

The invisible hand: Toddlers infer hidden agents when events occur probabilistically

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Abstract

This study looked at whether toddlers posit the existence of unobserved causes when events occur probabilistically. Older (18-24 months) and younger (12-17 months) children were introduced to novel events. An experimenter pressed a red handle and a lollipop emerged from a box; she then pressed a green handle and a cake emerged. These events were repeated three times. On the fourth trial, the experimenter switched either the order or relationship between events. In the Deterministic condition, the experimenter pressed the green handle first and the red handle second; in the Probabilistic condition, the red handle produced the cake and the green handle produced the lollipop. On the test trial, the experimenter pressed the red handle and a hand emerged, holding the lollipop. The older toddlers looked longer at the hand in the Deterministic than the Probabilistic condition, suggesting they inferred a hidden cause when the events occurred probabilistically.

Keywords: causal learning, determinism, toddlers, looking-time measures.

Introduction

The 19th century mathematician Pierre Simon-LaPlace speculated that if there were an intellect capable of analyzing all the forces operating in nature “to it nothing would be uncertain; the future, like the past, would be as the present before its eyes.” Twentieth century physics has made this view untenable; we now know that our universe is comprised of irreducible uncertainties. Nonetheless, the idea of indeterminate events boggles the imagination. We cannot resist explanation even if our world is resistant to it.

However inaccurate, a belief causal determinism may be advantageous for learning. A deterministic universe provides well-specified conditions under which a learner can infer the existence of hidden variables. If events appear to occur spontaneously, either an unobserved generative cause is present or an inhibitory cause is absent; if events appear to occur stochastically, either an unobserved inhibitory cause is present or a generative cause is absent.

Is a belief in causal determinism an artifact of Enlightenment thought or a fundamental feature of human cognition? Developmental evidence suggests that children resist both spontaneous and stochastic causation well before they receive formal science instruction. By the age of five, preschoolers posit hidden causes to account both for apparently uncaused events (Bullock, Gelman & Baillargeon, 1982; Chandler & Lalonde, 1994; Gelman, Coley, & Gottfried, 1994) and for caused events that occur

some, but not all, of the time (Schulz & Sommerville, 2006; see also Piaget & Inhelder, 1975).

However, relatively little is known about the origins of deterministic beliefs earlier in development. The vast majority of studies looking at indeterminate causation in infancy have focused only on the specific case of unexplained motion events (see Gelman & Gottfried, 1996; Gottfried & Gelman, 2005; Leslie, 1984; Luo & Baillargeon, 2005; Luo, Kaufman, & Baillargeon, 2009; Markson & Spelke, 2006; Muentener, Bonawitz, Horowitz, & Schulz, 2012; Premack, 1990; Saxe, Tenenbaum, & Carey, 2005; Saxe, Tzelnic, & Carey, 2007; Spelke, Phillips, & Woodward, 1995). Thus for instance, if an inanimate object flies over a wall, infants seem to be less surprised if a hand is revealed at the origin of the object’s movement than at the terminus of the movement, suggesting that infants posit hidden causes when objects appear to move spontaneously (Saxe et al., 2005; 2007). Recent work has extended these findings beyond motion events: infants infer the presence of agents as causes not only when objects move, but also when they change states spontaneously (i.e., when a box breaks apart or plays music; Muentener & Carey, 2010).

However, infants’ expectation that physical events have causes may not imply any broader commitment to determinism. Are toddlers sensitive to stochastic causal events as well as spontaneous ones? Some suggestive evidence that toddlers ($M = 18$ months) resist probabilistic causation comes from the finding that toddlers imitate deterministically effective actions more faithfully than they imitate probabilistically effective ones (Schulz, Hooppell, & Jenkins, 2008). However, we do not know whether toddlers actually posit the existence of unobserved causes when events occur probabilistically. The current study investigates this question. Given that positing unobserved variables might be more complex than differential exploration, we used 18-months as the bottom of our range to test a group of older toddlers, 18-24 months, and we compared their performance to younger children, 12-17 months.

We introduced toddlers to novel causal relationships that were either deterministic (Cause A generated effect A 100% of the time, and Cause B generated Effect B 100% of the time) or probabilistic (Cause A generated Effect A 75% of the time and Effect B 25% of the time; Cause B generated Effect B 75% of the time and Effect A 25% of the time). We hypothesized that if toddlers are causal determinists, then they might infer the existence of an unobserved agent given probabilistic evidence but would have no reason to expect

an unobserved causal agent given deterministic evidence. Following the approach used in previous studies (Muentener & Carey, 2010; Saxe et al., 2005; 2007) we used a human hand as the candidate causal agent. We predicted that when the hand is revealed, toddlers would look at it longer in the Deterministic condition, when no agent is expected, than the Probabilistic condition, where an unobserved cause might be inferred.

Methods

Participants

Sixty-four toddlers (mean age: 17.2 months; range: 12.0 to 23.5 months) were recruited at a Children's Museum. We tested both younger (12-17 months) and older (18-24 months) toddlers. There were 16 toddlers in each condition (age group \times evidence conditions). An additional 23 toddlers were recruited but not included in the final sample due to: experimenter error ($n = 10$), fussiness ($n = 9$), or parent interference ($n = 4$). There were equal number of boys and girls.

Materials

Toddlers were introduced to a purple box (37.6 cm \times 29.2 cm. \times 20.3 cm.) with two handles (21.6 cm in length). The left handle was red with black stripes. The right handle was green with white spots. See Figure 1. The box was placed in front of a black foam board screen (117.9 cm \times 97.8 cm). The experimenter could hide behind the screen and observe the child through pinholes in the screen. Two openings in the screen on either side of the box allowed the experimenter to reach her hands through to manipulate the handles. The box had an opening in the back and the top so that the experimenter could conceal her hand in the box and lift objects out of the box. When a handle was pressed the experimenter lifted either a lollipop (9.4 cm in diameter) or a toy cake (7.6 cm in height, 7.6 cm in width) out of the box. An MVP player was also used: the red handle was always accompanied by the sound of an ascending scale on a xylophone; the green handle was always accompanied by the sound of a descending scale on a xylophone.

Procedure

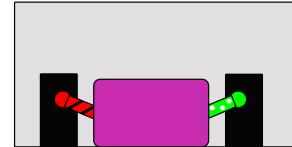
Toddlers were recruited from a local Children's Museum and tested in a private room located on the museum floor. The child was placed in a high chair approximately 100 cm in front of the box. The child's parent sat to the right of the high chair, out of the child's direct line of sight.

The experimenter pointed to the box and the two handles. See Figure 1. Then she went behind the screen. The experimenter knocked on the center of the box behind the screen and said, "Hi, [child's name]! Watch this box!" She began the **Familiarization Trials** by putting her hand out of the left hole and waving at the child. She then pressed the red handle and, with her other hand concealed in the box, triggered the ascending scale and lifted the lollipop

out of the box. Pilot work established that to an adult observer, it looked like the handle caused the lollipop to emerge from the box. She held the lollipop up for 2 seconds

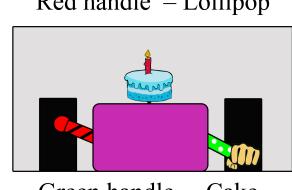
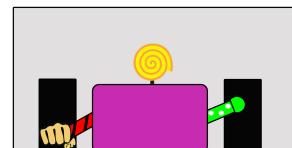
Initial Display

A box with two handles.



Familiarization Trials

When the red handle is pressed, the lollipop pops up; when the green handle is pressed, the cake pops up. This sequence was repeated three times.



Green handle - Cake

Switch Trial

Deterministic Condition
(Switch the order.)

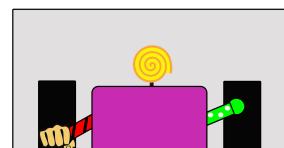


Green handle - Cake

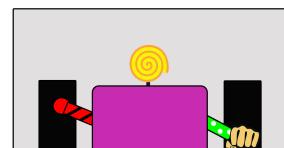
Probabilistic Condition
(Switch the relation.)



Red handle - Cake



Red handle - Lollipop



Green handle - Lollipop

Test Trial

When the hand presses the red handle, the other hand holding the lollipop pops up.

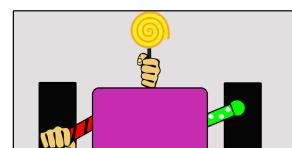


Figure 1: Procedure of the experiment.

and then released the red handle and simultaneously returned the lollipop to the box. She brought her hand back behind the screen. She then put her hand out of the right hole and waved at the child. She pressed the green handle and, with her other hand concealed in the box, triggered the descending scale and lifted the cake out of the box. She held the cake up for 2 seconds and then released the green handle and simultaneously returned the cake to the box. The

experimenter repeated the familiarization trials a total of three times.

On the **Switch Trial**, the experimenter said, “[child’s name], watch!” In the Deterministic condition, she switched the order of events, repeating the events in the Familiarization Trials except that she pressed the green handle first and the cake popped up; she then pressed the red handle and the lollipop popped up. In the Probabilistic condition, the experimenter switched the relationship between events, repeating the events in the Familiarization Trials except that when the experimenter pressed the red handle, the cake popped up; when she pressed the green handle, the lollipop popped up.

On the **Test Trial**, the experimenter put her hand out of the left hole and waved to the child. She then said “Aha!”, pressed the red handle and lifted her hand holding the lollipop all the way out of the box so that both her hand and the lollipop were visible to the child. She remained stationary in this position until the child looked away from the stage for at least 2 consecutive seconds. Note that she ran the familiarization, switch and test trials cohesively without measuring children’s looking times to each trial. Most of the children were engaged in the experiment and kept looking all through it. A coder blind to the conditions coded the children’s looking times from the beginning of the “Aha!” sound to the start of the 2-second looking away off-line from videotape. The blind coding from videotape corroborated the experimenter’s online judgment in all but three cases; three children were dropped from the analysis and replaced due to premature termination of the test trial. A second coder blind to the conditions coded one third of the clips. Inter-coder reliability was 95.6%.

Results

We examined the effect of the condition manipulation on toddlers’ looking time to the test trial separately within each age group (12-17 months, 18-24 months; see Figure 2). The 12 – 17 month olds, looked equally long at the test trial in the Deterministic and Probabilistic conditions (Deterministic mean: 10.5 s; Probabilistic mean: 9.8 s; $t(30) = .39$, $p = .698$). However, the 18 – 24 month-olds looked significantly longer at the test trial in the Deterministic condition than the Probabilistic condition (Deterministic mean: 13.7 s; Probabilistic mean: 8.2 s; $t(30) = 2.51$, $p = .018$). This is consistent with the possibility that children had inferred the presence of an unobserved candidate cause in the Probabilistic condition but not the Deterministic condition.

Note the Switch Trial and the Test Trial were perceptually more similar to each other in the Deterministic condition than the Probabilistic condition. In the Deterministic condition, the only difference between the last event of the Switch Trial and the Test Trial was the presence of the hand; in the Probabilistic condition both the handle pressed and the hand differed. This suggests that the toddlers in the Deterministic condition looked longer at the Test Trial not because it was perceptually more novel but because the

hand was more unexpected in the Deterministic condition than the Probabilistic condition.

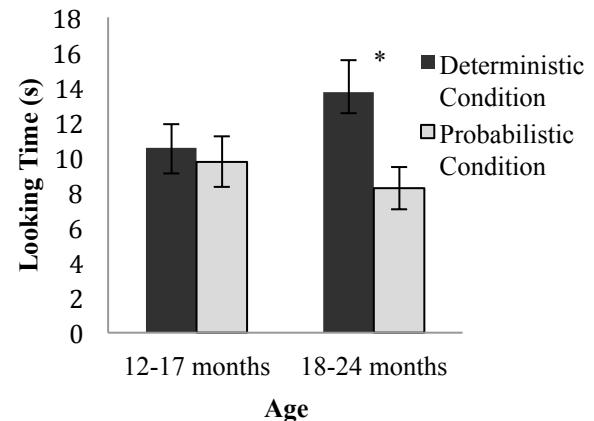


Figure 2: Looking times on the deterministic and probabilistic conditions as a function of age. * $p < .02$

Discussion

These results suggest that 18-24 month-olds posit unobserved causes when they observe probabilistic evidence. Toddlers who saw a stochastic relationship between causes and effects appeared to be less surprised that a human hand was involved in the events than toddlers who saw a deterministic relationship. This is consistent with the possibility that toddlers are causal determinists.

However, the current results also leave a number of questions unanswered. Children may assume that artifacts behave deterministically without extending this assumption to the physical world more broadly. Artifacts, including the stimuli used here, may have particularly salient, and familiar, deterministic causal relationships. We do not know to what extent toddlers would infer the presence of unobserved causes to account for naturally occurring probabilistic events. Additionally, we do not know to what extent either adults or children extend a belief in causal determinism beyond the physical world, to psychological and social events. Future research might investigate the extent to which children draw inferences consistent with causal determinism across a broader range of contexts.

Additionally, we do not know why the younger toddlers in our study failed to distinguish the Deterministic and Probabilistic conditions. It is possible that 12 – 17 month-olds accept that events can happen stochastically. Alternatively, given that there were only three Familiarization Trials and a single Switch Trial, the distinction between the conditions may have been too subtle for the younger toddlers to detect. Younger toddlers might have failed to learn the causal relationships initially, or failed to detect either the order or relational change. Given more exposure to the target events, even young toddlers and infants might posit unobserved causes to explain probabilistic evidence.

Finally, it would be interesting to know what kinds of unobserved causes children allow as explanations for

probabilistic evidence. Saxe et al. (2005) found that infants failed to treat one object as a cause of another object's motion, although they accepted both a hand and a novel, handless agent puppet as potential candidate causes (Saxe, et al., 2007). Similarly Muentener & Carey (2010) found that infants accepted a hand but not an object as a candidate cause of another object changing state. Finally, Newman, Keil, Kuhlmeier, and Wynn (2010) found that infants expected that agents (balls with eyes) could add order or structure to a scene but that objects (balls without eyes) could not. In this study, we only tested toddlers' inferences about human agents as candidate causal agents in probabilistic events; it would be interesting to know whether toddlers' inferences about the unobserved causes behind probabilistic events are limited to agents.

What the current study does establish is that even toddlers' causal inferences go well beyond the evidence they observe. Given sparse data for a novel probabilistic causal relationship, toddlers inferred the existence of an unobserved causal agent. To the degree that a belief in causal determinism shapes the inferences even of one-and-a-half-year-olds, they are well equipped for exploration and discovery.

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