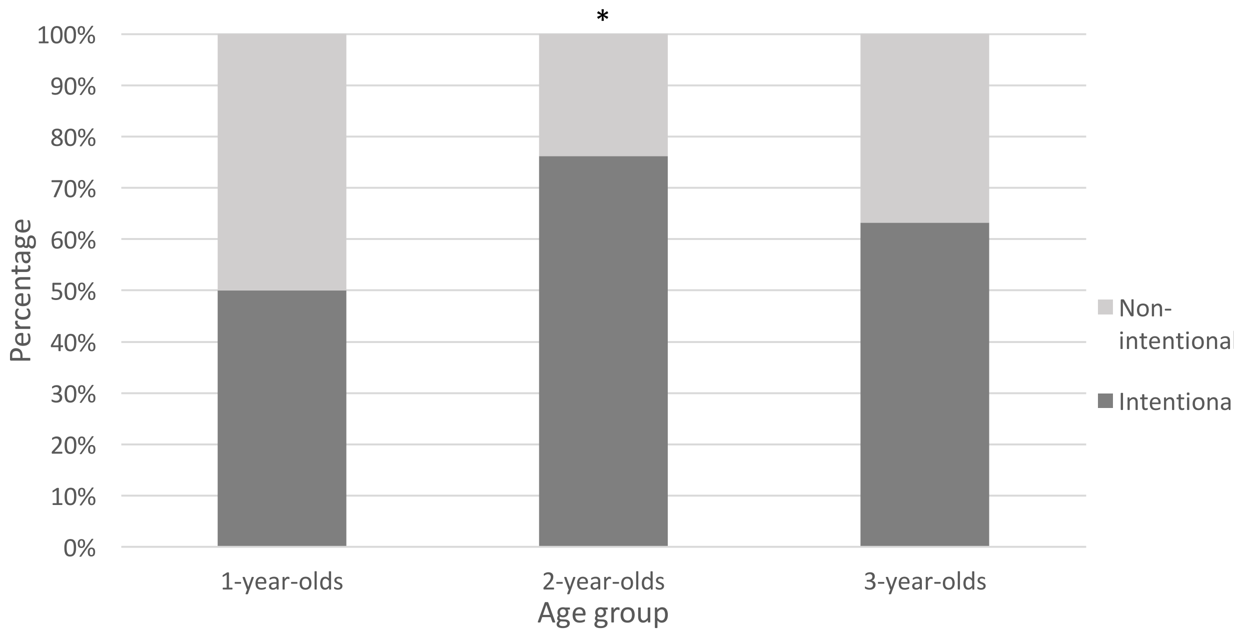

Figure 4: Children's button preference, given that their first button action was on one button only.

The 2-year-olds' preference suggests that they expected only the intentionally-pushed button to activate the toy. Since the preference was not evident in 1-year-olds, it may be attributed to cognitive developments that take place between the first and second year. While 3-year-olds also did not demonstrate a preference for either button, this result may have been caused by the higher percentage of children who pressed both buttons simultaneously.

The secondary outcome measure was predictive looking following their intervention on the buttons. Analyses revealed that predictive looking steadily increased over age. A binary logistic regression indicated that age reliably predicted children's likelihood of making a predictive look after their first button action (Wald's criterion, $p < 0.01$; chi square = 30.609, $p < 0.01$, df = 1). More 3-year-olds (87.5%, 28/32 children) made predictive looks than 2-year-olds (59%, 19/32 children), and more 2-year-olds did so than 1-year-olds (22%, 7/32 children) (Fisher's Exact test, $p = 0.02$). See Figure 5.

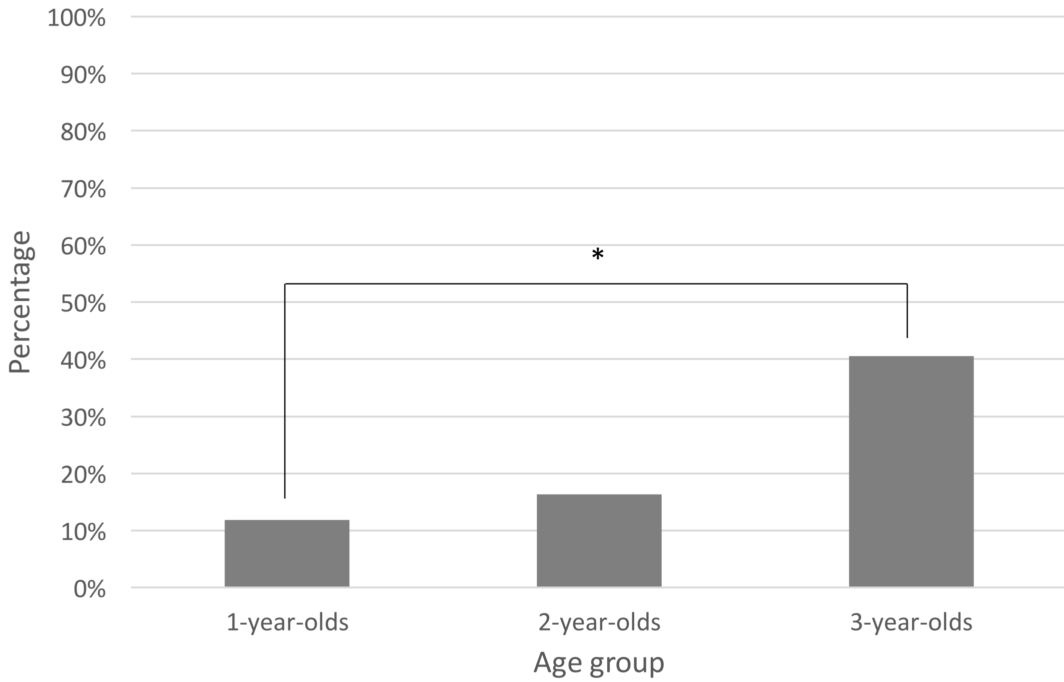

Figure 5: Children’s predictive looking behavior after their first button action.

Twenty percent (3/15 children) of 1-year-olds, 56 percent (9/16 children) of 2-year-olds, and 83 percent (9/12 children) of 3-year-olds who chose to explore the intentional button additionally made a predictive look. Age reliably predicted children’s likelihood of making a predictive look after selecting the intentional button, (Wald’s criterion, $p = 0.01$; chi square = 7.987, $p < 0.01$, $df = 1$). See Figure 6.

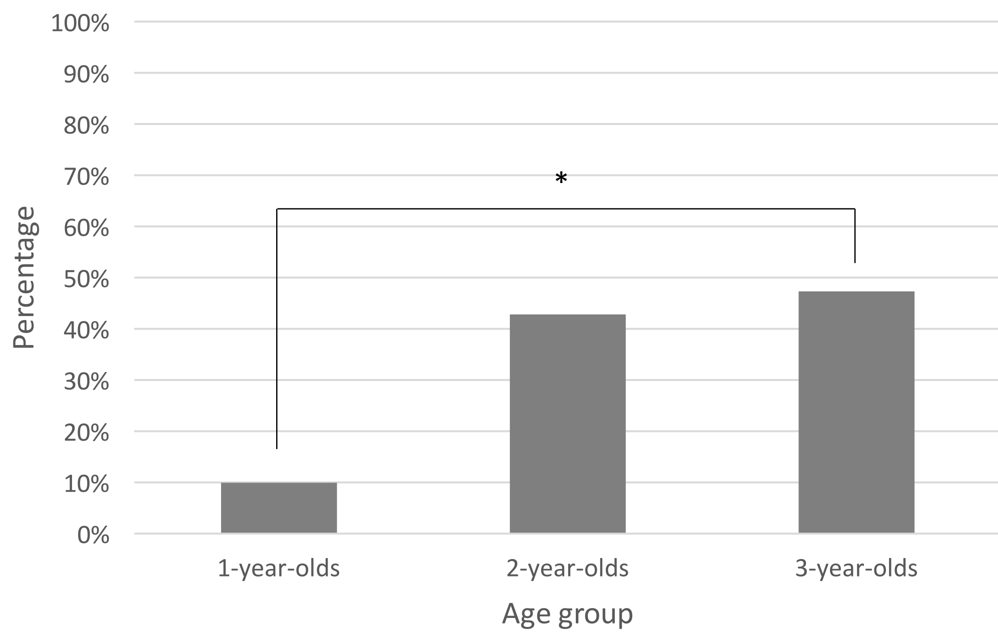

Figure 6: Children's predictive looking behavior, given that they chose to explore the intentional button as their first button action.

Since predictive looking belies the anticipation of an outcome, it supports the idea that the children's button preferences are causally motivated. However, it is necessary to first verify that the looking behavior is not attributable to external factors. The children may have looked at the light by chance, independent of causal reasoning.

The tertiary outcome measure was the children's cumulative actions on each button. Children's button preferences corresponded with their actions. Of the 2-year-olds, 69% percent (11/16 children, *ns*) who preferred the intentional button engaged with that button more overall, 60% who preferred the unintentional button engaged with that more (3/5 children), and those who chose both buttons played with the buttons more equally (55%, 6/11 children). Children also became more likely to explore both buttons with age: more 2-year-olds (34%, 11/32 children; Fisher's Exact test, $p = 0.01$) and more 3-year-olds (41%, 13/32 children; Fisher's Exact test, $p < 0.01$) explored both buttons than did 1-year-olds (6%, 2/32 children).

In Experiment 2, we sought to affirm that the 2-year-olds' looking behavior in Experiment 1 is truly predictive and causally motivated. To do this, we reversed the order of cause and outcome in the stimulus video, defying the laws of causality. We predicted that this modification would eliminate button preference and predictive looking if the children's behavior in Experiment 1 was motivated by causal exploration. We no longer included 1- or 3-year-olds because they performed at chance and did not expect either button to be more effective than the other.

Experiment 2

Method

Participants. Thirty-two children age two (N=32, 14 boys 18 girls, mean = 29.7 months, range = 24-35 months) were recruited from a children's museum. An additional 5 children were excluded from the final sample due to lack of interaction with the toy (N=1) or becoming too agitated to continue (N = 4). Participants generally reflected the demographic of the museum's visitors, who are typically middle to upper-middle class families with parents that received a high school education.

Materials. The same light-up toy used in Experiment 1 was used in Experiment 2 (see Figure 1). The stimulus video was identical to the one used in Experiment 1 with the exception that the order of events was modified (see Figure 7). After the spinning star appeared for 4 seconds (Figure 7a), the toy appeared (Figure 7b) and activated spontaneously (Figure 7c). The actors' hands entered the frame at 6 seconds to push the buttons (Figure 7d). The toy remained activated and the actors' hands stayed on the buttons for the remainder of the video, 5 seconds. The durations of the light-up toy being activated, and of the actors making contact with the buttons, were kept identical to Experiment 1.

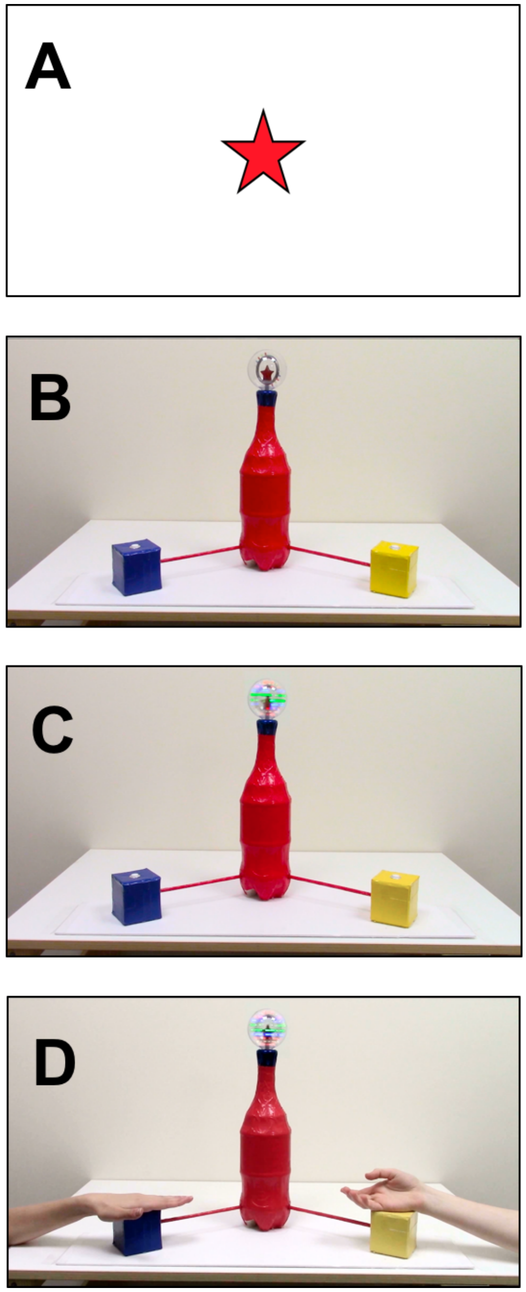

Figure 7. Description of video demonstration in Experiment 2. (a) A spinning star appears at the center of the screen, accompanied by a musical harp sound, to draw the children's attention. (b) Next, the inert novel light-up toy appears on the screen. (c) Then, the inert novel light-up toy activates spontaneously. (d) Finally, the actors' hands enter the frame to push the buttons with different actions, one intentional and one non-intentional. The toy remains activated and the hands remain on the buttons until the end of the video.

Procedure. The same procedure used for Experiment 1 was used for Experiment 2.

Coding. The same coding scheme used for Experiment 1 was used for Experiment 2.

Results and Discussion

The outcome measures were identical to those of Experiment 1. The primary outcome measure was whether children's first button choice was directed towards the button the experimenter interacted with in an intentional manner, and our analysis focused on only the subset of children who directed their first action towards a single button. In that subset, 2-year-olds no longer displayed a preference for the intentional button (65%, 15/23 children, *ns*). See Figure 8.

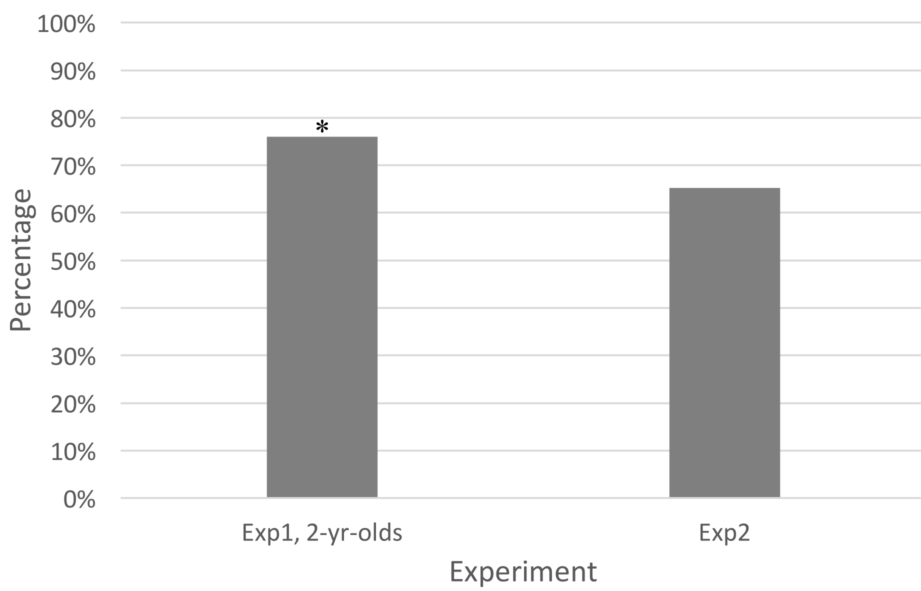

Figure 8: Children's button preference, given that their first button action was on one button only.

The secondary outcome measure was predictive looking following their intervention on the buttons, which did not diminish significantly compared to Experiment 1 (47%, 7/15 children, *ns*). See Figure 9.

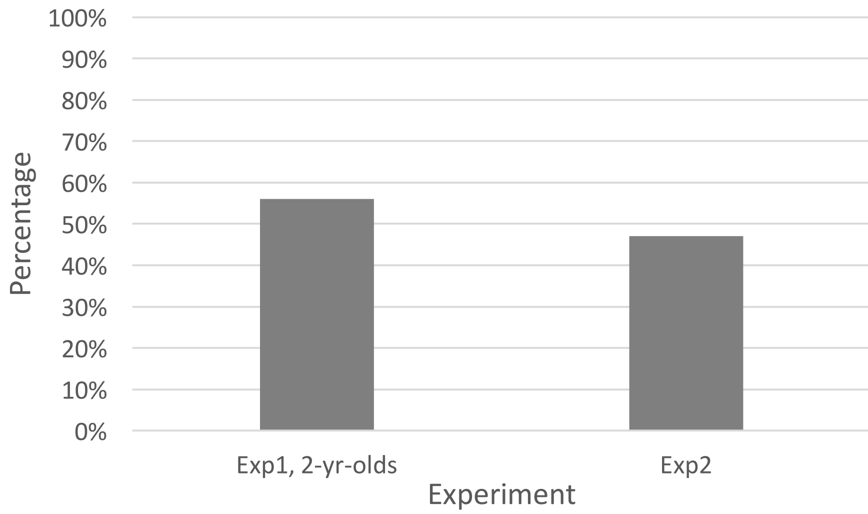

Figure 9: Children's predictive looking behavior, given that they chose to explore the intentional button as their first button action.

The tertiary measure was the children's cumulative actions on each button. Their button preference continued to correspond with their actions on the toy; 87% (13/15 children) of 2-year-olds who preferred the intentional button engaged more with it, as did all of those (7/7 children) who additionally made a predictive look.

These results suggest that 2-year-olds continued to expect the intentional button to activate the toy, even though they were not presented with any evidence that the buttons were causally related. Although the children were somewhat sensitive to the reversal of occurrences, the disruption of causal order was insufficient to convince them of the event's non-causality. One explanation may be that the children assumed the actions to have contributed to the toy's continued activation: although it began spontaneously, it remained active throughout the button actions. The temporal contiguity between the activation and the button actions may have led children to believe that the actions helped renew the toy's activation mechanism, thus making a causal inference plausible. To remedy this, we additionally disrupted the temporal contiguity in

Experiment 3 such that the occurrences would be both reversed and temporally separated. We hypothesized that this further disruption would eliminate the 2-year-olds' button preference and predictive looking.

Experiment 3

Method

Participants. Thirty-two children age two (17 boys and 15 girls, mean = 28.3 months, range = 24-35 months) were recruited from a children's museum. An additional 6 children were excluded from the final sample due to lack of interaction with the toy (N = 6). Five children were run in Mandarin Chinese, of which the experimenter is a native speaker. Participants generally reflected the demographic of the museum's visitors, who are typically middle to upper-middle class families with parents who received a high school education.

Materials. The same light-up toy used in Experiment 1 and 2 was used in Experiment 3 (see Figure 1). The stimulus video was similar to the one used in Experiment 2; however, the order of events was modified further (see Figure 10). After the spinning star was presented for 4 seconds (Figure 10a), the toy appeared (Figure 10b) and activated spontaneously for 7 seconds (Fig. 10c), after which it deactivated (Figure 10d). The actors' hands entered the frame at 11 seconds to push the buttons, and their hands remained on the buttons until the end of the video, 5 seconds (Figure 10e). The durations of the light-up toy being on, and of the actors making contact with the buttons, were kept identical to Experiments 1 and 2.

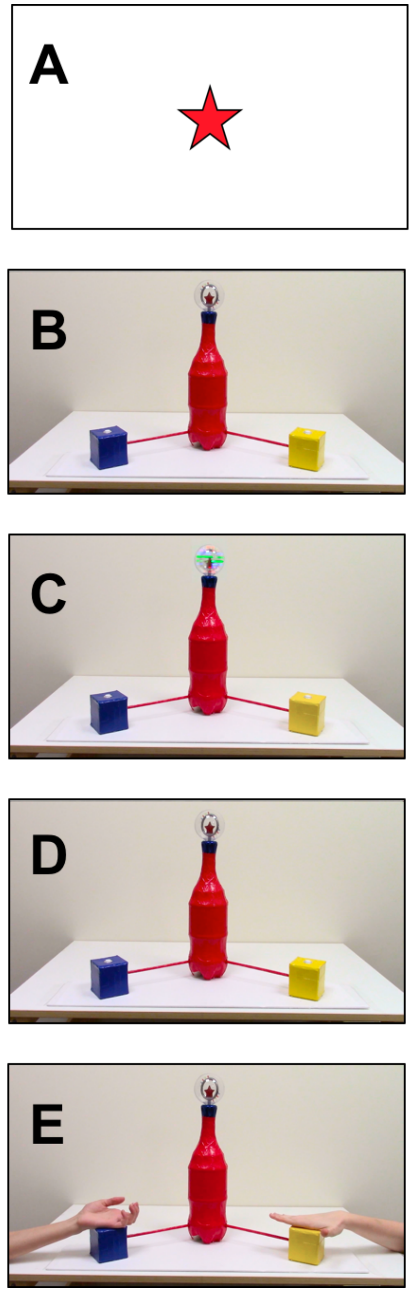

Figure 10. Description of video demonstration in Experiment 3. (a) A spinning star appears at the center of the screen, accompanied by a musical harp sound, to draw the children's attention. (b) Next, the inert novel light-up toy appears on the screen. (c) Then, the inert novel light-up toy activates spontaneously. (d) The activated novel light-up toy deactivates again spontaneously. (e) Finally, the actors' hands enter the frame to push the buttons with different actions, one intentional and one non-intentional. The hands remain on the buttons until the end of the video.

Procedure. The same procedure used for Experiment 1 and Experiment 2 was used for Experiment 3.

Coding. The same coding scheme used for Experiment 1 and Experiment 2 was used for Experiment 3.

Results and Discussion

The outcome measures were identical to those of Experiment 1 and Experiment 2. The primary outcome measure was whether children's first button choice was directed towards the button the experimenter interacted with in an intentional manner, and our analysis focused on only the subset of children who directed their first action towards a single button. Two-year-olds no longer displayed a button preference (58%, 15/26 children, *n.s.*) after watching the non-causal stimulus video. See Figure 11.

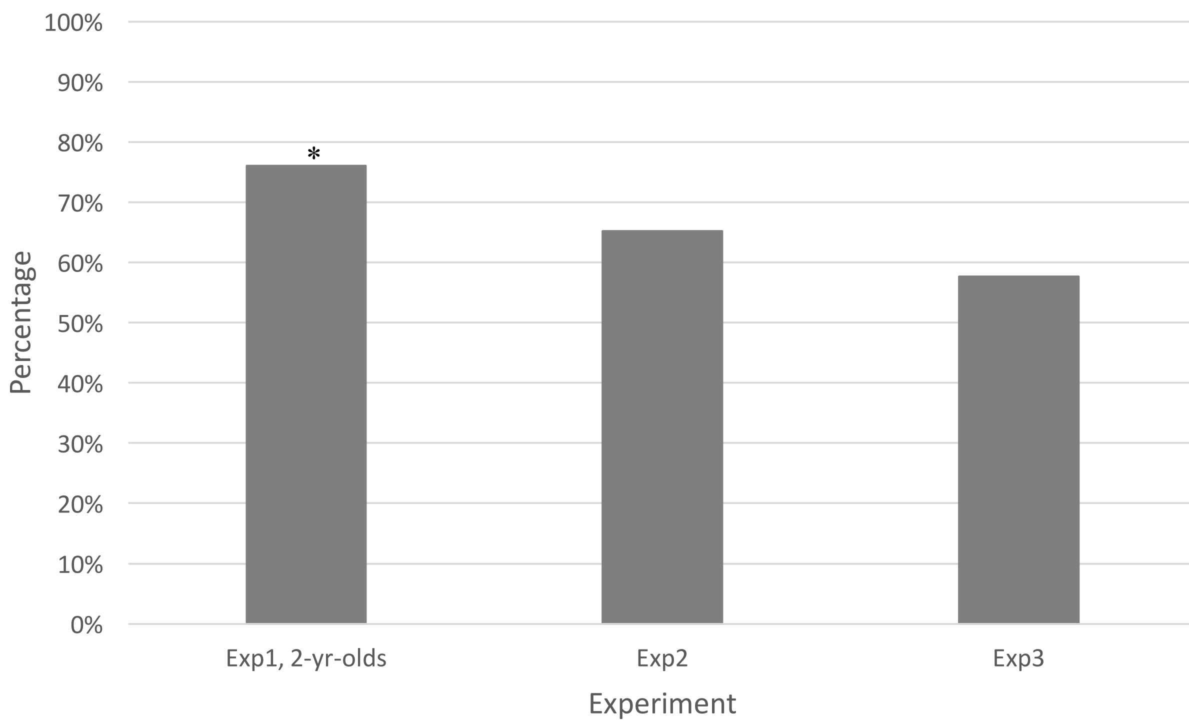

Figure 11: Children's button preference, given that their first button action was on one button only.

The secondary outcome measure was predictive looking following their intervention on the buttons, and we found that they no longer looked to the light after pressing the intentional button (13%, 2/15 children, Fisher's Exact test, $p < 0.05$). Predictive looking decreased overall: 28% (9/32 children) made a predictive look after making their first button action, compared to 53% (17/32 children) in Experiment 2 and 59% (19/32 children) in Experiment 1. See Figure 12.

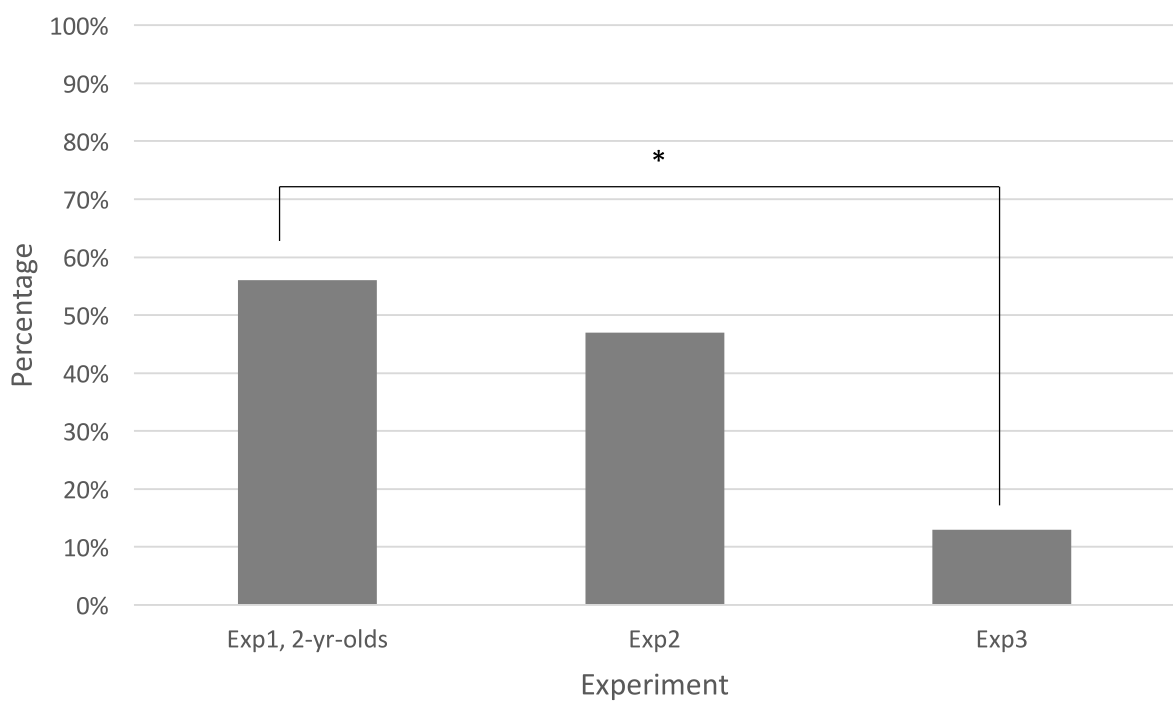

Figure 12: Children's predictive looking behavior, given that they chose to explore the intentional button as their first button action.

Our tertiary measure examining the children's cumulative button actions found that few children pressed both buttons simultaneously (19%, 6/32 children) in comparison to Experiments 1 and 2, and only half of the children performed their first action on either button at all (53%, 17/32 children).

Given the disruption of both temporal contiguity and causal order, 2-year-olds no longer demonstrated a preference for the intentional button or made predictive looks at the light as they played with the toy. This suggests that they no longer appear to consider the stimulus event to be causal in Experiment 3. Since they demonstrated a clear button preference in Experiment 1 and made significantly more predictive looks, this supports our hypothesis that the 2-year-olds's preference for the intentional button and predictive looking in Experiment 1 is causally motivated.

General Discussion

Our findings contribute to the existing literature about young children's causal reasoning by demonstrating that action information has a measurable effect on their causal inferences. When 2-year-olds are presented with intentional and non-intentional actions as potential causes for an outcome, they believe that intentional actions are more causally efficacious than non-intentional ones and prefer them (Experiment 1). In the control condition (Experiment 3), we verified that their preference for intentional actions is causally motivated by showing that they do not demonstrate this preference for non-causal events.

The findings of our current study indicate that children are able to use action and goal information to make causal judgments of effectiveness by age 2. While previous research has shown that young children prefer to imitate goal-directed and intentional actions in general, our study suggests that their preference is informed by their predictions about potential causal outcomes. Whereas younger children reproduce intentional actions regardless of goal completion, 2-year-olds do so only if there is a goal to be achieved. Since they are more physically capable of independent action and movement than ever, this selectivity helps them streamline their learning process as they navigate and learn about their environments: it helps them imitate only those actions that are most likely to successfully produce desired outcomes.

Another implication of this study is that young children may believe “accidents happen” quite literally. Although they believe that intentional actions are more likely than non-intentional actions to produce desired causal outcomes, it remains an open question whether this belies the stronger belief that intentional actions are *incapable* of producing undesired causal outcomes (such as spilling a cup of milk or knocking over a vase). If so, they may believe that mishaps occur spontaneously, and that people cannot be held responsible for undesirable outcomes that are unintended. In daily life, such a line of reasoning may lead children to erroneously believe that they are exempt of responsibility when accidents happen; this may cause them to be upset and confused when they are held responsible and reprimanded after all. Furthermore, such a belief may cause them to think that all “accidents”, or undesirable outcomes, are maliciously and intentionally executed. Similarly, the findings of this study do not necessarily entail that children believe non-intentional actions are *incapable* of producing desired outcomes (e.g. accidentally kicking a golf ball into the hole) or that they *must* always produce undesired outcomes.

This study provides developmental evidence of the interaction between action understanding and causal reasoning. One-year-olds did not selectively play with either button over the other, implying that they believed the buttons were either equally efficacious or equally useless. This is relatively surprising, since infants selectively imitate intentional reaching actions before their first birthday (Hamlin, Hallinan, & Woodward, 2008). However, the structure and mechanism of this particular causal toy may have exceeded their comprehension: 1-year-olds’ causal reasoning abilities are limited to simple contact and collision events (Oakes & Kannass, 1999). Furthermore, it is possible that 1-year-olds’ relatively limited experiences with buttons entail that they do not fully understand the different ways of interacting with them. Therefore, they may have failed to imitate the intentional action because the actions were ambiguous or unfamiliar. Lastly, they were comparatively the least physically capable of interacting with the toy; this difficulty may have barred them from exploring it in all the ways they wanted to. It is worth noting, however, that all participants were nevertheless able to perform some actions on the toy.

Our findings in the control conditions (Experiment 2 and Experiment 3) suggest that 2-year-olds are willing to tolerate sequential, but not temporal, disruption in potentially causal events. This is consistent with previous research. Sensitivity to spatiotemporal contiguity begins within the first few months of infancy (Leslie & Keeble, 1987; Oaks & Kannass, 1999; Saxe & Carey, 2006), and children believe that temporal contiguity is among the foremost requirements for causality (Mendelson & Schulz, 1976). However, young children do not believe that causal events must follow a particular sequence until the age of 3 (Bullock, Gelman, & Baillargeon; Kun, 1978; Bullock and Gelman, 1979; Rankin & McCormack, 2013). In fact, awareness of this causal rule develops in the middle of the third year: Schultz and Mendelson (1975) found that, given two potential causes of an event where one occurs after the other, younger 3-year-olds choose the erroneous (second) cause while older 3-year-olds do not. Awareness and application of this causal rule increases with age up to 5 years old (Rankin & McCormack, 2013). Given this, it is unsurprising that our modification in Experiment 2 failed to produce significant behavioral differences for 2-year-olds, who continued to attribute causality to the video.

One limitation of our study is that the children's actions were not limited to only one button at a time. This was particularly detrimental for our study of 3-year-olds, half of whom pushed both buttons simultaneously as their first button action. Thus, we were unable to gauge which button they believed would be more likely to activate the toy. Given that 2-year-olds believe that intentional actions are more likely that non-intentional ones to cause outcomes, however, it is likely that 3-year-olds share the same belief. One reason many 3-year-olds chose to push both buttons may simply be because they were larger, had a greater range of confident motion, and could therefore afford to perform more complex actions. Since they were shown that pressing both buttons guaranteed the toy's activation, they may have concluded that pressing both buttons in perfect imitation of the video would be the most reliable course of action.

Physical abilities aside, previous research has demonstrated that children begin to imitate others unnecessarily meticulously, or "over-imitate", beginning from age 3 (McGuigan & Whiten, 2009). They found that while 2-year-olds only emulated actions that were causally necessary in a demonstrated routine, 3-year-old children imitated all actions regardless of their necessity to the goal. In a separate study, 5-year-old children imitated all actions in a goal-directed sequence, even though they were able to selectively report only the necessary actions that actively contributed to the goal. (Kenward, Karlsson, & Persson, 2010). Kenward (2012) found that 3- and 5-year-olds insisted on a puppet character's completion of all actions – both necessary and unnecessary – even when its goal had already been achieved. Furthermore, there is cross-cultural evidence that the "over-imitation" phenomenon is innate and developmental: it was demonstrated in 3- to 6-year-old Westernized Australian children, Aboriginal Australian children, and African Bushmen children (Nielsen, Mushin, Tomaselli, & Whiten, 2014). Together, these studies suggest that over-imitation is a developmental phenomenon that indicates cultural and norm learning, and not causal learning. Therefore, the 3-year-olds in Experiment 1 may have pushed both buttons exactly as shown due to a belief that it would be the most socially appropriate and normative action. However, Schachner and Carey (2013) posit that children "over-imitate" because they infer that the actions are the goals themselves when they see mysterious but intentional actions.

In conclusion, we show that toddlers are able to integrate action understanding with causal reasoning to make judgments of effectiveness. They believe that intentional actions are more likely than non-intentional ones to be causally efficacious, and we show that this bias is not driven by an inherent preference for intentional actions. Instead, it appears to be driven by causal reasoning. However, this behavior is overridden by meticulous imitation later in toddlerhood. Our findings may elucidate the way toddlers learn about their environments and make decisions about their actions; in addition, it opens further questions about the scope and valence of possible outcomes that toddlers may attribute to different types of causal actions.

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