Causal Determinism and Preschoolers' Causal Inferences

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Abstract

Three studies investigated children's belief in causal determinism. If children are causal determinists, they should infer the existence of unobserved causes whenever effects occur stochastically. In Experiment 1, preschoolers saw a stochastic generative cause and inferred the existence of an unobserved inhibitory cause. In Experiment 2, preschoolers appropriately traded-off inferences about the presence of unobserved inhibitory causes and the absence of generative causes. Experiment 3 suggested that children resist inferring stochastic causation even though they accept non-causal stochastic relationships. Children's belief in determinism seems to support inferences about causal relations not obtainable from other cues

Introduction

Many researchers have suggested that children's knowledge about the world takes the form of causal theories, in which unobserved causes play a central role (e.g., Carey, 1985; Gopnik & Meltzoff, 1997; Keil, 1989; Wellman, 1990). However, children's theories, and the unobserved causes they posit, seem to change with evidence (Bartsch & Wellman, 1995; Slaughter & Gopnik, 1996). This suggests that children actually learn about unobserved causes from the pattern of events they see in the world. But what mechanisms might support this sort of learning? How could children learn about unobserved causes from observed events?

Recent research suggests that both adults and children can use patterns of evidence and interventions to infer an unobserved common cause of correlated events (Gopnik, et al., 2004; Griffiths, Baraff, & Tenenbaum, 2004; Kushnir, Gopnik, Schulz, & Danks, 2003). However, such findings do not explain how children infer unobserved causes of single events. Some researchers have suggested that a belief in causal determinism may play a role in this type of inference (Bullock, Gelman, & Baillargeon, 1982; Gelman, Coley, & Gottfried, 1994). If children believe that all events have causes, they should infer the existence of unobserved causes whenever effects occur spontaneously. Considerable research suggests that both adults and children do this (Bullock, et al.,, 1982; Gelman, et al., 1994; Luhmann & Ahn, 2003).

However, causal determinism can also reflect a much stronger belief; the belief that causes act deterministically. This belief was perhaps most famously articulated by the mathematician, Pierre-Simon Laplace, who noted that if there were "an intelligence knowing all the forces acting in nature . . . (and) its intellect were sufficiently powerful to subject all data to analysis, to it nothing would be uncertain" (1814/1951). From the perspective of Laplacian determinism, the appearance of stochastic causation implies that the causal account is incomplete; there must be unobserved causal factors we are failing to consider. If children are Laplacian determinists, they should infer the existence of unobserved causes, not only whenever effects occur spontaneously but also whenever observed causes produce effects stochastically.

We do not want to claim that Laplacian determinism provides an accurate picture of causal relations in the world. However, a belief in causal determinism need not be metaphysically accurate to be functionally adaptive. Indeed, assuming determinism may be adaptive precisely because it induces human beings to search for the existence of unobserved causal factors in indeterminate causal scenarios.

A belief in Laplacian determinism might also lead children to prefer certain causal hypotheses to others. It seems plausible that children infer the existence of unobserved causes parsimoniously; that is, they do not infer the existence of unobserved causes when observed causes could deterministically account for the available evidence. If so, then given a choice between two hypotheses: 1) a potential cause that deterministically produces an effect, or 2) another potential cause that produces the effect stochastically due to an unobserved variable, children should prefer the former account. Critically however, if children are causal determinists, their commitment to determinism should be specific to causal contexts. Thus we expect that even though children should resist inferring probabilistic causation, they should accept probabilistic associations.

In this paper, we look at whether children are causal determinists in the domain of physical causality. Experiment 1 looks at whether, consistent with Laplacian determinism, children infer the existence of unobserved inhibitory causes when observed causes behave stochastically. Experiment 2 looks at whether children appropriately trade-off inferences about the presence of unobserved inhibitory causes and the absence of unobserved generative causes. Experiment 3 looks at whether children resist inferring stochastic causation and whether this resistance is specific to causal contexts.

Experiment 1

In Experiment 1, we show preschool children a generative cause of an effect and lead them to believe that the generative causal account is complete. We then show the children that the generative cause sometimes fails to produce the effect: $1 > p(Y | X) > p(Y)$. If children are strong causal determinists and believe that effects should be perfectly predictable from their causes, children should infer the existence of an unobserved inhibitory cause. [1] In the control condition, the generative observed cause perfectly predicts the effect: $p(Y | X) = 1$, and children should not infer the existence of an unobserved inhibitor.

Methods

Participants
Thirty-two children ranging in age from 3;8 to 5;5 (mean age: 4;7) were assigned to either a Stochastic Causation condition or a Deterministic Causation condition.

Materials
A specially designed remote-operated toy was used. The toy consisted of a light encased in a 12 cm x 17 cm x 8 cm wooden box with an orange Lucite top. The box was attached to a remote control switch. When the sliding switch on the remote was put in the "on" position, the light turned on and the top glowed orange. When the remote was put in the "off" position, the light turned off. In addition, if the switch was pushed all the way the effect occurred and if it was pushed almost but not quite all the way forward the effect failed to occur. However, children were never able to see how far the switch was pushed; from the children's perspective, the switch was activated on every trial, and the toy sometimes lit up and sometimes did not.

A 7 cm diameter metal ring and a 3 cm black, disc-shaped squeezable keychain flashlight were also used. The bulb on the flashlight was inconspicuous and no child identified the squeezable object as a flashlight.

Procedure
The experimenter set the toy box and the remote control switch on the table. The experimenter placed the ring on top of the toy box. Then she pointed to the remote control and said, "See this switch? This switch makes my toy light up." The experimenter pushed the switch forward and the toy

box lit up. She then slid the switch back and the light extinguished. The experimenter repeated this three times. Children thus had evidence that pushing the switch forward was a generative cause of the effect.

Children were then given evidence for an inhibitory cause that could prevent the effect. The experimenter said, "The toy only works if this ring is on top of the toy. If I remove the ring, the switch won't work and the toy won't light up." The experimenter removed the ring from the top of the toy and pushed the switch. The toy failed to light up (in fact, because the experimenter surreptitiously pushed the switch only part way). From the child's perspective, however, removing the ring prevented the switch from working and the toy from lighting up. The experimenter pushed the switch forward twice more and each time the toy failed to light up.

The experimenter then put the ring back on top of the toy. The experimenter pushed the switch (all the way) and the toy lit up. For the remainder of the experiment, the ring remained on top of the toy. This procedure provided the children with an observed inhibitory cause that could prevent the effect; the children in both conditions knew that removing the ring would stop the switch from working and the toy from lighting up.

Stochastic Causation Condition, The experimenter gave the remote control switch to the confederate and said, "Now my friend Catherine is going to try to make the toy light up." The confederate pushed the switch and the toy failed to light up (even though the ring was on the toy). The experimenter said, "Hmm . . .the toy didn't light up." The confederate pushed the switch again. This time the toy lit up. These interventions were repeated so that the confederate pushed the switch a total of eight times according to the following pattern: no effect, light, no effect, no effect, no effect, no effect, light, no effect. From the child's perspective, the confederate pushed the switch eight times but the toy only lit up twice.

After the confederate pushed the switch forward and back for the eighth time, the experimenter opened the palm of her right hand, and said, "Look what I have in my hand". This revealed the flashlight, which the experimenter had held surreptitiously concealed in her hand throughout the trials. Children did not know about the concealed flashlight and had never seen it until that moment. The experimenter then placed the flashlight on the table. She took the remote control from the confederate and told the child, "We're going to play a game. On the count of three, I'm going to push this switch to make this toy turn on. Can you make it so the switch won't work and the toy won't turn on?" She placed the toy with the ring on top and the flashlight within reach of the child (left/right position counterbalanced between subjects), put her own hand on the remote control switch, and counted to three.

The children had both observed and been told that removing the ring would prevent the switch from working and the toy from turning on. However, the children had also observed that sometimes the switch succeeded in making

the toy light up and sometimes the switch failed -- even when the ring was on top of the toy.

If children believe in Laplacian determinism and are sensitive to instances of imperfect causation, children should infer the existence of an unobserved, inhibitory cause during the test trials. If so, the flashlight concealed in the experimenter's hand might plausibly be the unobserved inhibitor of the effect. (Conceivably, the experimenter might have sneakily prevented the effect some of the times the confederate had tried to generate it.) Thus although the children never saw the flashlight do anything at all, they might try to inhibit the effect by intervening on the flashlight rather than on the ring.

Deterministic Causation Condition. This was identical to the Stochastic Causation condition except that all eight times that the confederate pushed the button, the toy lit up. In this condition, the children should not infer the existence of an unobserved inhibitory cause, and should not identify the flashlight with that cause. When asked to inhibit the effect, children should pick the known inhibitory cause and remove the ring.

Results and Discussion

Children were coded as choosing the unobserved cause if they picked up the flashlight, aimed it at the toy, and either activated it or attempted to activate it by pushing on its surface. Children were coded as choosing the observed inhibitory cause if they removed the ring.

In the Stochastic Causation condition, 15 of the 16 children (94%) intervened on the unobserved inhibitory cause (the flashlight) and only one child (6%) intervened on the observed inhibitory cause (the ring). By contrast, in the Deterministic Causation condition, two of the 16 children (12.5%) intervened on the unobserved inhibitory cause while 14 children (87.5%) intervened on the observed inhibitory cause.

Children were significantly more likely to choose the unobserved inhibitory cause in the Stochastic Causation condition than in the Deterministic Causation condition and significantly more likely to choose the observed inhibitory cause in the Deterministic Causation Condition than in the Stochastic Causation condition (χ^2 (1, n = 32) = 21.21, $p <$ .001). Within the Stochastic Causation condition, children were significantly more likely to choose the unobserved inhibitory cause than the observed inhibitory cause (χ^2 (1, n = 16) = 12.25, $p <$ .001) and within the Deterministic Causation condition, children were significantly more likely to choose the observed inhibitory cause than the unobserved inhibitory cause (χ^2 (1, n = 16) = 9.00, $p <$ .005).

These results are consistent with the idea that children are strong causal determinists. When the observed generative cause behaved stochastically, children inferred the existence of an unobserved inhibitory cause; they prevented the effect by creating a novel intervention on a previously unobserved variable. However, when the observed generative cause behaved deterministically, children did not infer the existence of an unobserved cause; they ignored the

flashlight and imitated the experimenter's intervention on the ring. Note that the two conditions were identical in all other respects so children could not have been using pragmatic, spatio-temporal, or mechanical cues to make this inference – the pattern of probabilities was the only difference between conditions.

Experiment 2

The results of Experiment 1 suggest that children will infer the existence of an unobserved inhibitory cause if effects occur stochastically. However, in some cases, a generative cause might appear to act stochastically even if no inhibitory cause exists. Apparent violations of determinism might occur for instance, if you assume that the generative cause is present on every trial when in fact, it is only present some of the time. Thus, it is not *always* correct (even under the assumptions of Laplacian determinism) to infer the existence of an unobserved inhibitory cause to explain stochastic effects; children should only infer the existence of an unobserved inhibitory cause if they believe the generative cause is present and the generative causal account is complete.

In Experiment 2, we looked at what children would conclude if they were led to believe that the generative cause might have been absent when the effect failed to occur. We replicated the Stochastic Causation condition of Experiment 1 with a single modification. After seeing the evidence, children were led to believe that the switch might not have been activated on every trial. Thus the stochastic absence of the generative cause (although unobserved) could in principle account for the stochastic effects. If children are sensitive to the tradeoff between explaining stochastic causation as the absence of a generative cause or the presence of an inhibitory cause, they should be significantly less likely to infer the presence of an inhibitory cause in this experiment than in the Stochastic causation condition of Experiment 1.

Methods

Participants
Sixteen children were tested, ranging in age from 3;8 to 5;5 (mean age: 4;7).
Materials
The same materials used in Experiment 1 were used in this experiment.

Procedure
The procedure was identical to the procedure in the Stochastic causation condition of Experiment 1, except that after the confederate pushed the button for the eighth time, the experimenter took the switch from the confederate and said, "You know, in order to make the toy work, you have to push the switch all the way forward. If you just push the switch part of the way, the toy won't work." Children received this information after all the trials were completed, so they had no opportunity of observing, on any given trial,

whether the confederate moved the switch into the correct position or not.

Results and Discussion

The children's responses were coded as in Experiment 1. Twelve of the sixteen children (75%) chose the observed inhibitory cause (the ring) while only four of the 16 children (25%) chose the unobserved inhibitory cause (the flashlight) Children were significantly more likely to choose the observed inhibitory cause than the unobserved inhibitory cause (χ^2 (1, n = 16) = 4.00, p < .05). Critically, children were significantly less likely to choose the unobserved inhibitory cause in this experiment than they were in the otherwise identical Stochastic causation condition of Experiment 1 (χ^2 (1, n = 32) = 15.68, p < .001. Indeed, children were no more likely to choose the unobserved inhibitory cause in this experiment than were children in the Deterministic causation condition of Experiment 1 (χ^2 (1, n = 32) = .82, p = ns).

The Stochastic Causation conditions of Experiments 1 and 2 were identical except for a single manipulation: in Experiment 2, children were cued to the possibility that the generative cause might have been absent when the effects failed to occur. This manipulation had a dramatic effect on children's inferences. When the stochastic effects could plausibly be due to the failure of the switch, children were significantly less likely to infer the existence of an unobserved inhibitory cause.

Together with the results of Experiment 1, the results of Experiment 2 suggest that preschool children are capable of remarkably nuanced causal inferences. If children observe that a generative cause produces an effect stochastically, they infer the existence of an unobserved inhibitory cause. However, if children are given reason to believe that the failures of the effect might be due to the absence of the generative cause, they are less likely to infer the existence of an unobserved inhibitory cause.

Experiment 3

Experiment 1 showed, not only that children infer the existence of unobserved causes when effects occur stochastically, but also that children do not infer the existence of unobserved causes when effects occur deterministically. That is, children seem to be parsimonious about inferring the existence of unobserved causes. If children are causal determinists but are parsimonious about inferring the existence of unobserved causes, then they should resist attributing an effect to a stochastic cause whenever alternative (potentially deterministic) candidate causes are present.

Critically however, if children are causal determinists, then their belief in determinism should be restricted to causal contexts. Even if children resist inferring that X is a probabilistic cause of Y, they should accept that X and Y might be probabilistically associated. Experiment 3 tests the possibility that children will resist inferring probabilistic relations when the relationships are causal but will accept probabilistic relations when the relationships are non-causal.

Methods

Participants
Sixty-four children ranging in age from 3;11 to 5;3 (mean age: 4;6) were randomly assigned to one of four conditions: Causal Novel Pairing, Causal Unexpected, Associative Novel Pairing, and Associative Unexpected.

Materials
A black cardboard box (30 cm x 15 cm x 10 cm) was used in this experiment. One side of the box had a wax-paper cutout of a moon; the other had a cut-out of a flower. Two colored lights (green and purple) were on top of the box and two lights (red and yellow) were hidden inside the box. (See Figure 1.) A blue cellophane filter was also used. The lights were wired so that one concealed switch turned on the green and yellow lights (simultaneously); another concealed switch turned on the purple and red lights (simultaneously). The lights underneath the box were positioned so that the wax paper cutout glowed (red or yellow) when the appropriate switch was flipped. The red and yellow filters on top of the lights could be removed, allowing the lights to turn white (when no filter was on top) or blue (when the cellophane filter was used) instead of red or yellow. A black cardboard screen was also used.

Figure 1: Schematic of the toy used in Experiment 3

Procedure
Causal Novel Pairing Condition. The experimenter set the box on the table and said "Look, here's my toy. See? There's a moon on this side, and on top, there's a purple button and a green button." (The lights protruded from the box and could resemble colored buttons.) The experimenter turned the toy box around and said, "Look, there's a flower on this side and here's the green button and the purple button on top." Half the participants saw the moon first; half saw the flower first.

The experimenter turned the box so that one shape (e.g., the flower) faced the child and the child could not see the shape on the other side. She said, "I'm going to push the purple button and let's see what happens." She pushed the top of the purple light and simultaneously (surreptitiously) flipped the switch. The "button" turned purple and the flower turned red. Pilot work with adults suggested that this provided a strong illusion of causality; it looked as if the experimenter had pushed a purple button that simultaneously lit up and caused the flower to turn red.

The experimenter said, "Oh look, I pushed the purple button and the flower turned red!" She then removed her

hand from the purple light and simultaneously (surreptitiously) flipped the switch off. The lights extinguished. The experimenter then turned the box so the moon faced the child and the child could not see the flower. She said, "I'm going to push the green button and let's see what happens." She pushed on the green light and simultaneously (surreptitiously) flipped the switch. The "button" turned green and the moon turned yellow. She said, "Oh look, I pushed the green button and the moon turned yellow!" She repeated the entire procedure two more times. The order of presentation (moon vs. flower) was counterbalanced between participants.

The children were then given two inference tasks (order counter-balanced between participants). In one inference task, the experimenter placed a black cardboard screen over the top two lights so that the "buttons" were no longer visible. She told the children, "I'm going to hide the buttons now." The children saw a novel effect: either the moon turned red or the flower turned yellow. The experimenter asked, "Which button did I push?"

The other inference task was similar except that children were asked to make an intervention of their own. The black screen was not used. The experimenter turned the toy so that one of the shapes faced the child and asked the child to produce a novel effect: "Can you make the flower turn yellow?" or "Can you make the moon turn red?"

The children had never seen these effects before (the moon turning red or the flower turning yellow). However, for each choice, one button suggests stochastic causation (we will call this the Stochastic choice) while the other does not (the Alternative). The children knew for instance, that the green button caused the moon to turn yellow. If the children inferred that the green button also caused the moon to turn red, they would have to infer that the green button behaved stochastically: sometimes turning the moon yellow and sometimes not (i.e., when turning the moon red). The children had no information about what the purple button did to the moon; the experimenter had only pushed the purple button in the presence of the flower. However, if children resist inferring stochastic causation, they should consistently prefer the Alternative to the Stochastic choice. The children know that the purple button can turn things red, so they should readily infer that the purple button made the moon turn red. This condition thus provided a baseline measure of children's ability to make novel causal inferences in this task.

Causal Unexpected Condition. This condition was identical to the Causal Novel Pairing condition except that just before the inference tasks, the experimenter surreptitiously removed the yellow filter from one light and replaced it with a blue cellophane filter and removed the red filter from the other light (so the light would shine white). The novel effects for the inference tasks were now the moon turning blue or the flower turning white. As in the Causal Novel Pairing condition, one button for each event suggests stochastic causation while the other does not. When for instance, the moon turns blue, the children could infer that

the green button behaved stochastically (sometimes turning the moon yellow and sometimes turning the moon blue). Alternatively, the children could infer that the purple button turned the moon blue, although they had no information about what the purple button did to the moon and no information that the purple button could turn anything blue. However, if the children are determinists, they should resist the stochastic inference and prefer the purple button.

Associative Novel Pairing Condition. The Associative Novel Pairing condition was identical to the Causal Novel Pairing condition except that the top lights were identified as lights rather than buttons. Children were given a non-causal cover story: "The lights are on a timer. Sometimes the lights go on and off. Let's see what happens." The experimenter pointed to the purple light (instead of pushing it) and simultaneously (surreptitiously) flipped the switch. The light turned purple and the flower turned red. She said, "Oh look, the flower turned red and the purple light went on!" The same procedure was followed for the moon and the green light.

In the inference task, the experimenter placed the black cardboard screen over the lights and told the children, "I'm going to hide the lights now." On one trial, children saw the moon turn red, on the other they saw the flower turn yellow (order counterbalanced between participants). In each case the experimenter pointed towards the screen and asked, "Which light do you think went on?" (Because the Associative condition was non-causal, children were given two inference tasks rather than one inference and one intervention task.)

In this condition, the children might make either of two associative inferences. They might associate the buttons with the shapes and accept the probabilistic association with color, or they might associate the buttons with the color and accept the probabilistic association with the shape. In the non-causal context, neither inference violates causal determinism. If determinism is specific to causal contexts, then in this condition, the children should reason associatively and choose between the lights at chance.

Associative Unexpected Condition. This condition was identical to the Associative Novel Pairing Condition except that, as in the Causal Unexpected condition, just before the inference tasks the experimenter replaced the filters so the lights would turn blue or white. We predicted that the children would make the Stochastic inference in this condition. When, for instance, the moon turned blue, the children should choose the green light (accepting that the green light might be stochastically associated with the color yellow) because the alternative, the purple light, is not associated with either the color or the shape. If the children are reasoning associatively, they should consistently prefer the Stochastic choice to the Alternative in this condition.

Results and Discussion

There were no significant differences between the inference and intervention task in either Causal condition or between the two inference trials in either Associative

condition so for all conditions, we will report the data across both trials.

All the predictions were confirmed. The children were significantly more likely to make the Stochastic inference across trials in the Associative Novel Pairing Condition than in the Causal Novel Pairing condition (χ^2 (1, N = 32) = 5.00, p < .05); in the Associative Unexpected condition than in the Causal Novel Pairing condition (χ^2 (1, N = 32) = 10.49, p < .01); in the Associative Novel Pairing condition than in the Causal Unexpected condition (χ^2 (1, N = 32) = 7.31, p < .01); and in the Associative Unexpected condition than in the Causal Unexpected condition (χ^2 (1, N = 32) = 13.33, p < .001). Within both the Causal Novel Pairing and the Causal Unexpected conditions, children were children were significantly more likely to make the Alternative inference across trials than to make the Stochastic inference across trials (p < .025 by binomial test). Within the Associative Novel Pairing condition, children were exactly as likely to make the stochastic inference as the alternative inference across trials. Within the Associative Unexpected condition children were significantly more likely to make the Stochastic inference than the Alternative inference across trials (p < .025 by binomial test). In every condition, some children perseverated on a single light (i.e., they chose purple on both trials or green on both trials.) See the graph in Figure 2 for children's responses.
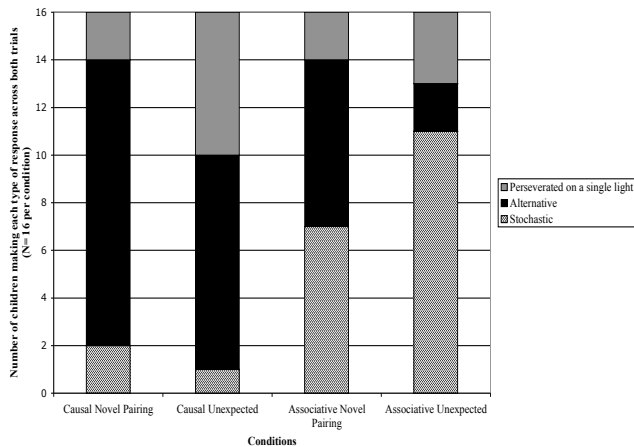

Figure 2: Children's responses in Experiment 3

These findings suggest that children's belief in determinism helps constrain their inferences about the cause of novel events. Children resist making causal attributions that would suggest stochastic causation. They look instead for alternative causal accounts. The results also suggest that children's belief in determinism is specific to causal contexts.

General Discussion

Children seem to believe that physical causes produce their effects deterministically. This assumption allows children to use probabilities to learn about unobserved causes. It also allows children to trade-off inferences about the presence of unobserved inhibitory causes and the absence of unobserved generative causes. Moreover, the assumption of causal determinism seems to constrain children's inferences about the cause of novel effects: given an alternative, children seek to avoid inferring probabilistic causation. Finally, children's assumptions about determinism are causally specific. Preschoolers are sensitive to the difference between causal interventions and observed associations and they draw different conclusions when the context is causal than when the context is associative. In all these respects the assumption of causal determinism seems to play an important role in shaping children's causal learning. Such inferences might allow children to discover new unobserved causal structures and might support changes in children's intuitive theories.

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