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# Just do it? Investigating the gap between prediction and action in toddlers' causal inferences

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## Abstract

Adults' causal representations integrate information about predictive relations and the possibility of effective intervention; if one event reliably predicts another, adults can represent the possibility that acting to bring about the first event might generate the second. Here we show that although toddlers (mean age: 24 months) readily learn predictive relationships between physically connected events, they do not spontaneously initiate one event to try to generate the second (although older children, mean age: 47 months, do; Experiments 1 and 2). Toddlers succeed only when the events are initiated by a dispositional agent (Experiment 3), when the events involve direct contact between objects (Experiment 4), or when the events are described using causal language (Experiment 5). This suggests that causal language may help children extend their initial causal representations beyond agent-initiated and direct contact events.

## Keywords

Causal reasoning; Cognitive development; Agency; Contact relations; Language

> … suppose that an individual ape … for the first time observes the wind blowing a tree such that the fruit falls to the ground… we believe that most primatologists would be astounded to see the ape, *just on the bases of having observed the wind make fruit fall* … create the same movement of the limb … the problem is that the wind is completely independent of the observing individual and so causal analysis would have to proceed without references to the organism's own behavior
>
> (Tomasello & Call, 1997; italics theirs)

Tomasello and Call's thought experiment suggests that the ability to recognize predictive relations among events may not entail the ability to recognize that such relations potentially support intervention. Recently, researchers have expressed a similar intuition across a variety of fields. Philosophers have suggested that only a cognitively sophisticated being would recognize "that the very same relationship that he exploits in intervening also can be

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present both when other agents intervene and in nature even when no other agents are involved" (Woodward, 2007). Similarly, psychologists have suggested that causal knowledge requires understanding causal relations as non-egocentric, stable relations among diverse events, not merely relations "that involve rewards or punishments (as in classical or operant conditioning), not just object movements and collisions (as in the Michottean effects), and not just events that immediately result from (one's own) actions (as in operant conditioning or trial-and-error learning)" (Gopnik et al., 2004). The implication is that human beings may be unique among animals in having a single representation ("causal knowledge") that encodes what is common across causal relationships that do not involve the actions of agents and the relationship between agent actions and outcomes.

To our knowledge, Call and Tomasello's thought experiment holds empirically for non-human animals. Non-human animals can generalize behaviors learned only through action to cues learned only through observation (i.e., in Pavlovian to instrumental transfer, Estes, 1948). They can also make systematic predictions about the interaction between cues learned through observation and intervention. For example, if a rat learns to associate a light with both a tone and food, the rat will expect food when it hears the tone; however, if the rat itself pushes a lever and triggers the tone, the rat no longer treats the tone as a cue to the food (Blaisdell, Sawa, Leising, & Waldmann, 2006; though see Dwyer, Starns, and Honey (2009) and Penn and Povinelli (2007) for critique) and Leising, Wong, Waldmann, and Blaisdell (2008) for a reply. However, no study has found that non-human animals spontaneously design appropriate novel interventions after only observing a predictive relationship between events, and one study suggests that dogs do not (Waisman, Cook, Gopnik, & Jacobs, 2009a, 2009b). Lack of evidence of course is not conclusive evidence of a lack. However, the absence of evidence from non-human animals, together with the abundance of evidence from adult humans, raises the question of whether the ability to generalize from observation to intervention arises not only late in phylogeny but also in ontogeny.

We propose that while adults live in a world rife with causal connections, the domain of causal relationships in early childhood is far more circumscribed. In particular, we suggest that although toddlers are sensitive to predictive relations between events, there are substantial constraints on their ability to infer that these relations might support effective manipulation. In better understanding the origins of, and limitations on, children's inferences about causal relations, we may better understand not only the gap between prediction and action in early childhood (and consequent discrepancies between children's performance across paradigms with different task demands; see e.g., Hood, Carey, & Prasada, 2000) but also the contextual and cultural cues that support adult-like causal inference.

The claim that very young children might not readily generalize from observed data to possible actions may seem surprising given the abundant evidence for very early and very sophisticated causal reasoning in young children (e.g., Bullock, Gelman, & Baillargeon, 1982; Gopnik & Sobel, 2000; Gopnik et al., 2004; Kushnir & Gopnik, 2005; Kushnir & Gopnik, 2007; Schulz & Bonawitz, 2007; Schulz, Goodman, Tenenbaum, & Jenkins, 2008; Schulz & Sommerville, 2006; Shultz, 1982; Sobel, 2004; Sobel & Kirkham, 2006; Williamson, Meltzoff, & Markman, 2008. However, three features of previous studies may have masked young children's limitations.

First, studies of causal reasoning in early childhood have almost always investigated causal understanding in the context of an agent's goal-directed actions. Events initiated by agent action characterize for instance, all studies of imitative learning (see e.g., Horner & Whiten 2004; Lyons, Young, & Keil, 2007; Meltzoff, 1995, 2007; Schulz, Hooppell, & Jenkins, 2008). Children might be able to imitate goal-directed actions, or even attribute causal efficacy to goal-directed actions, without extending this inference to predictive relations where no agent is involved.

Second, many studies of causal inference (and in particular infancy studies) have looked at the special case of causal events involving unmediated direct contact between objects (as in Michottean launching events, Michotte (1963)). Children's perception of causality might initially be constrained to such special cases. Indeed, both philosophers and psychologists have suggested that Michottean causality might be a modular process, specific to the visual system, and relatively divorced from causal knowledge more broadly (Scholl & Tremoulet, 2000; Woodward, in press; though see Schlottmann, 2000).

Finally, in most studies of causal reasoning, adults have given children additional information about the relationship between the events by describing the observed events with causal language. Causal language (by which we mean here language accessible to young children: "make go", "turn on") might facilitate children's causal reasoning in at least two respects. First, describing an observed correlation ("The block makes the toy go") with the same verb as the invitation to act ("Can you make the toy go?") might help children recognize the relevance of observational evidence to their own interventions. Second, causal language might facilitate children's causal learning simply by testifying that an observed relation is indeed causal (Harris, 2002; Lutz & Keil, 2002; Vygotsky, 1978).

Here we hypothesize that young children's understanding of causal events critically depends upon such supplemental information. That is, toddlers will not spontaneously intervene on a predictive relation unless the events are initiated by dispositional agents,[1] the events involve unmediated, direct contact between objects, or adults describe the events in causal language. Like Call and Tomasello's hypothetical ape, very young children do not otherwise spontaneously represent predictive relations as causal.

Here we show children a sequence of two events: a block contacts a base, and then a toy connected to the base lights up and spins. We assess whether children generalize from this observation to a potentially effective intervention: moving the block to the base themselves. Absent additional cues, we suggest that toddlers will not spontaneously perceive the possibility that predictive events might be causally related, and thus will fail to generate the target intervention.

Note that of course children may not (and indeed should not) assume that all predictive relations will support effective interventions. That is, in this experiment they need not expect that moving the block to the base will *definitely* cause the toy to activate. However, adults recognize that intervening is an effective way to discover the causal relationship between variables (e.g., whether they are related through a direct cause and effect relationship or as common effects of an unobserved cause). The logic of experimental design relies on this ability to use interventions to infer causal structure from observed correlations (see Glymour, Spirtes, and Scheines (2001), Gopnik et al. (2004), Pearl (2000), Schulz, Gopnik, and Glymour (2007) and Woodward (2007) for more details). Whether the child shares this logic, or whether she simply recognizes that events that predict each other sometimes cause each other, she can learn whether the observed predictive relation is indeed causal by performing the intervention.

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[1] We use the term "dispositional agent" to distinguish agents capable of goal-directed action from both the more general case of causal agents (which of course include inanimate entities), and the more specific case of agents engaging in intentional actions (versus for instance, accidental actions, a distinction we do not investigate here). There is some evidence that 6-month-old infants might restrict their causal inferences to relations involving specifically intentional rather than accidental agent action (Muentener & Carey, 2006), however, there is no evidence that children as old as the ones tested in this study (24 months) are similarly restricted.

In Experiment 1, we test the focal question of whether older and younger children can use a predictive relationship between two events to initiate an intervention and anticipate the outcome of their own action. We hypothesize that older but not younger children will succeed at this task. In subsequent experiments we look at how additional information about potential causal relationships including a dispositional agent's intentional action, direct contact between the two objects in the event, and explicit causal language affect children's performance.

# 1. Experiment 1

## 1.1. Method

**1.1.1. Participants—**Eighteen preschoolers (mean: 47.2 months; range: 37–60 months) and 18 toddlers (mean: 24.4 months; range: 19–30 months) participated. Two preschoolers and two toddlers were excluded from the action measure for failing to make the initial predictive look (see below). An additional two toddlers were excluded from the final success measure for failing to perform the action during the Prompted Action condition (see below). Most of the children were white and middle class but the sample reflected the diversity of visitors to a large metropolitan science museum.

**1.1.2. Materials—**A large stage blocked a confederate from view. A purple block was attached to a concealed lever that slid across a slit in the stage, creating a track for the block. The track led to a second block (the base), which remained fixed to the left of the stage. A visible orange wire attached the base to a toy airplane in the stage's upper left corner. The airplane was controlled by a button on the back of the airplane which could be surreptitiously activated by the confederate behind the stage and which caused the toy to spin and light up. See Fig. 1.

**1.1.3. Procedure—**All children were tested individually in a quiet corner of the museum. There were three phases: an Observation Phase, an Action Phase, and (for those children who failed to intervene spontaneously) a Prompted Action Phase.

**1.1.3.2. Observation Phase:** The child sat approximately 1 m away from the testing apparatus. At the very beginning of the experiment, the experimenter elicited the child's attention by saying, "Watch my show!" Throughout this and all subsequent experiments, the experimenter looked at the child rather than the stimuli.

Using the concealed lever, the confederate slid the block towards the base, so that the block appeared to move on its own. When the block contacted the base, the confederate immediately activated the spinning toy. The block remained in contact with the base and the toy continued to activate for three seconds, then the block moved back to its starting position. As soon as the block moved away from the base, the toy slowed to a stop. Pilot work confirmed that this provided a compelling causal illusion: adults believed that contact between the block and the base activated the toy.

This Activation sequence was repeated four times. On the fifth trial (the catch trial), the block contacted the base but the confederate did not activate the toy. The experimenter observed the child to see if the child looked predictively towards the toy. If the child failed to look to the toy, the experimenter added a sixth trial on which the toy activated, followed by a seventh trial in which the toy did not activate. If the child again failed to look predictively towards the toy, he was excluded from the analyses of the action measure. If the child looked predictively towards the toy (on either trial five or seven) the experimenter concluded with a final trial in which the block contacted the base and the toy activated.

**1.1.3.3. Action Phase:** The experimenter slid the block towards the child, pointed to the spinning toy and said, “Okay now it’s your turn. Can you make the toy go?” Children were given 60 s to play freely. At no point was the spinning toy activated for the child. If the child performed the target action during the 60 s of free play the experiment ended; if the child failed to touch the block to the base during the 60 s, she or he moved onto the Prompted Action Phase.

**1.1.3.4. Prompted Action Phase[2]:** The experimenter grasped the block and slid it almost all the way into the base, stopping just short of the base. She returned the block to the child and said, “It’s your turn”. The child was given another 60 s to perform the target action. If the child failed to perform the complete action following the imitative prompt, they were excluded from the analyses. Again, at no point was the spinning toy activated for the child.

## 1.2. Results and discussion

In all studies, we scored whether the child predictively looked, spontaneously intervened, intervened following prompting, and predictively looked following her own performance of the action. The first author and a second coder blind to the experimental conditions recoded these four measures from videotape. In every condition, 95–97% of the clips were reliability coded by both coders; the remaining clips could not be coded due to obstructed camera angles. Inter-rater agreement was 100% (kappa = 1). Results of Experiment 1 reported as significant are significant at $p < .05$ or less.

In order to ensure that children had learned the association between the block and the plane, we assessed whether children predictively looked to the plane during the catch trials. Almost all children predictively looked to the plane (preschoolers: 16/18; toddlers: 16/18); there were no differences between conditions ($\chi^2$ (1, 36) = 0, $p = ns$). Children who were unable to complete the predictive look were removed from subsequent analyses. These results confirm that children across both age groups had no trouble learning the predictive relation between block touching the base and the plane turning on.

Secondly, we assessed whether children replicated the target event by moving the block to the base. 10/16 preschoolers performed the action spontaneously. By contrast, none of the 16 toddlers performed the action spontaneously. Preschoolers were significantly more likely to perform the action spontaneously than were Toddlers ($\chi^2$ (1, 32) = 14.54; $\chi^2$ (1, 20) = 13.13). Thus toddlers never spontaneously generated the correct intervention to turn on the plane. Six additional preschoolers and fourteen of the toddlers performed the action when prompted. Thus, the toddlers were capable of moving the block to the base and did so, when prompted, even though they never did this action spontaneously.

Of course, these results alone do not establish that toddlers failed to represent a causal relation, or that preschoolers succeeded in doing so. The preschoolers might have moved the block to the base without any expectation that this action might cause the plane to turn on; and the toddlers might have failed to move the block to the base for any number of reasons (see discussion below). The critical measure of whether children generalized from the observed relation to their own actions is whether the children expected that their own action might generate the same effect; that is, whether they expected that moving the block to the base might cause the plane to turn on.

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[2] This imitative prompt was inspired by previous research suggesting that children could “read through” the goals of incomplete actions (Meltzoff, 1995). We anticipated that by showing children an incomplete version of the target action – bringing the block close to the base – we could prompt children to generate the complete target action: touching the block to the base. This hypothesis proved correct; virtually all of the children were able to complete the action with the imitative prompt.

Our primary measure of success was therefore whether children inferred that their own target action might generate the outcome. To be included in this analysis, children had to both predictively look to the toy during the Observation Phase *and* perform the target action during either the Action or the Prompted Action Phase. The stringent inclusion criteria meant that we could be confident that all the children in the subsequent analyses (16 preschoolers; 14 toddlers) had both learned the predictive association between the block and the toy, and were willing and able to perform the target action. Then we coded whether children predictively looked to the toy after they performed the target action. Children who predictively looked to the toy after performing the action, regardless of whether they performed the action spontaneously or with prompting, were counted as passing the task. Children were coded as failing on this task only if they never predictively looked to the toy after performing the action.

14 of the 16 preschoolers (87.5%) succeeded at the task. Of the children who succeeded, 10 of the 14 had intervened spontaneously; the remaining four succeeded during the Prompted Action Phase. The two children who failed never performed the action spontaneously and did not look to the toy after performing the prompted action. By contrast, none of the 14 toddlers succeeded at the task. That is, in a full minute of free play, no toddler performed the action spontaneously; the toddlers performed the action after prompting, but still none looked predictively to the toy. The preschoolers were significantly more likely to succeed at the task than the toddlers ($\chi^2$ (1, 30) = 23.0). See Table 1.

The striking discrepancy between the performance of the younger and older children is consistent with the possibility that only the older children believed the evidence of the Observation Phase indicated a possible causal relationship between the block and the toy. Despite being able to predict the outcome of the observed action as successfully as the older children, and being capable of performing the necessary action, the younger children did not show any indication of understanding that their own action might activate the toy.

Why did the toddlers fail? We can rule out the possibility that they were unwilling to interact with the block. Although they did not perform the target action spontaneously, all toddlers included in the analysis performed the action under prompting and children also performed many other actions consistent with object-directed play (sliding the block, banging the block, etc.). Nor were toddlers unmotivated to activate the plane. After the experiment, we showed all the children how the block could be used to activate the plane and all children then performed the action repeatedly. Experiments 2–4 and 5 further serve to rule out other general explanations for the toddlers' failure.

One possibility, however, is that toddlers perceived the catch trial as evidence *against* a causal relation between two events, since the block contacted the base but the toy failed to activate. In Experiment 2, we eliminated the catch trial to see if toddlers would be more likely to intervene on the block when the block activated the toy deterministically.

## 2. Experiment 2

### 2.1. Method

**2.1.1. Participants—**15 toddlers (mean: 25.3 mos; range: 18–30 mos) participated in Experiment 2.

**2.1.2. Materials—**The same materials used in Experiment 1 were used in this experiment.

**2.1.3. Procedure—**The same procedure used in Experiment 1 was used in this experiment, with one exception: there was no catch trial in the Observation Phase. That is, children observed the block contact the base and the toy activate on all trials, and never observed a trial in which the block contacted the base and the toy did not activate.

### 2.2. Results and discussion

Results were reliability coded as in Experiment 1 and inter-coder agreement was 100% (kappa = 1). Because there was no catch trial, we were unable to assess whether the toddlers in this experiment learned the predictive relation between the two events. However, since the vast majority of toddlers in Experiments 1, 3, 4 and 5 successfully learned the relationship from equivalent evidence, it seems plausible that the toddlers in this experiment similarly learned the relation.

We adjusted alpha to accommodate multiple comparisons; here comparisons to the Toddler condition of Experiment 1 would be significant at .05/2 or $p < .025$. (Throughout, statistical comparisons across experiments should be interpreted with caution; each experiment was conducted independently and thus children were not randomly assigned to conditions.) However, there was no significant difference between children’s performance in the Deterministic condition of Experiment 2 and the original toddler condition of Experiment 1. Replicating Experiment 1, only 1/15 toddlers performed the action spontaneously; an additional 13 children performed the action after prompting. Even after prompting, only 1/14 of the toddlers who performed the action then predictively looked towards the toy, not significantly different from children’s performance in Experiment 1 ($\chi^2$ (1, 28) = 1.04, $p$ = *ns*).

Since toddlers performed as poorly in Experiment 2 (without a catch trial) as in Experiment 1 (with the catch trial), toddlers’ failure to generate an intervention does not simply reflect confusion caused by the failed trial. We suggest that the toddlers’ failure reflects the young children’s restricted causal representations. That is, as suggested in the Introduction, toddlers may initially be unlikely to use observed correlations to infer a causal relation, unless other supporting evidence is available.

In Experiment 3, we introduce one source of supporting information: an agent’s intentional action. We replicate the procedure of Experiment 1, except that the movement of the block results from an agent’s action. If toddlers successfully anticipate the effects of their own action in this condition, it suggests that young children do treat an observed correlation as potentially causal (and therefore as supporting an intervention to recreate the effect) when the initial observation includes an agent’s intentional action. Additionally, Experiment 3 serves as an important control condition for Experiments 1 and 2. If toddlers succeed in Experiment 3, their failure in Experiments 1 and 2 is unlikely to be due only to superficial features (the block’s spontaneous movement, the children’s motivation to activate the plane, the distraction of the plane, etc.) of the task.

## 3. Experiment 3

Toddlers’ failures in Experiments 1 and 2 are especially striking in light of many recent demonstrations of sophisticated causal knowledge in infants and toddlers (e.g., Gopnik et al., 2004; Kushnir & Gopnik, 2005; Kushnir & Gopnik, 2007; Muentener & Carey, submitted for publication; Saxe, Tenenbaum, & Carey, 2005; Schulz & Bonawitz, 2007; Schulz & Sommerville, 2006; Schulz et al., 2008; Sobel, 2004; Sobel & Kirkham, 2006). We hypothesized that the young children’s limitations may have been masked in previous studies because the events included additional evidence of a causal relation between the observed events. One such source of evidence is the presence of a dispositional agent. Specifically, infants and toddlers may recognize deliberate actions by dispositional agents (henceforth, “agent actions”) as likely causes, and therefore may identify sequences involving agent actions as causal relations.

There is evidence that infants and toddlers construe agent actions as the cause of subsequent effects. Toddlers will not only imitate a novel action (e.g., touching their head to a box, Meltzoff, 1988) but will also look to see that the action produced the associated effect (e.g., that a light above the box activated; Carpenter, Nagell, & Tomasello, 1998; see also Meltzoff & Blumenthal, 2007). Toddlers also use their broader causal knowledge to inform their imitation of others’ actions. For instance, 18-month-olds will imitate an adult’s action more faithfully if the action deterministically generates its effects than if the action generates effects probabilistically (Schulz et al., 2008, see also Williamson et al., 2008). Moreover, if an intentional agent performs arbitrary actions, children will treat the action sequence as causally relevant to the subsequent outcomes (Gergely, Bekkering, & Király, 2002; Lyons et al., 2007; Meltzoff, 2007). Such findings suggest that young children understand observed agent actions as causal.[3]

However, the scope of young children’s inferences about agent actions remains unclear. One possibility is that toddlers restrict their inferences about causal relations to the goal-directed action itself. If so, they might be able to generalize from observed agent actions to their own actions but they would not have any expectation of whether the same sequence is causal if it occurs without an agent action. Alternatively, agent action might help children parse the causal structure of events: once they represent the relationship between an agent action and an outcome, they are able to represent the same sequence as causal even in the absence of an agent action. Some evidence supports this alternative. Meltzoff and Blumenthal (2007) showed 24-month-olds a (non-agentive) correlation between two events: a machine making a sound and an object several feet away lighting up. The distant object was occluded and children saw an experimenter poke a stick into the machine, making the sound. The occluder was then removed and the children were given the stick; the children both activated the machine themselves and looked predictively towards the distant object. A key difference between Meltzoff and Blumenthal’s (2007) paradigm, in which toddlers succeeded, and Experiments 1 and 2, in which toddlers failed, is the presence of an agent action. The experimenter poking the stick into the machine may have helped toddlers parse the causal structure of the previously observed correlation between the sound and the light.

In Experiment 3, we test the hypothesis that an agent action potentially associated with a goal facilitates children’s ability to represent the action as a cause of the outcome, even in non-agentive contexts. We test this hypothesis both in a condition in which children must generalize from the agent action to the non-agent action (the Agent to Ghost condition) and in a condition in which children must generalize from the non-agentive to the agent-initiated event (the Ghost to Agent condition). In the Agent to Ghost condition, children see an agent perform the target action. As in Experiment 1, they then receive a first catch trial (or two) in which the outcome does not occur to ensure that they learn the predictive relations between the observed events (i.e., to ensure they meet inclusion criteria). The initial event is then repeated and the children then receive an additional, critical catch trial in which the block appears to move spontaneously; we look at whether children predict that the outcome will occur on this critical, spontaneous movement catch trial.

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[3] Of course, it is not always correct to infer that events that immediately follow one’s own or another’s actions are effects of those actions. (One researcher for instance, cited a childhood anecdote in which she dropped a vase immediately before a city wide power outage and worried that she was to blame; Cheng, 1997.) However, while fallible, such inferences are nonetheless rational; it is more probable that an intentional action caused any consistently subsequent events than that the agent initiated the action and some other, temporally coincident cause, generated the subsequent events. As with visual illusions, the occasional “causal illusion” serves mainly to illustrate the usual utility of the inferential process.

The Ghost to Agent condition is the inverse. Children see the target action occur spontaneously; they receive a first catch trial (or two) to ensure that they learn the predictive relations between events (i.e., meet the inclusion criteria). Then after a final repetition of the initial event, children receive an additional, critical catch trial in which they see an agent perform the target action and the plane does not activate. Again, we ask whether children will predict that the target outcome will occur on the critical catch trial (when the event is generated by an agent). Finally, in both conditions, we ask whether children will intervene themselves and predict that the target outcome will occur as a result of their own interventions.

If children predictively look to the toy during the critical catch trials, it suggests that for the purposes of prediction, toddlers generalize across agent–ghost and ghost–agent contexts (from intentional action to spontaneous movement and from spontaneous movement to intentional action). That is, successful predictive looks on the critical catch trials would suggest that children form a common representation of agentive and non-agentive actions, at least for the purpose of predicting common outcomes. Additionally, if children do not merely imitate the observed action in both conditions but also predict the outcome of their own actions, this would suggest that intentional action by an agent (whether the intended outcome results or not) facilitates children's ability to construe predictive relations as events that potentially support effective manipulation.

## 3.1. Method

**3.1.1. Participants—**Twenty-one toddlers (mean: 24.3 months; range: 18–30 months) were assigned to the Agent to Ghost condition; 19 toddlers (mean: 23.5 months; range: 18–30 months) were assigned to the Ghost to Agent condition. In the Agent to Ghost condition, three toddlers were excluded from the action measure for failing to make the initial predictive look, and two toddlers were excluded from the final success measure for failing to perform the action. In the Ghost to Agent condition, two toddlers were excluded from the action measure for failing to make the initial predictive look, and one toddler was excluded from the final success measure for failing to perform the action.

**3.1.2. Materials—**The same materials used in Experiment 1 were used in this experiment.

**3.1.3. Procedure—**The procedures were identical to Experiment 1 except for changes to the Observation Phase as noted below.

**3.1.3.1. Agent to Ghost condition:** In the Observation Phase, the experimenter placed her hand on the block and slid it towards the base on the first four trials so that it looked as if she were moving the block into the base. (The block was actually controlled by the confederate throughout so that the motions were matched across conditions.) The fifth trial was identical except that the toy did not activate; this catch trial allowed us to assess whether the children had learned the predictive relation between the observed action and outcome. If the child failed to look to the toy, the experimenter performed a sixth trial on which the toy activated, followed by a seventh trial in which the toy did not activate. If the child again failed to look predictively towards the toy, they were excluded from further analyses. The child then received a subsequent trial in which the block contacted the base and the toy activated. The Observation Phase ended with the critical catch trial in which the block appeared to move spontaneously. The block contacted the base but the toy did not activate. This last catch trial allowed us to see whether the children generalized their prediction about the outcome of the intentional action to the outcome of the spontaneous movement.

**3.1.3.2. Ghost to Agent condition:** The Observation Phase was identical to Experiment 1 (with the block appearing to move spontaneously throughout). However, we included a final critical catch trial in which the experimenter placed her hand on the block so that it looked as if she were intentionally moving the block. (As above, the block was actually moved by the lever so that the motions were matched across conditions.) The block contacted the base but toy did not activate. This final catch trial allowed us to see whether the children generalized from the outcome of the spontaneous action to the outcome of the intentional movement.

## 3.2. Results and discussion

Coding and inclusion criteria were as in Experiment 1. Inter-coder agreement was 97% in the Agent to Ghost condition (kappa = .87) and 96% in the Ghost to Agent condition (kappa = .81); discrepancies were resolved conservatively. (That is, because we hypothesized that intentional action would facilitate children's success, children in dispute were coded as failing.) We adjusted alpha to accommodate multiple comparisons; here comparisons to the toddler condition reported as significant are significant at .05/4 or $p < .012$.

We first assessed whether children learned the initial relationship between the block and the plane by assessing whether children predictively looked to the plane during the initial catch trials of Experiment 3. Almost all children predictively looked to the plane (Agent to Ghost condition: 18/21; Ghost to Agent condition: 18/19), comparable to the results in Experiment 1. There were no differences between the two conditions ($\chi^2$ (1, 40) = .90, $p = ns$). Children who did not complete the predictive look were subsequently removed from analyses.

We then assessed whether children generalized their learning from the initial relationship between the block and the plane to the new action (i.e., from intentional action to spontaneous movement as in the Agent to Ghost condition, and from spontaneous movement to intentional action as in the Ghost to Agent condition). Of the children who passed the first catch trials (i.e., met the inclusion criteria), almost all also succeeded in looking predictively during the final, critical catch trial (Agent to Ghost condition: 15/18; Ghost to Agent condition: 15/18.) This suggests that, for the purpose of prediction, children had little difficulty generalizing either from intentional action to spontaneous movement or from the spontaneous movement to intentional action.

Next, we assessed whether children performed the target action on the block. In the Agent to Ghost condition, 12/18 preschoolers performed the action spontaneously and four additional toddlers performed the action after prompting. In the Ghost to Agent condition, 8/18 children performed the action spontaneously and an additional eight children performed the action after prompting. Toddlers were significantly more likely to perform the action spontaneously in both conditions of Experiment 3 than in Experiments 1 and 2 (Agent to Ghost condition vs. Experiment 1 toddlers: $\chi^2$ (1, 34) = 16.48; Ghost to Agent condition vs. Experiment 1 toddlers: $\chi^2$ = 9.30.) There were no significant differences between the conditions in Experiment 3: $\chi^2$ (1, 36) = 1.80, $p = ns$).

As with Experiment 1, our measure of success on the task was whether or not children predictively looked to the toy, following their own completion of the action. Also as in Experiment 1, for this analysis we included only children who made the initial predictive look and who completed the target action. In the Agent to Ghost condition, 13 of the 16 toddlers who met the inclusion criteria succeeded at the task (81%). Of the children who succeeded, 10 of the 13 intervened spontaneously (during the Action Phase), the remaining three succeeded during the Prompted Action Phase. Two of the three children who failed performed the target action spontaneously but did not look to the toy; one child never performed the action spontaneously and did not look to the toy after performing the prompted action. In the Ghost to Agent condition, nine of the 16 toddlers who met the inclusion criteria succeeded at the task (56%), predictively looking to the toy following their action. Of the children who succeeded, six of the nine intervened spontaneously (during the Action Phase), the remaining three succeeded during the Prompted Action Phase. Two of the seven children who failed performed the target action spontaneously but did not look to the toy; the remaining five children never performed the action spontaneously and did not look to the toy after performing the prompted action. The toddlers in both conditions of Experiment 3 were significantly more likely to succeed on the task than the toddlers in Experiment 1 (Agent to Ghost condition vs. Experiment 1 toddlers: $\chi^2$ (1, 30) = 20.07; Ghost to Agent condition vs. Experiment 1 toddlers (1, 30): $\chi^2$ = 11.25.) There were no significant differences between the Agent to Ghost and Ghost to Agent conditions ($\chi^2$ (1, 32) = 2.33, $p = ns$).

The results of Experiment 3 have several implications. First, compared with toddlers' performance at floor in Experiment 1, children's success in Experiment 3 suggests that the presence of intentional action substantially improves toddlers' ability to recognize that observed events might support manipulation. Children were able, not merely to imitate the modeled action, but also to predict that their own actions would result in the target outcome (consistent with Carpenter et al. (1998), Meltzoff and Blumenthal (2007)). Moreover, children succeeded even when, as in Ghost to Agent condition, they had to base their predictions on an inferred goal (activating the plane). That is, although Experiment 1 suggests that toddlers have difficulty using the association between a spontaneously occurring event and an outcome to infer a potentially effective action, they do not seem to have difficulty using the association between a spontaneously occurring event and an outcome to infer the goal of an *observed* action. Children were then able to imitate the modeled action and anticipate the fulfillment of the target goal. This is consistent with other studies suggesting that even 18-month-olds can infer the goal of an unfulfilled action (Meltzoff, 1995).

Second, the results of Experiment 3 help rule out several possible explanations for toddlers' failure in Experiments 1 and 2. First, Experiment 3 suggests that toddlers in Experiments 1 and 2 did not fail simply because they were frightened or distracted by the spontaneous movement of the block (since the block also appeared to move spontaneously in both conditions of Experiment 3). More importantly, Experiment 3 rules out the possibility that the toddlers are unable to form any common representation for non-agentive and agentive events. At least for the purpose of prediction, children are able to represent both spontaneous and intentional actions as the common event of 'the block moving'. Toddlers in Experiment 3 (as in Meltzoff and Blumenthal (2007)) integrated information about non-agentive relations and the outcome of goal-directed actions during predictive looking.

In sum, Experiment 3 suggests that intentional action helps children parse the causal structure of events; once children understand that an action is potentially associated with a goal, they seem to be better able to represent the action as a potential cause of the outcome. Toddlers' causal knowledge will thus appear relatively sophisticated when measured in events that involve agent actions, compared to their performance for sequences of non-agent actions.

## 4. Experiment 4

Experiments 1–3 suggest that intentional action might play a critical role in supporting children's ability to infer an effective action from an observed predictive relation. We now turn to the role of spatial contiguity. Adults expect physical causal relations to occur only if information or energy can be transmitted along a spatially continuous path connecting the causally related events (see Dowe, 2000; Salmon, 1984). (Quantum entanglement may violate this assumption but quantum entanglement so far violates adult causal intuitions that even Einstein called it “spooky”.)

There is evidence that children also privilege contact relations over action-at-a-distance relations. For instance, preschoolers initially assume that placing an object on top of a machine is more likely to activate it than simply suspending it overhead, though they will readily learn action-at-a-distance relations when they are given appropriate evidence (Kushnir & Gopnik, 2007). This suggests that in the absence of goal-directed action, children may be unlikely to construe apparent action at-a-distance relations as causal.

For adult observers, Experiments 1–3 did not involve even apparent action at a distance: the plane only activates when the block contacts the base and the plane is visibly connected to the base by a bright orange cable. However, this connection may be too indirect for toddlers, given that the causal force must be transmitted through the cable. Young children might not recognize a physical connection between a causal agent and patient that is not *itself* visibly transformed in the course of causal transmission. That is, children might not understand invisible means of transmission (as when water travels through a pipe, or electricity through cables).

Toddlers may be more likely to perceive a correlation as a causal relation supporting potential intervention if the two events are in direct spatial contact. One previous study directly supports this idea (Thompson & Russell, 2004). 14-month-old children spontaneously performed a target action (pushing a cloth to move a toy away) after purely observational evidence (i.e., the cloth appeared to push itself and move the toy). We hypothesize that toddlers succeeded on Thompson & Russell’s (2004) task, even though they failed in Experiments 1 and 2, because of the continuous visible transfer of momentum at the point of contact between the cloth and the toy.

In Experiment 4, we test the hypothesis that toddler’s ability to represent causal relations among physically connected events benefits from spatial contiguity. We predict toddlers are able to move from observation to intervention, if during the observed sequence the causal agent directly contacts the causal patient.

## 4.1. Method

**4.1.1. Participants—**Nineteen toddlers (mean: 22.6 months; range: 18–29 months) participated in Experiment 4, the Spatially Contiguous condition. One toddler was excluded from the action measures for failure to make the initial predictive look, and two toddlers were excluded from the final success measure for failing to perform the target action.

**4.1.2. Materials—**The block and the track were not modified. However, the base object was lengthened from approximately 7 cm to approximately 25 cm so that the right most edge remained in the same location (at the end of the block’s track) and the left most edge extended 18 cm farther to the left of the stage. The base was lengthened to ensure the possibility of coding a predictive look. Additionally, the wire connecting the airplane to base was removed and the airplane was directly inserted in the far end of the base; thus to an adult viewer, it appeared that the airplane and base were part of a single object. See Fig. 2.

**4.1.3. Procedure—**The procedure was identical to the procedure in Experiment 1 except for the changes to the stimuli noted above.

### 4.2. Results and discussion

Coding and inclusion criteria were as in the previous Experiments. Inter-coder agreement was 97% (kappa = .94); discrepancies were resolved conservatively. (That is, because we hypothesized that direct spatial contact would facilitate children's success, children under dispute were coded as failing.) We adjusted alpha to accommodate multiple comparisons; here comparisons to the Toddler condition reported as significant are significant at .05/5 or $p < .01$. We first assessed whether children learned the initial relationship between the block and the plane by assessing whether children predictively looked to the plane during the first catch trial. Almost all children predictively looked to the plane (18/19); comparable to the results of Experiments 1–3. The child who failed to complete the predictive look was subsequently removed from analyses.

Next, we assessed whether children performed the target action on the block. In this experiment, 10/18 preschoolers performed the action spontaneously and six additional toddlers performed the action after prompting, comparable to the results in Experiment 3. Toddlers were significantly more likely to perform the action spontaneously in this experiment than in Experiment 1 (Experiment 4 vs. Experiment 1 Toddlers: $\chi^2$ (1, 34) = 12.59).

Finally, we assessed whether children predictively looked to the toy following completion of the action. Eleven of the 16 toddlers (69%), who met the inclusion criteria (i.e., because they predictively looked during the catch trial and performed the action), succeeded at the task, comparable to the results in Experiment 3. Of the children who succeeded, eight of the 11 had intervened spontaneously (during the Action Phase), and the remaining three succeeded during the Prompted Action Phase. Two of the five children who failed performed the target action spontaneously but did not look to the toy; the remaining children never performed the action spontaneously and did not look to the toy after performing the prompted action. The toddlers in Experiment 4 were significantly more likely to succeed on the task than the toddlers in Experiment 1 (Experiment 4 vs. Experiment 1 toddlers: $\chi^2$ (1, 30) = 15.20).

The comparison with the toddlers' performance in Experiment 1 suggests that young children's causal understanding is sensitive to the contact relations between candidate causes and effects. Note that the toddlers' success in Experiment 4 rules out the possibility that the toddlers' failure in Experiment 1 was due to superficial features of the paradigm (motivation to activate the plane, distraction by the plane, or reluctance to act on the spontaneously moving block). The only difference between Experiment 4 and Experiment 1 was the spatial relationship between the base and the toy. The effect of spatial contiguity was dramatic: when the contacted base and the toy were distinct, although obviously connected objects, none of the toddlers produced the action in order to activate the toy; when the base and the toy could be construed as a single object, the majority of toddlers succeeded.

One possible explanation for the children's success in Experiment 4 is that the increased spatial contiguity between the block, the base, and the toy in Experiment 4 relative to Experiment 1 made the relationship between the moving block and the activating toy more salient and easier to encode. However, there is no evidence that toddlers in Experiments 1 and 2 failed to encode the predictive relation between the block and the toy. In all four Experiments, toddlers were equally able to learn the predictive relationship between the block and the toy. Rather we suggest that the toddlers in Experiments 1 and 2 failed to infer that the predictive relationship between the objects was causal because there was an apparent spatial gap in the process of causal transmission. Research suggests that even adults construe causation with and without intermediaries differently, and may use different causal language to describe the two kinds of events (see e.g., Wolff, 2003). This study suggests that young children may initially construe only a relatively small subset of predictive sequences of non-agentive physical events – those involving direct, unmediated contact – as genuinely causal.

## 5. Experiment 5

If, absent intentional action, children initially construe only a very limited set of physical sequences as causal, how do they eventually expand their sense of causal possibilities (such that preschoolers just two years older succeeded in Experiment 1)? We now turn to the hypothesis that causal language facilitates children's causal understanding. Investigating causal language allows us to explore a plausible process underlying the change in children's representations with age and experience. Moreover, while manipulating agency and spatial contiguity changes the perceptible features of the event sequence (as in Experiments 3 and 4), adding causal language does not. Thus investigating the role of causal language allows us a unique opportunity to contrast children's spontaneous perception of an event sequence with their perception of a physically identical event sequence, given only the supplemental cue of causal language.

Language could help children identify causal relations in two ways. First, causal language provides evidence that there is a common relation underlying observed covariations and agent actions, since the same words can be used to describe the events (e.g., "The block makes the toy go," "you can make it go"). Second, once children understand causal language, adults can provide testimony that an observed covariation actually reflects a causal relation (rather than a common cause), by simply asserting that a causal relation exists.

If causal language helps toddlers identify causal relations, we can ask whether the facilitative effect is relatively fragile and depends on providing an identical label for the events of the Observation and Action Phase (i.e., depends on using *precisely* the same words; "The block makes it go"; "Can you make it go?") or whether the effect of language is more robust and thus different words with the same meaning ("The block makes it go"; "Can you turn it on?") suffice. Thus in Experiment 5, we investigate the role of causal language in three conditions. In the Identical Causal Language Condition, the same words are used in the Observation Phase and the Action Phase ("The block can make it go"; "Can you make it go?"). If language facilitates toddlers' causal inferences, toddlers will perform better in this condition than in Experiment 1. In the Different Causal Language Condition, non-identical but semantically equivalent words are used ("The block can make it go." "Can you turn it on?"). If language acts as a fairly robust cue to children's causal learning, then toddlers' performance, relative to Experiment 1, should improve in this condition as well. Finally, in the Non-Causal Language control condition, language is used merely to attract children's attention to the events ("Look at the block! Let's watch my show! Here it goes!"). If any additional language increases the salience of events and improves children's performance, then children's performance, relative to Experiment 1, should improve in this condition as well. By contrast, if *causal* language is specifically facilitative, then the Non-Causal Language will provide a third replication of the toddlers' failure in Experiments 1 and 2.

### 5.1. Method

**5.1.1. Participants—**Twenty toddlers were tested in the Identical Causal Language Condition (mean: 24.5 months; range: 19–29 months), 21 toddlers were tested in the Different Causal Language Condition (mean: 23.6 months; range: 18–30 months), and 19 toddlers were tested in the Non-Causal Language Control Condition (mean: 23.6 months; range: 18–30 months). In the Identical Causal Language Condition two toddlers failed to make the initial predictive look, and two toddlers failed to perform the target action. In the

Different Causal Language Condition three toddlers failed to make the initial predictive look and two failed to perform the target action. In the Non-Causal Language Control three toddlers failed to make the initial predictive look.

**5.1.2. Materials—**The same materials used in Experiments 1–3 were used.

**5.1.3. Procedure—**The procedure was identical to the procedure in Experiment 1 except for the following changes. During the Observation Phase of the Identical Causal Language Condition, each trial began as the experimenter said, “Look, the block can make it go!” When the child was handed the block in the Action Phase, the experimenter said, “Now it’s your turn. Can you make it go?” During the Observation Phase of the Different Causal Language Condition, each trial again began as the experimenter said, “Look, the block can make it go!” When the child was handed the block in the Action Phase, the experimenter said, “Now it’s your turn. Can you turn on the toy?” During the Observation Phase of the Non-Causal Language Control condition, each trial again began as the experimenter drew attention to the events without reference to the causal relationship (“Let’s watch my show. See what’s happening? See the block? Here it goes!”.) When the child was handed the block in the Action Phase, the experimenter said, “Now it’s your turn. Can you make it go?”

## 5.2. Results and discussion of Experiment 4

Coding and inclusion criteria were as in the preceding experiments. In the Identical Causal Language Condition, inter-coder agreement was 92% (kappa = .79), in the Different Causal Language Condition, it was 97% (kappa = .90) and in the Non-Causal Language Condition, it was 98% (kappa = .96); discrepancies were resolved conservatively. (That is, debatable children in the Causal Language Conditions were counted as failing the task; debatable children in the Non-Causal Language Condition were counted as passing.) We adjusted alpha to accommodate multiple comparisons; here comparisons to the toddler condition reported as significant are significant at .05/7 or $p < .007$.

In all three conditions, most of the toddlers performed the predictive look (Identical Causal Language Condition: 18/20; Different Causal Language Condition: 18/21; Non-Causal Language Condition: 16/19) comparable to the results in Experiments 1–4. In the Identical Causal Language Condition 12/18 toddlers performed the action spontaneously and four additional children performed the action with prompting. In the Different Causal Language Condition, 9/18 toddlers performed the action spontaneously and an additional seven children performed the action with prompting. In the Non-Causal Language Condition, 6/16 toddlers performed the action spontaneously and an additional 10 children performed the action with prompting. Overall, toddlers were significantly more likely to perform the action spontaneously in this experiment than in Experiment 1 (Identical Causal Language Condition vs. Experiment 1 toddlers: $\chi^2$ (1, 34) = 16.48); Different Causal Language Condition vs. Experiment 1 toddlers: ($\chi^2$ (1, 34) = 10.88); Non-Causal Language Condition vs. Experiment 1 toddlers: ($\chi^2$ (1, 32) = 7.39). There was a trend for more children to perform the action spontaneously in Identical Causal Language Condition than the Non-Causal Language Condition ($\chi^2$ (1, 34) = 2.89, $p = .09$); there were no other significant differences among the conditions of Experiment 5.

In short, there was a general effect of language on children’s tendency to spontaneously perform the target action. We hypothesize that this general effect occurred because the experimenter referred to the block repeatedly. Whether the language was causal (“See, the block can make it go!”) or non-causal (“See the block? Here it goes!”) labeling the block seemed to increase the toddlers’ tendency to perform the target action relative to the toddlers’ performance in Experiment 1. As in the previous experiments however, the critical question was whether children who moved the block into the base did so because they inferred that the block might activate the toy.

In the Identical Causal Language Condition, of the children who met the inclusion criteria, 8/16 (50%) succeeded at the task, predictively looking to the toy following their own action. Seven of the eight succeeded after intervening spontaneously (during the Action Phase), the remaining child succeeded during the Prompted Action Phase. Five of the eight children who failed performed the target action spontaneously but did not look to the toy; the remaining children never performed the action spontaneously and did not look to the toy after performing the prompted action.

Similarly, in the Different Causal Language Condition, of the toddlers who met the inclusion criteria, 10/16 (62%) succeeded at the task. Nine of the 10 succeeded after intervening spontaneously (during the Action Phase); the remaining child succeeded during the Prompted Action Phase. None of the six children who failed performed the target action spontaneously; all of the six children who failed the task never performed the action spontaneously and did not look to the toy after performing the prompted action.

By contrast, in the Non-Causal Language Control condition, of the children who met the inclusion criteria, only one of the 16 (6%) succeeded at the task; that child succeeded after a spontaneous intervention (during the Action Phase). Five of the 15 children who failed the task performed the target action spontaneously but failed to look predictively at the toy; the remaining 10 children never performed the action spontaneously and did not look to the toy after performing the prompted action.

Thus the toddlers in the two Causal Language Conditions were significantly more likely to succeed on the task than the toddlers in Experiment 1 (Identical Causal Language Condition vs. Experiment 1 toddlers: $\chi^2$ (1, 30) = 9.54; Different Causal Language Condition vs. Experiment 1 toddlers: $\chi^2$ (1, 30) = 13.12). There was no difference between the two Causal Language Conditions ($\chi^2$ (1, 32) = .50, $p = ns$). However, the toddlers in the Non-Causal Language Condition were no more likely to succeed on the task than the toddlers in Experiment 1 (Non-Causal Language Condition vs. Experiment 1 toddlers: $\chi^2$ (1, 30) = .90, $p = ns$). Similarly, children's performance in the Non-Causal Language Condition was significantly different than their performance in the Causal Language Conditions (Non-Causal Language Condition vs. Identical Causal Language Condition: $\chi^2$ (1, 32) = 7.57; Non-Causal Language Condition vs. Different Causal Language Condition: $\chi^2$ (1, 32) = 11.22).

These results suggest that describing observed events with causal language supports children's ability to recognize that non-agentive events support manipulation. The effect of language was relatively robust, surviving minor changes in wording as long as the meaning was preserved. Critically, the effect of language was not entirely general; merely calling children's attention to the events did not contribute to their success on the task. As noted, children performed more spontaneous actions in the Non-Causal Language Condition than in Experiments 1 and 2, presumably because the language increased children's attention to the block. Nevertheless, Non-Causal Language did not affect children's recognition that the relationship between the block and the toy potentially supported a causal intervention; children were no more likely to look predictively to the toy after performing the action in the Non-Causal Language Condition than in Experiment 1.

Future research might investigate precisely how causal language supports children's causal reasoning. Our experiment did not distinguish between the two mechanisms by which causal language may influence toddler's causal inferences: either by helping children form an integrated causal representation of events (i.e., by helping children bind together information about prediction and action) and/or by helping children extend their already integrated understanding of causal relationships to novel sequences (see Section 6). Additionally, our experiment did not address the specific features of causal language (e.g., semantics vs. syntax) that impacted children's causal representations. In particular, research suggests that how adults talk about potential causes influences they way cause is conceptualized. Lexical causatives (e.g., “the block activated the toy”) can be used for any direct causation in English but are typically used for animate agents. Our use of the periphrastic causative (“the block made the toy go”) may have supported children's recognition that a non-agentive event was nonetheless causal (see e.g., Wolff, 2003; Wolff, Jeon, & Li, 2009). Longitudinal studies of acquisition of causal language might clarify the precise processes by which toddlers' causal reasoning benefits from causal language.

## 6. General discussion

These five experiments suggest that there are substantial constraints on young children's ability to use predictive relations between physically connected events to initiate causally effective actions. Toddlers had no difficulty learning a predictive relationship between events (the block contacts the base, and then the plane turns on) and no difficulty performing the relevant action (moving the block to the base). Nevertheless, toddlers in Experiments 1, 2 and the Non-Causal Language Condition of Experiment 5 failed to treat the predictive relationship as genuinely causal: they did not move the block in order to turn on the plane, and when they did move the block, they did not expect the plane to turn on. Unlike preschoolers, toddlers needed extra information in order to move directly from observation to action: toddlers only represented the events as causal when a dispositional agent initiated the observed events, the observed events involved direct contact relations, or the observed events were described with causal language. Moreover, toddlers' success in Experiments 3–5 suggest that toddlers do not have absolute difficulty using predictive relations as the basis for planning and executing effective motor acts. Rather, there seem to be only limited conditions under which toddlers represent predictive relations as supporting potentially effective action.

There are several important implications of these findings. First, if infants in general fail to treat non-agentive predictive relations as relations that support intervention, this might help explain some longstanding puzzles in the developmental literature. Several studies have shown that infants can understand a concept based on their pattern of looking time behavior and yet older children fail on very closely matched action paradigms. In particular, infants often seem to have expectations about object properties and relations under observation, yet fail to infer relevant interventions from these relations (e.g., Baillargeon, Needham, & DeVos, 1992 vs. Karmiloff-Smith & Inhelder, 1974 and Bonawitz, Lim, & Schulz, 2007; Spelke, Breinlinger, Macomber & Jacobson, 1992 vs. Hood et al., 2000). The current results suggest that such gaps might not reflect mere failures of performance (e.g., due the increased complexity of acting vs. looking) but genuine constraints on children's causal representations.

More broadly, these findings suggest several questions about what changes in the understanding of causal relations during early childhood. One possibility for instance, is that the older, but not the younger children, understood something about the causal mechanism that could connect the block and the toy. Previous research suggests that neither adults nor children will infer a causal relationship based purely on covariation information unless they believe there is a plausible causal mechanism at work (Ahn, Kalish, Medin, & Gelman, 1995; Koslowski, 1996; Shultz, 1982).

For several reasons however, we believe this cannot fully account for the current results. First, the relationship between the block and the toy was deliberately arbitrary to avoid calling upon specific mechanism knowledge. Given that there was no actual mechanism connecting the block and the toy, it seems unlikely that the successful four-year-olds could have had a much richer understanding of precisely *how* the block activated the toy than the failing toddlers. More importantly, none of the manipulations that contributed to the toddlers' success – introducing a dispositional agent, increasing the spatial contiguity between the block and the toy, or adding causal language – added additional information about how one event caused the other. That is, agent action, spatial contiguity, and causal language appear to help children specify the existence of a causal relation, without specifically increasing children's understanding of the causal mechanism.

If changes in children's understanding of causal mechanisms do not underlie these results, an alternative possibility is that the toddlers' failure might be due to a broader discontinuity in the causal representations of younger and older children. Very young children might be sensitive to the characteristic properties of causal sequences (including predictive relations, spatiotemporal parameters, and the ability to support intervention) without integrating these into a common causal representation. If so, young children might initially use observed relations to make predictions about future events, and use experiences of agent actions to design new actions, but only gradually recognize that the relationships that support prediction can often also support effective intervention.

One intriguing possibility is that causal language might play a crucial role in bringing such disparate representations together. Researchers have proposed (see Spelke, 2003) that in domains of knowledge where component abilities are ontogenetically early and phylogenetically broad, language may play a critical role in uniting otherwise separate, modular, inferential systems. Evidence for such linguistic bootstrapping accounts has been advanced in the domain of number as a means of uniting the small exact number system and the large approximate number system, (Le Corre & Carey, 2007), and as a means of uniting geometric and landmark cues in spatial navigation (Hermer & Spelke, 1996). Given that component abilities of causal inference – learning statistical associations between events, a sensitivity to contact relations among objects, and learning the relationship between one's own actions and immediate outcomes – are present both in early infancy and in non-human animals, it is tempting to suggest that linguistic representations (explicitly provided to children in Experiment 5, and possibly automatically accessed by older children), might support the integration of these component systems into adult-like causal reasoning.

Another compelling idea is that language might help children integrate disparate representations by creating new conceptual resources that help identify commonalities in previously distinct (but not necessarily modular) initial representations. Researchers have suggested theoretically, and demonstrated empirically, that language might play such a role in transforming children's early theories in domains including object disappearances, tool-use relationships, and object categories (Gopnik, Choi, & Baumberger, 1996; Gopnik & Meltzoff, 1986; Gopnik & Meltzoff, 1992; Gopnik & Meltzoff, 1997; Gopnik & Nazzi, 2003). For instance, both 20-month-olds and preschoolers will categorize objects causally rather than perceptually if causal language is used to describe the objects (Nazzi & Gopnik, 2000; Nazzi & Gopnik, 2001) and preschoolers explore perceptually identical objects with disparate causal properties more if the objects share a common label than if they do not (Schulz, Standing, & Bonawitz, 2008). Collectively, these results suggest that the use of common (or distinct) terms across many apparently disparate (or common) contexts could alert children to the similarity and differences between these contexts and lead to new theoretical concepts.

Critically however, the current data do not definitely establish that toddler's causal representations are discontinuous, rather than merely distinct, from older children's and adult's causal knowledge. It is possible that very young children have an adult-like concept of what it means for events to be causally related but initially apply to that concept only to a very restricted class of events. Infants for instance, might recognize causal relationships between their own actions and their immediate outcomes (Rovee-Collier, 1987; Watson & Ramey, 1987), in the goal-directed actions of others (e.g., Gergely et al., 2002; Meltzoff, 2007) and among objects involving continuous transfer of motion (as suggested by Leslie and Keeble (1987) and Oakes and Cohen (1990) and consistent with Thompson and Russell (2004)). Later they may come to recognize causal roles in change of state events involving direct contact between objects (as suggested by Cohen, Amsel, Redford, and Casasola (1998); and consistent with results of the current study). Ultimately, they might recognize the possibility of causal relations involving apparent spatial gaps in the processes of causal transmission or causal transmission across invisible connections among events. On this account, causal language would broaden children's causal understanding by testifying that sequences with different surface properties are all nonetheless instances of causality.

Critically, whether discontinuous or merely distant from adult representations, the current research suggests that the causal world of the young child is strikingly constrained. Unless explicitly told otherwise, very young children may think they can act to change the outcome of events only if the events are initiated by agents or involve direct, unmediated physical contact. A toddler may know that mom turning on the tap caused the water to flow, that her rubber ducky bumped into and launched the toy boat, and (because she is told) that the soap can make her clean. However, only the parent may recognize that the steam rising from the tap causes the mirror to fog; that the knock on the door caused the shampoo to spill, and that the shampoo caused the bubbles under the faucet. While adults and young children may live in much the same world of observable objects and their properties, the current findings suggest that they might live in quite different causal worlds even with respect to perceptible events. If "causality is the cement of the universe" (Hume, 1789), the child's world might still, even at its foundations, be under construction.

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## Further reading

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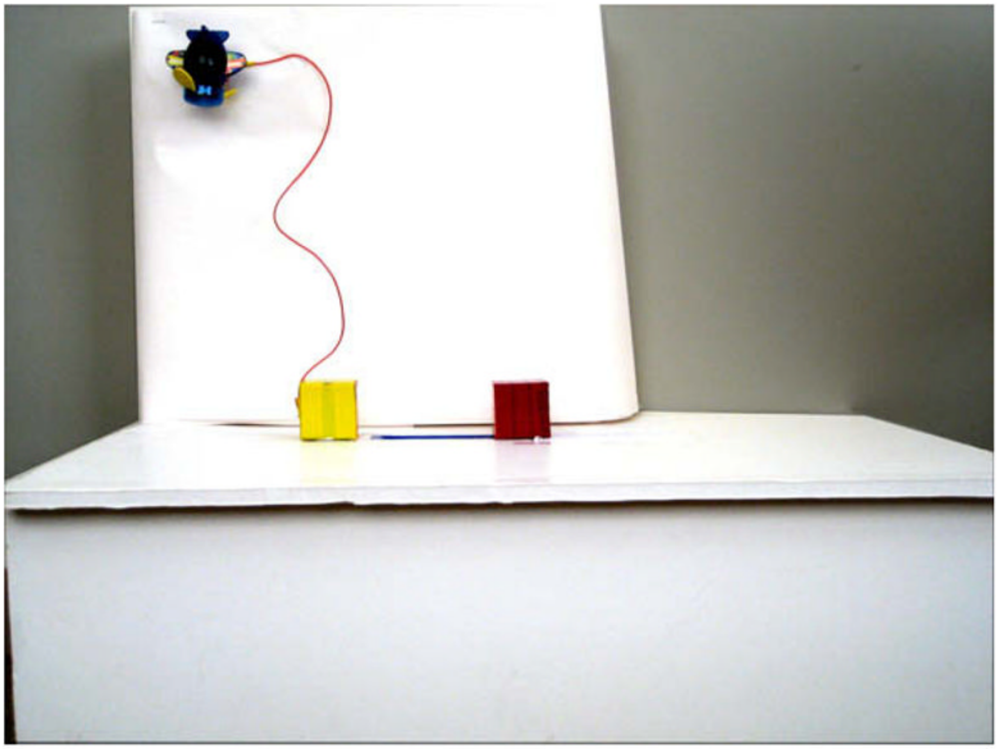

**Fig. 1.**
Stimuli and stage used in Experiments 1–3, and 5.

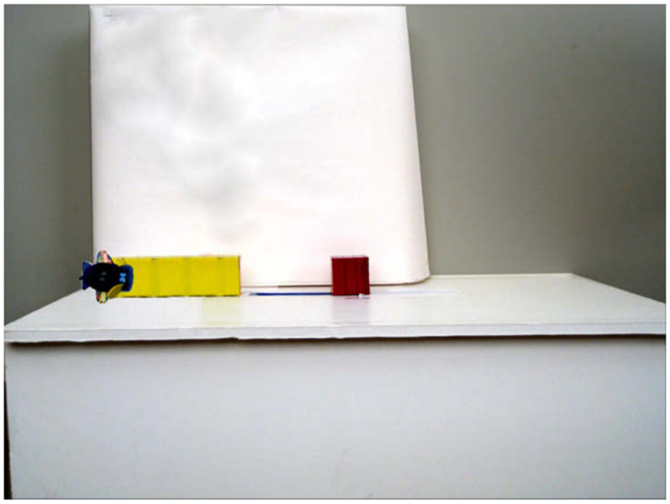

**Fig. 2.**
Stimuli and stage used in Experiment 4.

## Table 1

Results of Experiments 1–5. Number of children who performed the action spontaneously or with prompting and whether they did or did not predictively look to the toy following their own action. Children who failed to look to the toy were counted as failing the task; children who looked to the toy following their own action (whether the action was spontaneous or prompted) were counted as succeeding at the task. *N* = 14 for the Toddler condition of Experiment 1 and the Deterministic condition of Experiment 2; *N* = 16 for all other conditions. Experiments 2–5 involve toddlers.

| **Condition** | **Experiment 1** | | **Experiment 2** | **Experiment 3** | | **Experiment 4** | **Experiment 5** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Pre-school** | **Toddlers** | **Deterministic** | **Agent-ghost** | **Ghost-agent** | **Spatio-temp** | **Ident. CL** | **Diff. CL** | **Non-CL** |
| Spontaneous (no look) | 0 | 0 | 1 | 2 | 2 | 2 | 5 | 0 | 5 |
| Prompted (no look) | 2 | 14 | 12 | 1 | 5 | 3 | 3 | 6 | 10 |
| Total Fail | 2 | **14** | **13** | 3 | 7 | 5 | 8 | 6 | **15** |
| Spontaneous (look) | 10 | 0 | 0 | 10 | 6 | 8 | 7 | 9 | 1 |
| Prompted (look) | 4 | 0 | 1 | 3 | 3 | 3 | 1 | 1 | 0 |
| Total Success | 14 | **0** | **1** | 13 | 9 | 11 | 8 | 10 | **1** |