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Which one made it go? The emergence of diagnostic reasoning in preschoolers

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ABSTRACT

We evaluate the hypothesis that children's diagnostic causal reasoning becomes more sophisticated as their understanding of uncertainty advances. When the causal status of candidate causes was known, 3- and 4-year-olds were capable of diagnostic inference (Experiment 1) and could revise their beliefs when told their initial diagnosis was incorrect (Experiment 2). In Experiments 3 and 4, only 4-year-olds made successful inferences when the causal status of candidate causes was uncertain. The results suggest that by age 3, children appreciate that an effect can have multiple candidate causes, but it is not until age 4 that they begin to reason correctly when the causal status of candidate causes is unknown.

Achieving a goal requires selecting an effective intervention. A doctor must choose a course of treatment, an auto mechanic must decide what to fix, and governments must institute public policy initiatives. All of these cases call for diagnostic inference, reasoning backward from an outcome (e.g., a cough, a noisy engine, a rise in violent crime) to its likely cause or causes (e.g., tuberculosis, a broken fan belt, a decrease in the price of narcotics). Once a cause has been identified with some measure of certainty, one can make predictions about the effectiveness of a given intervention.

Diagnostic inference is aimed at identifying the best cause among a set of possibilities. Philosophers and computer scientists refer to such inferences as 'abduction' or 'inference to the best explanation' (Harman, 1965; Josephson & Josephson, 1994; Lipton, 2001; Peirce, 1965). This form of inference is particularly challenging because it requires the reasoner to seek out and represent the set of possible causes. The search for candidate causes is difficult because it is 'global' in the sense that relevant

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considerations might be completely independent of the current discourse context (Fodor, 2000). Peirce (1965) describes abduction, therefore, as the only form of inference that "introduces something new (p. 171)." Representing and reasoning over multiple uncertain possibilities also requires substantial resources for causal inference. To make good judgments, one must understand the causal structure of the scenario, maintain a representation of multiple causal candidates, and weigh them against one other in a way that is sensitive to their base-rates and causal efficacy.

Studies with adults show that people do eventually come to these capabilities; they make diagnostic judgments of likelihood by using causal knowledge to set up an appropriate mental model (Fernbach, Darlow, & Sloman, 2011; Waldmann & Holyoak, 1992) and they evaluate the model by retrieving context-specific information from memory (Thomas, Dougherty, Sprenger, & Harbison, 2008). These abilities, however, are not easily acquired. A general finding of research on scientific reasoning is that school-age children often struggle to recover candidate causes from data (Klahr & Nigam, 2004; Kuhn, Garcia, Zohar, & Andersen, 1995; Kuhn, Pease, & Wirkala, 2009; Lehrer & Schauble, 2000; Ruffman, Perner, Olson, & Doherty, 1993; Sodian, Zaitchik, & Carey, 1991). Even 10-year-olds struggle with such inferences compared to adults (e.g., Schauble, 1996). This research suggests that children's diagnostic reasoning is prone to many heuristics and biases (Schauble, 1990) and over-reliance on pre-existing beliefs at the expense of observed data.

In stark contrast to these results is a substantial literature suggesting that preschoolers possess sophisticated diagnostic reasoning abilities. For instance, Bullock, Gelman, and Baillargeon (1982) found that 3-year-olds used factors like temporal priority and spatial proximity to diagnose the cause of an event. Shultz (1982) demonstrated that children made such inferences on the basis of their mechanism knowledge (see also Buchanan & Sobel, 2011). Similarly, preschoolers can diagnosis whether objects have hidden properties based on their causal power, as opposed to other potential bases for such inference, such as perceptual similarity (Gottfried & Gelman, 2005; Sobel, Yoachim, Gopnik, Meltzoff, & Blumenthal, 2007). Young children can also resolve ambiguous information as to which of two causes produced an effect by appealing to external information like the base-rate of events having such causal efficacy, their knowledge of the functional form of a causal relation and their existing knowledge of the specific causal mechanism (Griffiths, Sobel, Tenenbaum, & Gopnik, 2011; Kushnir & Gopnik, 2007; Lucas, Gopnik, & Griffiths, 2010; Schulz, Bonawitz, & Griffiths, 2007; Sobel & Munro, 2009; Sobel, Tenenbaum, & Gopnik, 2004).

What might explain such divergent findings? Some suggestive results come from a study in which children were given a relatively simple diagnostic reasoning task. Sodian et al. (1991) asked children to infer the size of a mouse (big or small) from evidence that was either ambiguous or conclusive for one of the options. They found that 6-year-olds often struggled with this diagnosis (although older children usually did succeed). Why should these children struggle in this case, but younger children succeed in others cases of diagnosis? Critically, in the Sodian et al. procedure, one pattern of evidence was conclusive while the other pattern was not. The presence of such uncertainty might have affected children's inferences. In contrast, in the cases of preschoolers' successful inferences, children are usually shown a small, exclusive set (usually two) of candidate causes, the causal relations children observe are deterministic, and there are no hidden or unknown causes. Children simply have to choose which of the alternatives produced the effect.

We hypothesize that what determines performance on diagnostic reasoning tasks is the requisite representational requirements for reasoning over alternative possibilities. Even young children will succeed when those requirements are small, for instance, when potential causes are readily available and unambiguous. In contrast, greater difficulty will emerge with diagnostic inferences that involve events that are not present or whose efficacy is unknown. Success under those conditions requires a more sophisticated understanding of uncertainty and broader thinking about possible causes.

Here we focus on two related abilities that must be present for successful diagnostic inference. First, children must understand that an observed event could have been brought about by more than one cause and that belief should be spread over the candidates. We refer to this kind of understanding as *first-order diagnostic uncertainty*. To illustrate, consider a doctor evaluating a patient who presents with a rash and reports being exposed to poison ivy and eating some bad shellfish. The doctor might choose which event is a more likely cause of the rash, but retain the other as a possibility. This would require an understanding of first-order diagnostic uncertainty. One measure of whether a child understands