Stretching to learn: Ambiguous evidence and variability in preschoolers' exploratory play

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Abstract

Children seem to learn about the causal structure of the world even in the absence of formal training. One possibility is that children can learn causal relationships from evidence generated in the course of their spontaneous, exploratory play. In this study, we looked at whether the pattern of children's free play with a toy is affected by the quality of evidence they observe. When children received fully disambiguating evidence about the causal structure of a toy, their free play was largely restricted to the most convenient, effective actions. However, when children saw confounded evidence about the toy, their pattern of free play was more variable and exploratory. These results suggest that children's exploratory play can provide evidence to support causal learning.

Keywords: Causal learning; exploratory play; ambiguous evidence; cognitive development; preschoolers

Introduction

Young children reason about causality in many domains (Ahn, Gelman, Amsterlaw, Hohenstein, & Kalish, 2000; Flavell, Green, & Flavell, 1995; Gelman & Wellman, 1991; Harris, German, & Mills, 1996; Hatano & Inagaki, 1994; Perner, 1991; Wellman, Hickling, & Schult, 1997). Previous research suggests both that young children can learn new causal relationships using the patterns of evidence they observe, and that they can use their knowledge of causal relationships to generate novel predictions and interventions (Gopnik et al., 2004; Gopnik, Sobel, Schulz, & Glymour, 2001; Kushnir & Gopnik, 2005; Schulz & Gopnik, 2004; Schulz, Gopnik, & Glymour, 2007; Shultz & Mendelson, 1975; Siegler & Liebert, 1975). However, in most studies of causal learning, the relevant evidence has been provided by an experimenter through explicit demonstrations. Given that abundant research suggests children are poor at independently designing controlled experiments (Chen & Klahr, 1999; Kuhn, 1989), it is not clear how children might get informative evidence for accurate causal learning in the absence of such explicit demonstrations.

One significant source of information to support children's causal learning may be their spontaneous, exploratory play. Piaget (1930) believed that young children come to understand causal relationships through active exploration of their environment. While researchers have long acknowledged that children learn through play (Bruner, Jolly, & Sylvia, 1976; Singer, Golinkoff, & Hirsh-Pasek, 2006), surprisingly few studies have systematically investigated how exploratory play can support accurate causal learning. One such study, Schulz, Gopnik, & Glymour (2007), suggested that although children's self-generated data were much noisier than the data provided by an experimenter, children could use evidence generated by their own interventions to distinguish causal chains and common cause structures on a gear toy. Previous research also showed that the pattern of children's exploratory play can be affected by quality of the evidence children initially observe (Schulz & Bonawitz, 2007). In that study, children were introduced to a box with two levers. In one condition (the Confounded condition) the child and the experimenter held each lever and pushed the levers simultaneously; the child saw two toys pop up from the middle of the box (providing confounded evidence about the relationship between the levers and the toys). In another (Unconfounded) condition, the child and the experimenter "took turns" pushing the levers down so that the child could see which lever made which toy pop up (providing unconfounded evidence about the toy). The children were then left alone to play freely with this box and with another box: a new, one-lever box. Children who saw unconfounded evidence showed the standard novelty preference and chose to play more with the novel box; however, children who saw confounded evidence overrode the novelty preference and chose to play more with the familiar one.

These studies provide support for the claim that children selectively explore stimuli whose causal structure is ambiguous, and that children may resolve this ambiguity using evidence from their own interventions. However, in the paradigm used by Schulz and Bonawitz (2007), children's preference for the familiar toy was measured only in relation to their preference for a comparably salient novel toy. Given that children are rarely confronted with a choice between playing with two toys that are closely matched, this scenario is arguably somewhat artificial. If ambiguity of evidence genuinely affects the pattern of children's exploratory play, then observing different evidence should lead to differential exploration of one and the same toy. That is, the ambiguity of evidence should affect not just *whether* children explore a toy or not, but *how* they explore the toy.

In this study, we hypothesized that if children do not know the causal structure of a toy, they should exhibit relatively variable exploratory play. That is, children should engage in the type of play that might generate novel, informative evidence. By contrast, if children receive unambiguous evidence about the toy, they should exploit this knowledge and play with the toy in a way that is effective and convenient but less variable. If children do exhibit more variable exploratory play when confronted with ambiguous than unambiguous evidence, children's exploratory play could generate evidence to support causal learning.

Experiment

Methods

Participants Thirty-two preschoolers (mean age: 56 month; range: 48 – 66 months) were recruited from the Discovery Center in a metropolitan Science Museum. Sixteen children were tested in each of two conditions: a Confounded condition and an Unconfounded condition. There were approximately equal number of boys and girls in each condition. Children who attended to the toy for less than 20 seconds were dropped from the study: two children in the Unconfounded condition were replaced for this reason.

Materials The experimental stimuli consisted of a foam mat (24 x 12 inches) divided into two squares (12 x 12 inches), two semi-transparent acrylic boxes (approximately 8 x 8 x 4 inches) with light bulbs inside, and two acrylic blocks (2 x 2 x 1 inches). The boxes lit up when the blocks were placed on the foam mat. One side of the mat was colored black and the other white. Each side was also covered with wire mesh with distinct patterns (i.e. a square grid and a diamond grid), so that the sides of the mat appeared to be differentially wired and therefore be potentially plausible candidate causes for the differential activation of light boxes. Each block had distinct colors, blue and yellow, with a small knob on top. The boxes were covered with red and green felt. Each box contained red and green light bulbs, respectively, which were visible through a transparent window of the box. Each block was wirelessly connected to each box: when the blue block was placed anywhere on the mat (i.e., on either of the two sides), the red light went on and stayed on as long as the block remained on the mat. Similarly, the yellow block controlled the activation of the green light. The blocks activated the lights only when they were placed on the mat; however, the distinction between the two sides was only perceptual and not functionally meaningful for activation of the different lights.

Procedure Children were tested in a quiet corner in the Discovery Center, sitting next to the experimenter at a round table. The mat was positioned vertically with respect to the child so that one side (e.g. the black side) was directly in front of the child and the child had to reach across this side in order to place the block on the other (e.g. white) side. Because it was more convenient for children to play on the closer side of the mat; we predicted that children should play on the further side of the mat only if they were trying to discover whether the side of the mat was causally relevant to the outcome. The experimenter's position was equidistant from both sides of the mat. The light boxes were placed just beyond the mat, out of reach of children. The experimenter first asked the subject to point to each side of the mat, each box, and each block in order to draw attention to all of the stimuli. The position of the mat and the boxes, as well as the sequence of demonstrations by the experimenter (see Figure 1), was counterbalanced.

In the Confounded condition, the experimenter took one block (e.g., the blue block) and placed it on the closer (e.g., the black side) of the mat; the red box lit up, and the experimenter pointed to the light and said, "Wow, look! The red light turned on!" She repeated this action twice. Then she took the other block (yellow) and put it on the further (white) side of the mat, making the green box light up. She again pointed to the light, repeating this action twice. In this condition, the experimenter's demonstration provided insufficient evidence for disambiguating the causal structure of the toy: the different blocks or different sides of the mat might have triggered the differential activation of the lights.

In the Unconfounded condition, the experimenter took one (e.g., blue) block and put it on one the closer (e.g., black) side of the mat, pointing to the light that turned on (i.e., red). She then placed the same block on the far (white) side of the mat, showing that the blue block on the far side also activated the red light. Similarly, children saw that the yellow block activated the green light on both sides of the mat. In this condition, children saw unambiguous evidence that the kinds of blocks were causally relevant for the activation of the lights, and that the sides of the mat were irrelevant. In both conditions, after the child observed the evidence, the experimenter said "I'll be back in a minute, so you can go ahead and play" and walked out from the child's line of sight. She returned to the table after 60 seconds, or when the child lost interest, whichever came first.

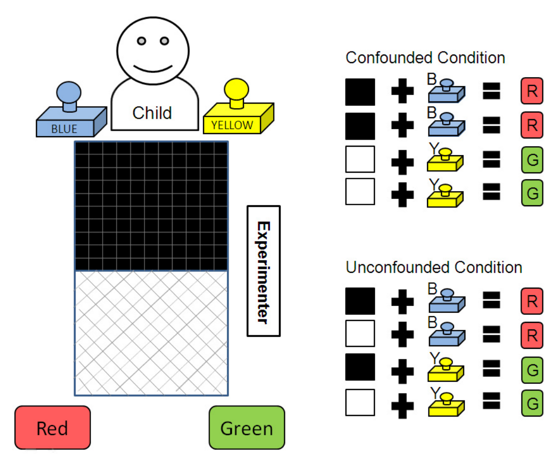

Figure 1: Schematic drawing of the experimental setup, and the sequence of demonstrations in Confounded and Unconfounded conditions.

Results & Discussion

In coding children's free play, we looked at: 1) the time children played with each block (Block Usage), 2) the time children played on each side of the mat (Mat Usage), and 3) how many children preferentially played on the closer side of the mat. We also looked at whether children in the Confounded condition generated informative evidence about the toy (that is, whether they tried each block separately on each side of the mat at least once over the course of free play). Children were counted as playing with a given block as long as a block remained in contact with the mat (regardless of the mat side). We calculated the Block Usage Ratio by looking at the proportion of time children played with a given block relative to the summed time playing with both blocks. We did not expect a preference for one block over another, so we arbitrarily chose the blue block to calculate the ratio (BU Ratio = Blue Block / (Blue Block + Yellow Block)).

Similarly, children were counted as playing on a side of the mat as long as either block remained in contact with that side of the mat. We calculated the proportion of time children spent playing on a given side of the mat relative to their summed play time on both sides. Because we predicted that, all else being equal, children would spend more time playing on the closer, more convenient side of the mat, we calculated the ratio with respect to the closer side (MU Ratio = Closer Side / (Closer Side + Further Side)). For example, a value of 0.5 in Mat Usage Ratio would indicate that the child spent exactly the same amount of time on each side of mat; by contrast, a Mat Usage Ratio of 1.0 would indicate play only on the closer side. For individual preference for the mat side, a child was considered to preferentially play on the closer side if the Mat Usage Ratio was larger than 0.60. This criterion was chosen to avoid considering small deviations from 0.5 as evidence of preferential play.

There was no difference in the total time children played in each condition ($t(30) = 0.16$, $p > 0.8$). Block usage analysis confirmed that children in both conditions played equally with blue and yellow blocks ($t(30) = 0.32$, $p > 0.7$). However, we predicted that children in the Unconfounded condition would preferentially play on the closer (thus more convenient) side of the mat whereas children in the Confounded condition would override this preference and play equally on both sides. Mat Usage analysis confirmed this prediction: children in the Unconfounded children spent more time playing on the closer side of the mat than children in the Confounded condition ($t(30) = 2.57$, $p < 0.02$). Consistent with this result, more children played preferentially on the closer side of the mat in the Unconfounded condition (10 of 16 children) than in the Confounded condition (2 of 16 children) (χ^2 (1, N=32) = 8.53, $p < 0.003$). Seven of the sixteen children (44%) in the Confounded condition tried each block separately in each position at least once – generating exhaustively informative evidence about the toy.[1]

Table 1: Total play time, ratio of play time on the closer side, and the percentage of children who preferentially played on the closer side.

	Confounded	Unconfounded
Total Play Time (seconds)	52.19	52.75
Block Usage Ratio	0.49	0.51
Mat Usage Ratio*	0.56	0.67
Preferred Closer Side * (%)	12.5	62.5

* $p < 0.05$

General Discussion

These results suggest that children are not just sensitive to the formal properties of evidence such as confounding, but that their pattern of exploration is genuinely affected by the ambiguity of the evidence they observe. Children in both conditions saw interventions involving each block, each side of the mat, and each light exactly twice. The main difference between the two conditions was whether the combination of the blocks and the mat sides generated confounded or unconfounded evidence about the relationship between the causes and the colored lights. In the Unconfounded condition, the demonstration provided unambiguous evidence that the blocks were relevant and the mat sides were irrelevant to the differential activation of the lights; in the Confounded condition, the evidence failed to distinguish these possibilities. The children who observed disambiguating evidence used this knowledge to play with the toy in a less variable but more convenient way, whereas the children who observed confounded evidence engaged in more variable exploration of the toy (even though it required stretching across the mat). In the course of one minute of such free play, many of the children in the Confounded condition generated evidence that fully disambiguated the causal structure of the toy (akin to the evidence provided by the experimenter to children in the Unconfounded condition). Note that this differential pattern of play was not observed in the children's use of the blocks: children in both conditions had observed same evidence regarding the association between the lights and the blocks (see Figure 1), and both blocks were equally accessible. As expected, children in both conditions played equally with the yellow and blue blocks. Note further that in neither condition did the children merely copy the experimenter's actions. In the Unconfounded condition, the experimenter manipulated the

[1] It may seem odd that more children failed to generate the disambiguating evidence in the course of 60 seconds of free play. However, it was easy to hold one block in each hand and many of the children tended to play with both blocks simultaneously, which prevented them from placing only one block on the mat.

block equally often on both sides; the children however, showed a side preference. In the Confounded condition, the experimenter always paired a single color of block with a single side; many of the children, by contrast, tried each block on each side.

There are three possible explanations for children's differential play in this study: 1) children might engage in less variable play when evidence is unambiguous; 2) children might engage in more variable play when evidence is confounded or 3) both factors might play a role. That is to say, children might use the unconfounded evidence to learn the relevant causal relationships and therefore be able to eliminate the inconvenience of reaching across the mat and/or children might understand that the confounded evidence does not disambiguate the causal relationships and therefore they might be more willing to explore quite broadly. Further research should clarify the precise motivation behind children's differential exploration. In this paper we offer what might be considered a computational level account (i.e., in terms of the goals and logic of the behavior) of the relationship between the ambiguity of evidence and children's exploratory play, rather than an account at the level of the representational algorithm (i.e., how the behavior might be implemented; Marr, 1982). Critically therefore, we note that both motivations result in an equivalent, adaptive outcome. Children's tendency to engage in relatively more variable exploratory play when evidence is confounded than unconfounded increases the probability that children will generate informative evidence to support causal learning.

Of course, engaging in playful, casual exploration and observing informative evidence about a causally ambiguous stimulus does not ensure accurate learning or explicit recognition of the causal structure underlying the evidence. Preschoolers in particular may fail to notice the significance of the evidence they have generated because informative events often occur sparsely or incidentally in the course of free play. This study fell short of looking at whether children actually learned from the evidence they generated in free play. However, if children are sensitive to ambiguous causal structures and tend to engage in more extensive exploration of stimuli where there is potential for information gain, children will be well-positioned to learn from the evidence of their own interventions. Further research must explore the possibility that children who initially observe ambiguous evidence not only engage in more variable play, but actually acquire accurate causal knowledge from the evidence they generate. This study however suggests that children do respond to ambiguity with variable exploration. Given that preschoolers do not receive formal training about causal relationships in many domains, this sensitivity and preferential exploration of ambiguity may make a significant contribution to their causal knowledge.

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