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Children's Causal Inferences From Conflicting Testimony and Observations

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Preschoolers use both direct observation of statistical data and informant testimony to learn causal relationships. Can children integrate information from these sources, especially when source reliability is uncertain? We investigate how children handle a conflict between what they hear and what they see. In Experiment 1, 4-year-olds were introduced to a machine and 2 blocks by a knowledgeable informant who claimed to know which block was better at activating the machine, or by a naïve informant who guessed. Children then observed probabilistic evidence contradicting the informant and were asked to identify the block that worked better. Next, the informant claimed to know which of 2 novel blocks was a better activator, and children chose 1 block to try themselves. After observing conflicting data, children were more likely to say the informant's block was better when the informant was knowledgeable than when she was naïve. Children also used the statistical data to evaluate the informant's reliability and were less likely to try the novel block she endorsed than children in a baseline group who did not observe data. In Experiment 2, children saw conflicting deterministic data; the majority chose the block that consistently activated the machine as better than the endorsed block. Children's causal inferences varied with the confidence of the informant and strength of the statistical data, and informed their future trust in the informant. Children consider the strength of both social and physical causal cues even when they disagree and integrate information from these sources in a rational way.

Keywords: preschoolers, testimony, causal learning, social learning, statistical learning

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We live in a causally rich and complex world. Events do not just randomly occur around us, but rather result from the causal architecture of our environment—rain falling makes the ground wet, which can cause us to slip, drinking sour milk can lead to a stomach ache, and flipping a switch can turn on a light. Discovering the causal structure of the world is one of the most challenging learning problems children encounter, but there are a variety of information sources they can rely on to aid them in this process. Two particularly important sources of evidence are the verbal testimony that children receive from others about causal relationships and the statistical contingency evidence that children can directly observe.

Having multiple sources of evidence available could make causal learning easier by providing children with more information about the nature of the causal system. However, receiving evidence from several sources could also create a learning dilemma for children since at times these sources are unreliable. The world is stochastic and unpredictable: People can be ignorant or mistaken, our observations are often probabilistic, and sometimes, different sources even disagree. In these situations, rather than facilitating learning, having various sources available could actually add ambiguity and make learning harder. How do children handle having multiple, possibly unreliable, sources of information present at once? Here, we aim to better understand how children

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incorporate information from more than one source by examining a situation where two sources of causal evidence disagree.

In two experiments, we explore children's causal inferences (i.e., causal strength judgments) and social inferences (i.e., reliability judgments) when a conflict arises between what children hear from an informant about a causal relationship and what children see when observing the causal system in action. How children resolve this conflict will shed light on how they are weighing the causal information gained from social and physical cues. It is possible that in these situations, children would simply rely on one source of information—always trusting the statistical data, or always trusting the testimony of others. However, it is also possible that children will rationally combine their prior beliefs about the reliability of these types of sources with the new evidence *each* source provides to inform their causal judgments.

We also explore whether a situation that calls into question the reliability of an informant not only affects children's current learning from this source but also affects their future causal learning. If children are indeed considering information from both the social informant and the causal system, then their inferences about the causal system should inform whether they rely on this informant as a source of causal knowledge later on. Children's capacity to update their confidence in an informant is important as they continue to learn in a given social and physical environment, as it supports their discovery of who is an expert in a particular domain.

Background

Much of what children know about the world they learn from what other people tell them to be true (e.g., Callanan & Oakes, 1992). However, many causal relationships can be inferred directly from observation without needing explicit instruction. For instance, children can learn that flipping a particular switch causes a light to turn on from someone telling them this is the case, but children can just as successfully learn this link from watching someone flip the switch and seeing the light actually turn on (e.g., Callanan & Oakes, 1992; Kushnir & Gopnik, 2005). If children can rely on *either* testimony or observed contingency data alone to infer cause and effect, how might these sources of information interact in children's causal learning when both are present?

Prior research in the physical domain has shown that even preschoolers have the capacity to make advanced causal inferences (e.g., Gopnik et al., 2004; Schulz, Bonawitz, & Griffiths, 2007; Schulz, Gopnik, & Glymour, 2007; Sobel, Tenenbaum, & Gopnik, 2004). Very young children can use both deterministic contingency patterns and even probabilistic data in which the frequency of the causal outcome is controlled to infer causal structure and strength (e.g., Kushnir & Gopnik, 2005, 2007). For example, Kushnir and Gopnik (2007) showed that 4-year-olds consider an object that activates a machine two out of three times more causally effective than one that activates it two out of six times. Waismeyer, Meltzoff and Gopnik (2015) showed that 24-month-olds could do the same.

In parallel, research in the social domain has shown that just as children can asses the relative efficacy of causes from statistical patterns of evidence, children can also assess the relative credibility of informants based on their past accuracy (e.g., Corriveau, Meints, & Harris, 2009; Einav & Robinson, 2011; Pasquini, Corriveau, Koenig, & Harris, 2007). By 4 years of age, children *selectively trust* testimony from informants who have previously proven to be knowledgeable and accurate over those who have demonstrated ignorance or inaccuracy (Koenig & Harris, 2005). In addition, children are more likely to trust speakers who are certain and confident in their statements than those who are unsure (e.g., Jaswal & Malone, 2007; Tenney, Small, Kondrad, Jaswal, & Spellman, 2011). However, when an informant expresses certainty, is she in fact correct? Another cue available to assess the value of an informant's testimony is her self-knowledge, how well her confidence predicts her accuracy. In research on eye-witness testimony, Tenney et al. (2011) found that children are indeed sensitive to an informant's confidence and past accuracy but not to her level of self-knowledge, whereas adults are attuned to all three cues.

In this previous research, the informants' inaccuracy was established by showing them making factual errors, such as supplying the incorrect label for common objects for example calling a key a spoon (e.g., Koenig, Clement, & Harris, 2004; Koenig & Harris, 2005), or by giving the incorrect location for a hidden object (Ganea, Koenig, & Millett, 2011; Jaswal, Croft, Setia, & Cole, 2010; Ma & Ganea, 2010). What happens when the evidence for the informant's accuracy is more ambiguous and must be inferred rather than directly observed? While an object cannot be in two locations at once, and it is unlikely to be both a key and a spoon, effects can have multiple causes, and some causes are more effective than others. Can children use observed contingency data rather than preexisting factual knowledge to infer that an informant who endorses a weaker cause over a stronger one is less reliable? This question is especially interesting given recent findings indicating that in some cases, children persist in trusting an informant over their own (noncausal) observations (e.g., Jaswal et al., 2010, 2014). However, when children believe their direct perception could be misleading or when their prior knowledge in a domain is weak, they are more likely to accept testimony that conflicts with their perception (Lane, Harris, Gelman, & Wellman, 2014), or their prior beliefs (Chan & Tardif, 2013). These results suggest that children may balance observation and testimony in a more rational way, rather than simply privileging one source over the other.

Much of the earlier work on children's causal reasoning and their trust in testimony considered either causal or social inferences in isolation. However, learning does not take place in isolation. What might children learn from other people's causal statements about the world, and what might the world tell children about the credibility of those statements and thus, other people? Recent research on how children combine social information with their own causal observations has found that just as children consider testimony from certain informants more credible than that from others, they find the interventions of particular causal demonstrators more informative than those of others. For example, children weigh the causal interventions of a demonstrator who claims to be knowledgeable (Kushnir, Wellman, & Gelman, 2008) or provides a relevant rationale for her actions (Sobel & Sommerville, 2009) more heavily than the interventions of a demonstrator who claims to be ignorant or supplies an irrelevant rationale. Similarly, they imitate a knowledgeable teacher more faithfully (Buchsbaum et al., 2011) and persistently (Bonawitz et al., 2011; Butler & Markman, 2012) than a naïve demonstrator. They are also sensitive to the relative causal expertise of informants, seeking help from those with the relevant domain knowledge (Kushnir, Vredenburgh, & Schneider, 2013).

Taken together, the findings of the research discussed support an emerging view of learning from testimony as a process of rational inference, where the same inference mechanisms that support children's causal inferences from statistical data can also support children's social inferences from testimony (Sobel & Kushnir, 2013). If such a unified account is appropriate, then social and physical evidence should interact in children's causal learning. However, in previous studies of children's causal learning in social contexts, the testimony provided by informants generally helped to disambiguate the causal situation. What happens when an informant's statements explicitly conflict with the data? Will children use information from these cues to both inform their inferences about the physical causal system and their judgments about the reliability of the social informant? And in the future, will children extend trust to an informant who has just made causal assertions that disagree with their own observations?

In the experiments presented here, we introduce a conflict between social and statistical evidence and also systematically vary the strength of both types of evidence. We contrast a more or less certain informant with probabilistic versus deterministic statistical evidence. We examine the inferences children make about the credibility of the informant by comparing children's confidence in the informant's statements before and after they receive data challenging her claims. If children are integrating information across these domains, their inferences should fluctuate with the strength of both the social and physical evidence provided.

Experiment 1: Conflicting Testimony and Observations

In this experiment, we investigate how preschoolers resolve a conflict between verbal informant testimony and observed causal data and the consequences for their later causal reasoning when given new testimony from this informant. We focused on 4- to 5-year-olds, because children this age can consistently and reliably ascertain informant credibility from testimony (e.g., Koenig & Harris, 2005) and also infer causal strength from probabilistic evidence (e.g., Kushnir & Gopnik, 2007). Younger children may show some competencies at these tasks but their performance across previous studies is inconsistent (e.g., see Corriveau et al., 2009; Koenig & Harris, 2005; Sobel et al., 2004).

In all conditions, an informant showed children a machine that could be activated by placing blocks on top and told them that one of two blocks was better at making it go. The informant either claimed to know which block was better, or claimed to be guessing. In the baseline conditions, children were then simply asked to choose a block to place on the machine. In the contrast conditions, children then observed probabilistic evidence that conflicted with the informant's testimony and were asked which block was better at activating the machine. Next, the informant brought out two new blocks. The informant, regardless of her earlier knowledge state, claimed to know which of these two new blocks was a better activator, and children selected one of these blocks to make the machine go.

Children may favor either testimony or observation, so that if they conflict, children will trust the privileged source and disregard the other. However, if children in our experiment incorporate information from both sources, their causal strength judgments should be impacted by both the strength of the informant's testimony and the contrasting statistical data.

In the baseline conditions, when children only have verbal testimony available, they should rely on this source and intervene more often with the block the informant claimed was better. Children should also be more trusting of the knowledgeable than the naïve informant's endorsement. In the contrast conditions, the conflicting statistical data should provide evidence against the informants' testimony, decreasing children's preference for the informant's block compared with baseline. However, for the first block pair, children should again weigh confident testimony more heavily than uncertain testimony and choose the endorsed block as better more often with the knowledgeable than with the naïve informant. If children use their inference about the causal strength of the blocks to make a further inference about the informant's reliability more generally, they should also be less likely to trust the informant's endorsement about the second block pair compared with baseline. However, if children cannot use indirect, probabilistic evidence of informant inaccuracy, then their trust in the informant should return to baseline.

Finally, to probe children's sensitivity to variations in self-knowledge, both previously knowledgeable and naïve informants expressed certainty about the second pair of blocks. Though both informants' prior endorsements were contradicted by the data, the knowledgeable informant was incorrectly certain, while the naïve informant was correctly *un*certain, that is, her confidence was a better predictor of her accuracy. If children are sensitive to self-knowledge as a cue to reliability, then when both informants claim to know about the second block pair, children should intervene with the newly endorsed block more often when the informant said she was naïve about the first two blocks than when she said she was knowledgeable. Alternatively, if children are unable to track this cue, they might extend trust equally across conditions.

Method

Participants. Participants were seventy 4- to 5-year-olds (M = 54 months, *range* = 48–64 months) recruited from Bay Area preschools and children's science museums. An additional nine participants were excluded from the study because of experimenter error (1), participant interference with the causal demonstrations (4), nonproficient English understanding (2), inadvertent inclusion in two conditions (1), and failure to answer all of the questions (1). Children were randomly assigned to one of four between subject conditions: the knowledgeable baseline condition (n = 16, M = 52 months, *range* = 48–58 months, 38% female), the naïve baseline condition (n = 16, M = 54 months, *range* = 50–59 months, 50% female), the knowledgeable contrast condition (n = 19, M = 55 months, *range* = 49–64 months, 47% female), and the naïve contrast condition (n = 19, M = 55 months, *range* = 48–62 months, 42% female). A range of ethnicities resembling the diversity of the population was represented.

Stimuli. The machine was a small, wooden box with a Lucite top that lit up and played music when objects were placed on top. The experimenter controlled which objects activated the machine by flipping a hidden, inhibitory switch. The objects were four wooden blocks, differing in shape and color. In all conditions, the block the informant endorsed in each pair and whether it was on the right or left were counterbalanced across participants. In the contrast conditions, the first and second block pair and the order of demonstration were also counterbalanced.

Procedure. Children were tested individually in a location separate from their main classroom at a preschool or in a location separate from the main exhibits at a museum. In all conditions, children sat at a table across from two experimenters.

Baseline conditions. One experimenter (the *informant*) introduced children to a machine that lit up and played music when blocks were placed on top. The informant then brought out two blocks and told children that ". . . the {*endorsed* block} almost always makes the machine go and the {*unendorsed* block} almost never makes it go, so the {endorsed block} is better at making the machine go." In the knowledgeable baseline condition, the informant was confident, first stating, "I have played with these blocks a lot and so I really *know* which block is better at making the machine go." In the naïve baseline condition, the informant was uncertain and more hesitant, first saying,

> I have never ever played with these blocks before, and I have no idea which block is better at making the machine go. Hmm . . . even though I don't know anything about them, I'm just going to guess that the {endorsed block} almost always makes the machine go. And I'm going to guess that the {unendorsed block} almost never makes it go. So . . . I'm guessing that the {endorsed block} is better at making the machine go.

Both verbal and nonverbal cues to certainty were used to make sure children understood the informant's confidence level (see Jaswal & Malone, 2007; Kushnir et al., 2008). The amount of certainty the informants expressed was the only difference between the conditions. For a specific and more complete example of the script, please refer to the online supplement.

In both conditions, after providing her testimony about the blocks, the informant excused herself from the room. The second, *neutral experimenter* (who was present but uninvolved when the informant gave her testimony) then asked children to intervene on the machine: "Can you make it go?" Children were only permitted to choose one block. Lastly, the neutral experimenter asked children to recall which block the informant said was better at making the machine go.

Contrast conditions. The contrast conditions had two within subject phases: the *conflict phase* and the *generalization phase*. The experiment began with the conflict phase. As in the baseline conditions, children were told by *either* a confident, supposedly knowledgeable informant (the knowledgeable contrast condition) or an uncertain, ignorant informant (the naïve contrast condition) that one of two blocks was better at activating a machine. The language in these conditions was identical to that used in the baseline conditions.

After providing her testimony about the blocks, the informant left the room, and the neutral experimenter continued the game in the informant's absence. Unlike the baseline conditions, the neutral experimenter next demonstrated each block on the machine. To control for activation frequency, the endorsed block caused the machine to light up and play music 2/6 times (activating the machine on the second and fifth trials), while the unendorsed block activated it 2/3 times (activating the machine on the first and third trials; see Kushnir & Gopnik, 2007). This evidence contradicted the informant's claim: The endorsed block was *less* causally effective (statistically speaking) than the unendorsed one. The neutral experimenter then asked children, "Which block is better at making the machine go?" Children were not permitted to try either block. The experimenter also asked children to recall which block the informant had endorsed.

Next, in the generalization phase, the informant returned with two new blocks. This time, in both conditions, the informant claimed to *know* which block was the better activator, using the same language to express her endorsement as the knowledgeable informant used in the conflict phase. The informant then left the room once more, and the neutral experimenter asked children to select one block to make the machine go. After children placed a block on the machine, the experimenter asked them to recall which of these two new blocks the informant had endorsed. For more details on the procedure, please refer to the online supplement.

Coding

Contrast conditions. In the conflict phase, the block children touched, pointed to, or named was coded as their answer to which block was better at making the machine go. The same criteria were used for coding children's answers to the memory questions. If children did not answer or chose both blocks, the neutral experimenter asked a forced-choice question to prompt selection of one block. In the generalization phase, the block children placed on the machine was coded as their intervention choice.

With parental permission, children's performance was video recorded. Responses for participants without video were coded online (four in the knowledgeable contrast condition and three in the naïve contrast condition). All responses for participants with video were coded offline by the first author and a researcher blind to the experiment hypotheses and to which blocks the informant had endorsed. Agreement was high for both the test questions (98%; 61/62 responses) and the memory questions (98%; 61/62). Cohen's unweighted κ analysis revealed that this agreement was substantial (test questions: $\kappa = 0.97$; memory questions: $\kappa = 0.97$). All discrepancies were resolved by a third coder.

Baseline conditions. Coding was identical to the coding in the generalization phase of the contrast conditions. Six participants in the knowledgeable baseline condition and three in the naïve baseline condition did not have video permission, so their responses were coded online. For participants with video, the same blind coding procedure as in the contrast conditions was used. Agreement was 100% for both the test question (23/23 responses) and the memory question (23/23 responses).

Results

Preliminary analyses revealed no differences in performance based on participant gender or counterbalancing, so data were collapsed across these dimensions. Excluding children who failed the memory check questions did not change the significance values of the results, so these participants were included in the analysis.

Because children provided only a single response per phase of the experiment and some cells of the resulting contingency tables had zero counts, exact tests (binomial or Fisher's) were the most appropriate for our data. We conducted planned comparisons of the number of children who chose the endorsed block to test the following hypotheses: (a) In the baseline conditions, children will favor the block the informant endorsed because no conflicting data is observed; (b) In the baseline conditions, children will favor the endorsed block more often than in the conflict phase, where children observe data that conflicts with the informant's endorsement and (c) more often than in the generalization phase, which follows this conflict; (d) In the conflict phase, children will be less likely to choose the endorsed block than in the generalization phase, because in the conflict phase, data directly challenged the informant's claim, whereas in the generalization phase, data challenged a previous endorsement; (e) In both the baseline conditions and the conflict phase, children will more often choose the block endorsed by the knowledgeable than the naïve informant; and (f) In the generalization phase, children will be more likely to choose the block endorsed by the previously naïve than knowledgeable informant, indicating an understanding of self-knowledge.

Baseline conditions. All children in the knowledgeable baseline condition intervened with the endorsed block (two-tailed binomial test, $p < .001$), while children in the naïve baseline condition did not choose the endorsed block significantly more often than chance (two-tailed binomial test, $p = .21$). Additionally, children in the knowledgeable condition chose to intervene with the endorsed block significantly more often than children in the naïve condition (two-tailed Fisher's exact test, $p = .04$, $\Phi = 0.43$). Results are summarized in Table 1.

Contrast conditions. Results are summarized in Table 2.

Conflict phase. A majority of children in the conflict phase of the naïve contrast condition chose the unendorsed block as the better cause, a number significantly greater than chance (two-tailed binomial test, $p < .001$). Children in the knowledgeable contrast condition were at chance in choosing the endorsed or unendorsed block as better at activating the machine (two-tailed binomial test, $p = 1$). Comparing children's performance across conditions, significantly more children chose the endorsed block when the informant was knowledgeable than when she was naïve (two-tailed Fisher's exact test, $p = .01$, $\Phi = 0.45$).

We also compared children's performance in the baseline conditions to their performance in the conflict phase of the contrast conditions. Children in both the knowledgeable (two-tailed Fisher's exact test, $p = .001$, $\Phi = 0.54$) and naïve (two-tailed Fisher's exact test, $p < .001$, $\Phi = 0.60$) contrast conditions chose the endorsed block as the better cause significantly less often in the conflict phase than they chose to intervene with the endorsed block in the baseline conditions. There was a longer delay between endorsement and the test question in the conflict phase of the contrast conditions than in the baseline conditions. However, children's memory for which block was endorsed did not vary (two-tailed Fisher's exact test, $p = .59$, $\Phi = 0.09$), so performance differences cannot be attributed to poorer recall in the contrast conditions.

Table 1
Numbers of Children in the Baseline Conditions of Experiment 1 Choosing to Intervene With the Endorsed or Unendorsed Block

Baseline conditions	Endorsed block	Unendorsed block
Knowledgeable	16	0
Naïve	11	5
Total ($N = 32$)	27	5

Table 2
Numbers of Children in the Contrast Conditions of Experiment 1 Choosing the Endorsed or Unendorsed Block as "Better" in the Conflict Phase and to Intervene With in the Generalization Phase

	Conflict phase		Generalization phase	
Contrast conditions	Endorsed block	Unendorsed block	Endorsed block	Unendorsed block
Knowledgeable	10	9	10	9
Naïve	2	17	11	8
Total ($N = 38$)	12	26	21	17

Generalization phase. Children in both the naïve (two-tailed binomial test, $p = 0.65$) and knowledgeable (two-tailed binomial test, $p = 1$) conditions were at chance in choosing to intervene with either the endorsed or unendorsed block. Unlike the conflict phase, there was no difference in performance between conditions (two-tailed Fisher's exact test, $p = 1$, $\Phi = 0.05$). Comparing performance across the two phases, children in the naïve condition were more likely to favor the endorsed block in the generalization phase than in the conflict phase (two-tailed Fisher's exact test, $p = .005$, $\Phi = 0.50$). There was no significant difference between the conflict and generalization phases for children in the knowledgeable condition (two-tailed Fisher's exact test, $p = 1$, $\Phi = 0$).

Finally, we can compare children's performance in the generalization phase of the contrast conditions to their performance in the knowledgeable baseline condition.[1] Children were significantly less likely to intervene with the endorsed block in the generalization phase of both contrast conditions than in the knowledgeable baseline condition (two-tailed Fisher's exact test, knowledgeable: $p = .001$, $\Phi = 0.54$; naïve: $p = .004$, $\Phi = 0.50$).

Discussion

These results suggest that children find informant testimony and statistical data gleaned from direct observation jointly informative for inferring a causal relationship. In the baseline conditions when there was only informant testimony available, children were sensitive to the strength of that testimony and trusted the knowledgeable informant more often than the naïve one. In the knowledgeable contrast condition, when there was strong evidence for each block, children appeared to take both the informant's confident testimony and the conflicting probabilistic data into account, and as a group, were at chance between inferring one block or the other as more causally efficacious. However, in the naïve contrast condition, where the informant was less certain and so there was weaker evidence supporting the endorsed block's causal efficacy, children favored the block that had a higher observed probability of activating the machine.

The fact that children in the naïve contrast condition chose the more effective unendorsed block as the better cause demonstrates that children in the knowledgeable contrast condition were not at chance because they were confused by the probabilistic causal

[1] In the generalization phase, both the previously knowledgeable and naïve informant claim to be knowledgeable, so the knowledgeable baseline is the appropriate comparison for both conditions.

data. Instead it seems that the children placed more confidence in the knowledgeable informant's claim than in the naïve informant's guess, causing them to be more uncertain about the relative causal strengths of the two blocks. As predicted, children were sensitive to the expressed confidence of the informant and, consequently, their causal inferences (about the same pattern of statistical data) varied with the social context.

In the generalization phase, we tested how children's assumptions about the reliability of the informant, formed in the conflict phase, might affect their later confidence in that informant's statements. Children in both conditions chose the endorsed block less often in the generalization phase than in the knowledgeable baseline condition. In fact, 100% of children trusted the informant in the knowledgeable baseline condition, while roughly 50% of children did so in the generalization phase of the contrast conditions. This finding suggests that once data contradicted the informant's claims, children considered her subsequent testimony less credible.

Children not only integrated the conflicting testimony and causal observations in the moment to inform their inferences about the causal system, they also used both sources to make a further inference about the reliability of the informant's future testimony. In previous work, unreliable or inaccurate informants usually made statements that were unambiguously false. Here, children's inferences about the informant's inaccuracy depended on their own online inferences about causal strength, inferences that are necessarily uncertain, rather than on more deterministic preexisting knowledge of common object labels or observed object locations.

Finally, there were three cues available to children when evaluating the trustworthiness of these informants: their accuracy, their expressed confidence, *and* their self-knowledge. In the conflict phase, both informants were wrong in their endorsements, but the knowledgeable informant exhibited less self-knowledge because she was unaware that she was mistaken, while the naïve informant *knew* that she did not know. In the generalization phase, if children were capable of evaluating an informant's self-knowledge, they might have been more trusting of the naïve informant because she is more likely than the knowledgeable informant to actually know when she says that she does. However, there was no difference in performance between conditions in the generalization phase. This finding implies that, as previous research in other domains suggests (Tenney et al., 2011), children are more attuned to an informant's expressed knowledge level about the world than to her level of self-knowledge.

There could be alternative explanations for children's apparent insensitivity to self-knowledge. For instance, children in the knowledgeable condition may have been less convinced that the informant was in fact inaccurate than children in the naïve condition. In this experiment, the conflicting data was probabilistic, leaving room for some doubt about the true causal structure. Perhaps children inferred the existence of unobserved causes such as battery failure or faulty wiring to explain the conflict (see Schulz & Sommerville, 2006). Thus, children in our experiment could be sensitive to self-knowledge and still rationally extend trust more or less equally to the knowledgeable and naïve informant.

In this experiment, we varied the strength of the informant's testimony and kept the observed statistical data constant. In Experiment 2, we once again presented children with conflicting testimony and observed causal data; however, the statistical data were deterministic rather than probabilistic. If children are indeed integrating information from both sources, they should weigh the stronger deterministic contingency data more heavily than they did the data in Experiment 1. Doing so would make them more likely to choose the unendorsed block as more causally effective whether the informant was certain or uncertain in her endorsement. Deterministic data also provides stronger evidence that the informant was wrong, rather than the causal system malfunctioned. Therefore, we predicted that children would be even less likely than in Experiment 1 to trust the informants in the future, especially the one who claimed to be knowledgeable in the past.

Experiment 2: Conflicting Testimony and Deterministic Causal Data

In this experiment, we first explore how increasing the strength of the observed causal data affects children's resolution of the conflict between statistical evidence and testimony. Second, we examine whether the increased statistical strength of the contrasting data decreases children's future trust in the informants more dramatically than in Experiment 1. Moreover, deterministic data might highlight the informant's level of self-knowledge, making children less likely to extend trust to the informant in the knowledgeable than in the naïve condition.

Method

Participants. Participants were thirty-two 4- to 5-year-olds ($M = 55$ months, *range* = 48–62 months) recruited from Bay Area preschools and children's science museums. An additional six participants were excluded from the study because of experimenter error (4), participant interference with the causal demonstrations (1), and sibling interference (1). Children were randomly assigned to one of two between subject conditions: the knowledgeable condition ($n = 16$, $M = 55$ months, *range* = 49–61 months, 63% female) and the naïve condition ($n = 16$, $M = 56$ months, *range* = 48–62 months, 19% female). A range of ethnicities resembling the diversity of the population was represented.

Stimuli. The same stimuli as in Experiment 1 were used.

Procedure. The procedure was identical to the procedure for the contrast conditions in Experiment 1 with one exception: The observed causal data in the conflict phase were deterministic rather than probabilistic; the endorsed block activated the machine 0/6 times, while the unendorsed block did so 6/6 times. This data pattern was selected to provide unambiguous evidence that the endorsed block was the weaker cause. There were no baseline conditions.

Coding. Answers were coded in the same way as in Experiment 1. Two children in the naïve condition did not have video permission, so their responses were coded online. All responses for participants with video were coded offline by the first author and a researcher blind to the experiment hypotheses and to which blocks the informant had endorsed. Agreement was high for both the test questions (98%; 59/60 responses) and the memory questions (98%; 59/60). Cohen's unweighted κ analysis revealed that this agreement was substantial (test questions: $\kappa = 0.97$; memory questions: $\kappa = 0.97$). All discrepancies were resolved by a third coder.

Results

Preliminary analyses revealed no differences in performance based on participant gender or counterbalancing, so data were collapsed across these dimensions. Excluding children who failed the memory check questions did not change the significance values of the results, so these participants were included in the analysis. Following Experiment 1, we ran planned comparisons of the number of children who chose the endorsed block to test the following hypotheses: We predicted that compared to Experiment 1 (a) In both the conflict and generalization phases, children would similarly favor the block the informant endorsed less often than in the baseline conditions because of the contrasting statistical data they observe; (b) In both the conflict and the generalization phases, children would also be less likely to favor the endorsed block because deterministic (rather than probabilistic) data directly challenged the informant's endorsement in the conflict phase; and (c) In the generalization phase, children would more often favor the block endorsed by the previously naïve than knowledgeable informant because deterministic data challenged the informants' past endorsements. Results are summarized in Table 3.

Conflict phase. All children in both conditions chose the unendorsed block as the better cause (two-tailed binomial test, naïve: $p < .001$; knowledgeable: $p < .001$). Comparing across experiments, children in both the knowledgeable (two-tailed Fisher's exact test, $p < .001$, $\Phi = 1$) and naïve (two-tailed Fisher's exact test, $p < .001$, $\Phi = 0.72$) conditions chose the endorsed block significantly less often in the conflict phase than in the baseline conditions of Experiment 1. Children in the conflict phase of Experiment 2 also chose the endorsed block significantly less often than children in the conflict phase of Experiment 1 (two-tailed Fisher's exact test, $p < .001$, $\Phi = 0.42$). This difference was significant for the knowledgeable condition alone (two-tailed Fisher's exact test, knowledgeable: $p < .001$, $\Phi = 0.58$; naïve: $p = 0.49$, $\Phi = 0.23$).

Generalization phase. There was no difference in performance between the two conditions in the generalization phase (two-tailed Fisher's exact test, $p = 1$, $\Phi = 0$). Children in the naïve (two-tailed binomial test, $p = 0.21$) and knowledgeable (two-tailed binomial test, $p = 0.21$) conditions chose to intervene with either the endorsed or unendorsed block at chance. Children in both conditions were more likely to favor the endorsed block in the generalization phase than in the conflict phase (two-tailed Fisher's exact test, naïve: $p < .001$, $\Phi = 0.72$; knowledgeable: $p < .001$, $\Phi = 0.72$).

Children in both conditions were also significantly less likely to choose the endorsed block in the generalization phase than in the knowledgeable baseline condition of Experiment 1 (two-tailed Fisher's exact test, knowledgeable: $p = .04$, $\Phi = 0.43$; naïve: $p = .04$, $\Phi = 0.43$). Children's performance in the generalization phase of Experiment 2 did not differ from children's performance in the generalization phase of Experiment 1 in either condition (two-tailed Fisher's exact test, knowledgeable: $p = .49$, $\Phi = 0.16$; naïve: $p = 0.73$, $\Phi = 0.11$).

Table 3
Numbers of Children in Experiment 2 Choosing the Endorsed or Unendorsed Block as "Better" in the Conflict Phase and to Intervene With in the Generalization Phase

	Conflict phase		Generalization phase	
Deterministic conditions	Endorsed block	Unendorsed block	Endorsed block	Unendorsed block
Knowledgeable	0	16	11	5
Naïve	0	16	11	5
Total ($N = 32$)	0	32	22	10

Discussion

In the conflict phase of Experiment 2, all children in both conditions chose the unendorsed but more effective block as the better cause. Children chose the endorsed block significantly less often than in Experiment 1, especially in the knowledgeable condition. This finding suggests that children were indeed sensitive to the increased strength of the statistical data and correctly weighed the deterministic evidence provided by the causal system in Experiment 2 more heavily than the probabilistic evidence provided in Experiment 1.

In Experiment 2, we used a 0/6 and 6/6 activation pattern for the endorsed and unendorsed blocks, respectively, to eliminate any doubt about the blocks' relative causal strengths. Consequently, the unendorsed block was seen for more trials in Experiment 2 than in Experiment 1. Since children in Experiment 1 saw the endorsed block more often than the unendorsed block, but were sensitive to the unendorsed block's higher probability of activation, we do not think that increased exposure to the unendorsed block is responsible for children's choices here.

The conflicting deterministic evidence in Experiment 2 more strongly contradicted the informants' statements than the probabilistic evidence in Experiment 1. However, contrary to our prediction, there was no difference between the two experiments in children's willingness to extend trust to the informants in the generalization phase. As in Experiment 1, the earlier inaccuracy of the informants attenuated children's confidence in their later testimony. However, the increased conflict created by the contrasting deterministic data did not seem to further increase children's skepticism of the informants' reliability. Four-year-olds may not be sensitive to the *extent* that an informant's past statements have conflicted with their own observations when determining whether or not to trust that informant in the future.

In the generalization phase of Experiment 2, there was also no difference between the knowledgeable and naïve conditions in children's willingness to trust the informant's claim and intervene with the endorsed block. This finding provides more evidence that 4-year olds cannot use self-knowledge to inform their trust in a speaker, and instead supports past research suggesting that young children are only capable of using a speaker's confidence and past accuracy as cues to reliability (Tenney et al., 2011). Though children's trust in the informants was dampened by the conflict between the informants' testimony and the statistical data, their future trust did not vary with the informant's level of self-knowledge.

Overall, these results demonstrate that when children receive conflicting evidence from two different sources, varying the strength of either source has implications for how children integrate evidence from these sources and reconcile this conflict. Children weigh testimony differently based on the informant's confidence and also weigh statistical evidence differently depending on its statistical strength. However, increasing the strength of the contrasting data does not seem to impact children's future trust in that informant's causal knowledge.

General Discussion

In this article, we investigate how children incorporate information from multiple sources to support their causal learning, particularly exploring a contrast between informant testimony and contingency data. Though causal structure can be inferred without testimony, children do not ignore an informant's statements when they conflict with the statistical data. Similarly, despite learning a great deal from others, children do not discount their own observations in favor of what an adult has told them. Children appear to integrate information across these domains to infer the causal relationship. In addition, children did not just use testimony to make a causal inference—they used this causal inference to make a social judgment about the future reliability of the informant. In other words, children jointly inferred the causal strength of the blocks and the trustworthiness of the informant.

Our experiments show that children's causal inferences are dependent on the strength of the evidence produced by each source. Children are not simply choosing between the informant and the data they observe, but are flexibly adapting their causal theories to incorporate both sources of evidence. Experiment 1's results indicate that children weigh information from an informant differently depending on her certainty level and that changing this certainty changes children's evaluation of the same causal data. When the observed contingency data were probabilistic and the informant was naïve, children tended to choose the block they had observed being more effective as the better cause. When the informant was knowledgeable but her testimony conflicted with the data, children were less confident about the blocks' relative causal efficacies. Similarly, Experiment 2's results suggest that children weigh information from statistical data differently depending on its strength, and that changing this strength changes children's evaluation of the same informant testimony. Children in Experiment 2 were much less likely to choose the knowledgeable informant's block than children in the contrast conditions of Experiment 1 where the conflicting data were probabilistic rather than deterministic.

Moreover, differences in performance across the knowledgeable baseline condition and the generalization phases of Experiments 1 and 2 show that children are tracking the informants' past accuracy. Though children do not make an explicit judgment about the reliability of the informant, the variance in their causal interventions indicates that they are indeed making a social inference about the informant's credibility as a source of causal knowledge. Children are less likely to trust an informant whose past causal assertions have conflicted with observed statistical data, even when those data were probabilistic. Children were able to use their inferences about causal strength as a means of appraising the accuracy of the informants. Figure 1 depicts how children's trust in the informant varied inversely with the strength of the statistical data. However, in the generalization phases, children were no less trusting when the previously conflicting data were deterministic versus probabilistic, nor were they less trusting of the previously overconfident informant compared with the previously correctly uncertain informant.

Children may be unable to use an informant's level of self-knowledge as an indicator of her later credibility. Additionally, they may be unable to use the extent of the discrepancy between the informant's testimony and their own observations. Instead, children may simply focus on whether or not a discrepancy existed when considering the reliability of the informant's future statements. Recent research has shown that 4- and 5-year-olds have trouble evaluating *error magnitude*—the degree to which an answer differs from the truth (Einav & Robinson, 2010). Identifying the contexts that enable children to use error magnitude in their inferences remains a future area of research.

It is possible that different paradigms might still reveal that children are capable of using self-knowledge and error magnitude to gauge informant trustworthiness. In the generalization phases of

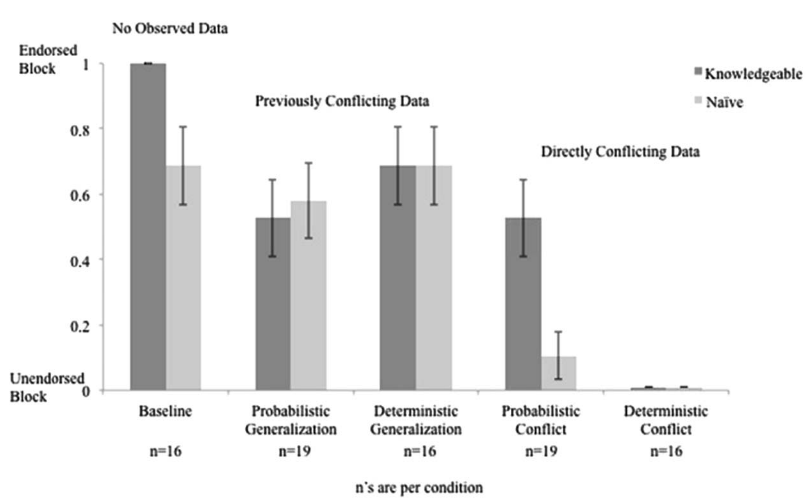

Figure 1. Proportion of children favoring the endorsed block across experiments and experiment phases. This figure shows how children's reliance on the informant's testimony to guide their causal inferences changes as the conflicting data increases in strength. Error bars represent ±1 *SE*.

our experiments, children were at chance in choosing a block to make the machine go. This may suggest that they believed the informants' statements were uninformative rather than wrong. In this case, doubting the causal efficacy of the endorsed block does not entail that the unendorsed block is the better activator. Recent work has shown that children tend to be more skeptical of an inaccurate informant when a second, accurate informant is also present (Vanderbilt, Heyman, & Liu, 2014). Future work could directly contrast confident testimony from previously knowledgeable and naïve informants, which would provide competing evidence for both blocks and potentially increase the salience of differences in self-knowledge. Testimony conflicting with either probabilistic or deterministic data could also be directly compared.

An open question is whether our results are reliant on the fact that one of the information sources was a person who verbally communicated her causal testimony. Would children's inferences vary in the same way if the testimony came from a robot or a computer? Or if the testimony were presented in print rather than in spoken word? We advance the view that social information is not a privileged information type but rather another piece of evidence children evaluate in light of their prior knowledge to update their beliefs (see Sobel & Kushnir, 2013). Children have prior beliefs about what expressed confidence and knowledge indicate about a speaker's actual knowledge. If children do not hold similar beliefs about robots or computers, we would not expect to find the same results since these beliefs contribute to children's determination of the strength and reliability of the testimony provided. Relatedly, recent work with older children indicates they make different inferences about printed versus spoken testimony (Eyden, Robinson, Einav, & Jaswal, 2013), suggesting that children in our experiments might make different inferences about the strength of the testimony provided if it was read aloud rather than simply spoken. Further investigation is needed to see how children evaluate the strength of and combine evidence from different types of sources, as well as evidence presented in different formats.

We have focused on how children's inferences vary with the strength of the social and physical causal information they receive. However, the order in which children receive this information might also impact their incorporation of evidence from different sources. First hearing testimony from the informant might have primed children in our experiments to expect the causal system to work as the informant described, increasing their tendency to identify the endorsed block as more effective. Future work should explore how children's inferences might differ if they first observed the causal system in action and *then* were given contrasting testimony from an informant and how the strength of the physical causal evidence might affect their evaluation of the informativeness of this testimony (see Chan & Tardif, 2013).

Finally, our pattern of results in which children are integrating information from different sources is qualitatively similar to techniques of Bayesian inference. We are currently developing a formal Bayesian model (Buchsbaum et al., 2012) to help us disambiguate how children might be relating testimony and direct observation in their social and causal inferences (for a related model see Shafto et al., 2012). Such a model might provide more quantitative predictions about children's behavior in the situations highlighted as future areas of research.

In conclusion, uncovering the causal structure of the world may be a daunting task, but children are sophisticated causal learners. They are able to use various sources of evidence in their environment to infer causal relationships, and are capable of weighing and taking into account the information offered by at least two sources, even in situations of ambiguity. Earlier research demonstrated that children can use both social and physical cues to infer causal relationships. The current study extended these findings by investigating both how an informant's testimony informs children's reasoning about observed causal data and how the observed data informs children's evaluations of that informant's credibility. Preschoolers not only use each source to guide their current causal inferences but also use the information to assess the reliability of the informant, influencing how they learn from this person in later situations. Our current results support a more unified framework for understanding children's learning from social and physical causal cues as a process of rational inference. Even preschoolers are remarkably adept at combining uncertain sources of information to make inferences about both their physical and social world.

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