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Toddlers’ understanding of prediction, intervention, and means of transmission: When psychological outcomes are easier than physical ones

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Abstract

Adults recognize that if event A predicts event B, intervening on A might generate B. Research suggests that although preschoolers draw this inference much like adults, toddlers do not (Bonawitz et. al, 2010). Here we look at whether toddlers’ failure is domain-general (i.e., they lack an adult-like concept of causality that integrates prediction, intervention, and agency) or domain-specific (i.e., toddlers have trouble recognizing some physical processes as causal but might succeed with psychological events). We showed toddlers (24 months) a block moving into a base, after which an effect occurred; we then gave children the block and asked them to generate the effect. Toddlers performed the intervention and predicted the outcome when the effect was psychological (a puppet laughing) but, replicating previous studies, not when the effect was physical (a toy activating). Experiment 2 showed that this was not due to the relative saliency of the psychological effect.

Keywords: causal reasoning; domain-specific; domain-general; physical causality; psychological causality; prediction; intervention.

Causal representations are central to human cognition. They support prediction, explanation, and intervention and underlie folk theories across domains (Carey, 1985; Gopnik & Meltzoff, 1997; Wellman & Gelman, 1992). Moreover, causal representations cross-cut conceptual boundaries. Adults are equally adept at reasoning about causal events in the physical domain (e.g., driving a car) and psychological domains (e.g., making someone laugh).

Considerable research testifies to the sophistication of causal inferences even early in development. Children can distinguish spurious associations from genuine causes, reason about unobserved variables, and use the conditional dependence of interventions and outcomes to distinguish a range of causal structures (e.g., Bullock, Gelman, & Baillargeon, 1982; Gopnik & Sobel, 2000; Gopnik et al., 2004; Kushnir & Gopnik, 2007; Schulz, Goodman, Tenenbaum, & Jenkins, 2008; Schulz & Sommerville, 2006; Shultz, 1982; Sobel & Kirkham, 2006; Williamson, Meltzoff, & Markman, 2008.) Critically however, studies of causal reasoning tend to investigate children’s inferences in the context of an agent’s goal-directed actions: children are almost uniformly asked to reason about events initiated by people or puppets.[1] Recent research suggests that in very early childhood, children’s causal reasoning may be restricted to such contexts.

Specifically, Bonawitz et. al (2010) showed toddlers several trials of predictive relations in which a block began moving spontaneously towards, and contacted, a base, after which a toy airplane connected to the base immediately began to spin. For adults, evidence that event A predicts event B suggests the possibility that intervening on A might generate B (i.e., intervening on A to see if B occurs is a good way to learn whether the relationship is genuinely causal). However, although both four-year-olds and toddlers readily learned the predictive relationship, only four-year-olds spontaneously pushed the block into the toy and anticipated the outcome (i.e., looked predictively towards the toy). Toddlers succeeded only in restricted contexts, in particular when the events were initiated by dispositional agents.[2]

One possibility is that although toddlers recognize predictive relations and are capable of learning the relationship between their own interventions and outcomes they do not bind these two kinds of reasoning into a single, adult-like concept “cause”. Indeed, many researchers have proposed that adult humans may be unique in integrating the kind of predictive reasoning involved in classical conditioning with the ability to anticipate the outcome of interventions characterized by operant learning (Gopnik et al., 2004; Tomasello & Call, 1997; Woodward, 2007). Although animals can make different predictions under observation and intervention (Blaisdell, Sawa, Leising, & Waldmann, 2006), there is no evidence that animals spontaneously design novel interventions after learning predictive relations. Arguably, this ability develops relatively late, even in human ontogeny.

Alternatively, toddlers might have an adult-like concept of causation but fail to token many physical event sequences as potential causal relationships. Several findings suggest that children develop an expectation of “causation-on-contact” very early. Research has shown that infants expect objects to move or change state on contact (Ball, 1973; Muentener & Carey, 2010; Kotovsky & Baillargeon, 2000; Luo, Kaufman, & Baillargeon, 2009) and this expectation persists through early childhood; although four-year-olds can learn to accept causation-at-a-distance, they too initially

[1] Investigations of Michottian causality (Michotte, 1963) are an important exception to this claim; however, Michottean causality is arguably a modular process, divorced from causal knowledge more broadly (Scholl & Tremoulet, 2000; Woodward, in press; though see Saxe & Carey, 2006, and Schlottmann, 2000)

[2] One might worry that toddlers failed to intervene simply because they were troubled by the spontaneous movement of the block. Control conditions in the earlier study (Bonawitz, et al., 2010) ruled out this possibility. In particular children succeeded with spontaneously moving blocks as long as there were other cues that the events were causal (i.e., causal language).

expect that effects occur only on contact (Kushnir & Gopnik, 2007).

Bonawitz et. al (2010) focused on physical causal events in which the block contacted a base, which was connected to the toy by a bright orange wire. From an adult perspective, a block contacting a base and activating an airplane connected to the base by a wire does not involve any violation of contact causality. However, it is possible that toddlers failed to understand the transmission relationship involved in these events. The lack of any apparent transformation or visible transmission of force or energy within the wire itself might have impaired the children's ability to recognize the instantiation of contact causality.

This suggests the possibility that toddlers might be able to integrate prediction and action into an adult-like concept of cause, and might succeed in domains where the transmission relationships are less restricted: in particular toddlers might be more successful in the domain of psychological causality where events can occur either through direct contact or (and even more typically) at a distance. That is, if we remove constraints on toddlers' expectations about mechanisms of causal transmission, toddlers might have no difficulty with the basic task of integrating prediction and intervention.

In the current study we replicate the Bonawitz et al., (2010) procedure and compare toddlers' causal reasoning about physical outcomes with their reasoning about psychological outcomes. We present toddlers with predictive events in which a block moves spontaneously towards a base, connected to a toy. In the Physical condition, the toy is an airplane that immediately begins to spin. In the Psychological condition, the toy is a puppet that immediately begins to laugh. If toddlers lack a domain-general concept of causation and only integrate prediction and action when events are initiated by agents, they should fail in both conditions (since the block always begins to move spontaneously; agents are never involved in initiating the events). By contrast, if toddlers have a domain-general understanding of causation but simply fail to understand some mechanisms of physical transmission, they should fail in the physical condition but succeed in the psychological condition.

Experiment 1

Methods

Participants Forty two toddlers (mean: 24.5 months, range –18 - 30 months) were recruited at a Children's Museum. An additional 6 toddlers were recruited but not included in the final sample due to: inability to complete the session (n = 2), parental interference (n = 2), or experimenter error (n = 2). Twenty-two toddlers were assigned to the Physical condition and sixteen toddlers were assigned to the Psychological condition. There were no age differences between the conditions ($p = ns$).

Materials All events occurred on a white stage (60 cm^2 x 50 cm) that blocked a confederate from view (See Figure 1.) A

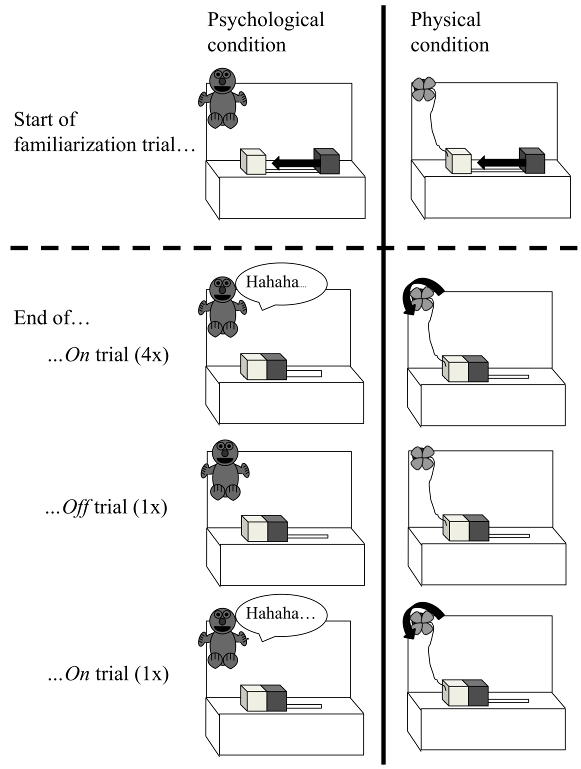

Figure 1: Procedure for Experiment 1. Toddlers viewed 4 *On* familiarization trials, an *Off* familiarization trial, and another *On* familiarization trial. If toddlers failed to look towards the effect in the *Off* familiarization trial, then they viewed three additional trials (*On*, *Off, On)*.

blue block (the base) and a green block (both 6 cm^3) were on opposite ends of the stage. The green block was attached to a stick extending through the floor of the stage, allowing the hidden confederate to surreptitiously move the block across the stage to the base. In the Physical condition, a toy airplane, attached to the base by a wire, was located on the back stage wall. In the Psychological condition, a puppet with eyes was seated on a perch on the back stage wall. The confederate controlled the actions of the airplane and puppet.

Procedure

Familiarization There were two types of familiarization trials: *On trials* and *Off trials*. Toddlers first viewed 4 *On trials*, which provided an opportunity to encode the predictive relationship between the block's motion and the effect. In the *On trials*, the block began at the far right of the stage. The experimenter drew the toddlers' attention to the stage saying, "Watch my show." The block then moved towards and contacted the base. As soon as the block contacted the base, an effect occurred. In the Physical condition, the airplane spun for 3 s. In the Psychological condition, the puppet, laughed and wiggled for 3 s. At the end of the trial, the stage was covered by an occluder and the scene was reset.

Following the *On trials*, the toddlers viewed one *Off trial.* The *Off trials* were identical to the *On trials*, with the exception that the effect did not occur. The experimenter ended the trial after the toddler looked towards the airplane or after 3 s, whichever came first. The *Off trial* served as an indicator of whether the toddlers had encoded the predictive relationship between the block's motion and the effect. If toddlers did not look towards the effect during the *Off trial*, the experimenter repeated another *On trial*, followed by another *Off trial*. All toddlers then viewed one final *On trial*. Thus, all toddlers saw a maximum of 8 trials. (If toddlers looked towards the effect on the first *Off trial*, then they saw only 6 trials.)

Test At the start of the test phase, the experimenter handed the block to the toddler and asked the child to make the effect occur. If the child did not place the block in contact with the base within 60 s, the experimenter prompted the toddler to place the block in contact with the base. The prompt involved the experimenter pushing the block across the stage towards, but just short of, the base block. The experimenter then returned the block to the toddler and encouraged them to make the effect occur.

Results

The first set of analyses assessed whether toddlers had learned the predictive relationship between the block's motion and the effect. We assessed this by coding whether toddlers looked up towards the effect on the *Off trial*, in which the effect did not occur. We counted a behavior as "looking up" if the toddlers either overtly moved their head and looked towards the effect or only shifted their gaze towards the effect. The majority of toddlers learned the predictive relationship. In the Physical condition, 18 of the 22 toddlers (81.82 %) looked up towards the toy airplane after the block contacted the base. In the Psychological condition, 15 of the 16 toddlers (93.75 %) looked up towards the puppet after the block contact the base. There was no significant difference between the conditions (χ^2 (1, 38) = 1.15, p = *ns*). To ensure that any differences that emerged during the test phase were not due to differential encoding of the predictive relationship, children were only included in the test phase if they learned the predictive relationship.

Next, we assessed whether toddlers were able to perform the target intervention: pushing the block into the base. Note that merely performing this action is not sufficient grounds for inferring that toddlers' recognized that the action was causal: toddlers might push the block into the base simply because they had encoded that portion of the event sequence, or simply for fun. To assess whether the intervention was causal, we also need to assess whether toddlers predicted that the target outcome would occur. Conversely, toddlers might understand the causal relationships perfectly well and yet be unwilling or unable to perform the target action (e.g., due to shyness). Thus we wanted to ensure that all toddlers included in the critical analysis (predictive looking after the intervention) were in fact willing and able to perform the target action.

Toddlers were less likely to intervene spontaneously in the Physical condition than in the Psychological condition. Seven of the 18 toddlers (38.89 %) in the Physical condition spontaneously placed the block in contact with the base during the test phase. By contrast, 11 of the 15 toddlers (73.33 %) in the Psychological condition spontaneously performed the action (χ^2 (1, 33) = 3.92, $p < .05$). The remaining 4 toddlers in the Psychological condition and 8 of the 11 remaining toddlers in the Physical condition completed the action following a prompt by the experimenter. Three toddlers in the Physical condition failed to perform the action either spontaneously or following a prompt and were thus removed from further analysis (i.e., toddlers were only included for the final analysis if they performed the target intervention).

Our primary measure of interest was whether, having learned the predictive relationship between the block and the outcome, toddlers predicted that their own intervention might generate the outcome. Thus the final analysis assessed whether, after learning the predictive relationship between the block's motion and the effect and successfully performing the intervention (whether spontaneously or under prompting), toddlers looked up predictively to the toy (which never activated at test). In the Physical condition, only 5 of the 15 toddlers (33.00 %) looked to the toy after intervening. By contrast, in the Psychological condition, all of the toddlers did so (15/15 toddlers; 100.00 %; χ^2 (1, 30) = 12.15, $p < .0001$).

Discussion

The results of Experiment 1 suggest that the nature of the effect influenced toddlers' causal representations. We replicated prior research in showing that toddlers do not seem to represent non-agentive physical predictive relationships as potential causal relationships. Although toddlers learned the predictive relationship between the block and the airplane's motion, toddlers did not spontaneously intervene to cause the event to occur. Moreover, even after toddlers were prompted to intervene, they did not look towards the airplane in expectation that the effect might occur. In contrast toddlers represented the predictive relations as potential causal relationships for psychological events: they readily learned the predictive relationship, spontaneously intervened on the event, and expected their intervention to cause the outcome.

It is possible however, that toddlers might simply have been more attentive to the task in the psychological condition. The laughing puppet may have been more interesting and salient than the activating plane. Arguing against this account, there were no differences in toddlers' ability to learn the predictive relationship between conditions, suggesting that toddlers were equally attentive to the familiarization events. Additionally, anecdotally, toddlers were riveted by the activating plane and activated it repeatedly at the end of the test period when they were all shown how. However, in Experiment 2, we directly test this alternative account by involving a laughing puppet in the physical events. If mere increased arousal or attention improves children's performance, they should succeed in this Psychological Control condition of Experiment 2; if they continue to fail to represent non-agentive physical relationships causally, toddlers should learn the predictive relationship but fail to predict the outcome of their own interventions.

Experiment 2

Participants Twenty three toddlers (mean: 23.65 months, range – 18 - 30 months) were recruited at a Children's Museum. One additional toddler was recruited but not included in the final sample due to an inability to complete the session (n = 1). All children were assigned to a Psychological Control condition. There were no age differences between this condition and either condition from Experiment 1 ($p = ns$).

Materials The same materials used in the Physical condition of Experiment 1, and the puppet from the Psychological condition of Experiment 1, were used in Experiment 2.

Procedure

Familiarization The familiarization phase was identical to the Physical condition in Experiment 1 except that at the start of each familiarization trial, the experimenter drew the child's attention to the puppet, who was seated next to the stage, on the experimenter's lap. The experimenter asked the child to say hello to the puppet and the puppet then laughed and wiggled for 3 s (exactly as in the psychological condition of Experiment 1). After the puppet laughed, the experimenter told the child that the puppet was going to watch the show with them and then turned the puppet to face towards the stage. The puppet then giggled in an identical manner at the start of every trial. (Note, we had the puppet laugh before the trials rather than after so that the puppet's laughter could not be construed as an effect; we had the puppet laugh on the experimenter's lap rather than on the stage so the puppet could not be construed as a dispositional agent initiating the events.)

The trials then proceeded as an *On trial* or *Off trial*, which mirrored the Physical condition from Experiment 1. Toddlers first viewed 4 *On trials*, in which the block moved towards and contacted the base and the effect occurred. Following the *On trials*, the toddlers viewed one *Off trial*, in which the effect did not occur. As in Experiment 1, if toddlers did not look towards the effect during the *Off trial*, the experimenter repeated another *On trial*, followed by another *Off trial*. All toddlers then viewed one final *On trial*. Thus, toddlers saw a maximum of 8 trials. If toddlers looked towards the effect on the first *Off trial*, then they saw only 6 trials.

Test The test trial was identical to Experiment 1. The puppet, while present and seated on the Experimenter's lap, did not laugh or move.

Results

We compared toddlers' performance in the Psychological Control condition of Experiment 2 to their performance in the Psychological and Physical conditions of Experiment 1. We adjusted alpha to accommodate for multiple comparisons (.05/3 or $p < .0167$). First, we found that as in Experiment 1, toddlers readily learned the predictive relationship between the block and the effect. Seventeen of the 22 toddlers (77.27 %) looked up towards the plane during the *Off trial*. Toddlers' ability to learn the predictive relationship in Experiment 2 was no different from their performance in either the Psychological condition (χ^2 (1, 38) = 1.89, $p > .05$) or the Physical condition (χ^2 (1, 44) = .14, $p > .05$) of Experiment 1. The 5 toddlers who failed to learn the predictive relationship in the Psychological-Control condition of Experiment 2 were removed from subsequent analyses.

Ten of the 17 toddlers (58.82 %) spontaneously intervened by placing the block in contact with the base. Toddlers' tendency to intervene spontaneously in the Psychological Control condition did not differ from either the Psychological condition (χ^2 (1, 32) = .74, $p > .05$) or the Physical condition of Experiment 1 (χ^2 (1, 35) = 1.39, $p > .05$). Five additional toddlers completed the intervention following the experimenter's prompted action. The final two toddlers never performed the intervention and were removed from subsequent analysis.

As in Experiment 1, our critical measure of interest was whether, having learned the predictive relationship and demonstrated their ability to perform the target intervention, the toddlers predicted that the outcome would result from their intervention. Only 6 of the 15 toddlers (40 %) did so. Toddlers were significantly less likely to look predictively towards the toy following their intervention in the Psychological Control condition of Experiment 2 than in the Psychological condition of Experiment 1 (χ^2 (1, 30) = 12.85, $p < .05$); their responses were not significantly different from the performance of children in the Physical condition of Experiment 1 (χ^2 (1, 30) = .14, $p = ns$).

Discussion

The results of Experiment 2 suggest that children's success in the Psychological condition of Experiment 1 was not due merely to the inclusion of a salient, laughing puppet. When the puppet was included in Experiment 2 toddlers' performance did not improve; toddlers did not expect their interventions to cause the physical effect. This finding replicates the findings from Experiment 1 that, in the absence of agent-initiated action, toddlers do not readily represent physical predictive relations as causal events. The results are also rule out the alternative explanation of toddlers' success in the Psychological condition of Experiment 1, suggesting that toddlers' success was due not merely to the salience of the puppet but to children's ability to represent psychological events causally because they permit a range of possible transmission relationships; by contrast in physical relationships, toddlers may require direct, unmediated contact.

General Discussion

The results of previous work (Bonawitz et al., 2010) left open the possibility that toddlers lacked a domain-general concept of causation that integrated prediction and intervention. The current study provides evidence against that view. Toddlers were able to observe a non-agentive predictive relationship and move from learning the prediction to designing an appropriate intervention and anticipating the outcome. Critically however, they only did so when the outcome was a psychological one (and the events might plausibly have occurred at a distance). That is, toddlers appear to have access to an integrated concept of causation which bridges the gap between prediction and intervention, but they the events to which they apply this concept depend on how causation is instantiated in particular domains.

How then do children reason about physical causal events? One speculative possibility is that children initially only recognize agent-initiated events as causal: events involving their own actions, Rovee-Collier, 1987; Watson & Ramey, 1987, or those other goal-directed agents (e.g., Gergely et al., 2002; Meltzoff, 2007; see also Slobin, 1981, 1985). With respect to non-agentive events, infants might initially apply the concept of causation only to contact causality resulting in object motion (i.e., Michottian launching events; see Leslie & Keeble, 1987; Cohen & Oakes, 1990). Evidence suggests that recognizing contact causality for object changes of state (Muentener & Carey, 2010) may be a later development. By the second year, toddlers may recognize non-agentive causal relationships as long as there is a continuous, visible transmission of force or energy (e.g., consistent with work by Thompson & Russell, 2004). Only relatively late in development may children realize that they can engage in causal reasoning for a larger class of events, including non-agentive events that occur without visible transmission of energy or information (through wires) or even through invisible connections.

In future work, we hope to conduct empirical studies to test this developmental story about how children might understand mechanisms of physical transmission. Even if an account like this is correct however, the question remains of why children readily accept the entire range of these transmission events as causal, as long as the events are initiated by goal-directed agents. Future research might look at whether children can bootstrap from their understanding of the goal-directed causal events to their understanding of means of transmission in the absence of dispositional agency.

What about causal transmission for psychological events? We have suggested that mechanisms of transmission for psychological outcomes are relatively less constrained than those for physical events: causes do not have to contact the entities they effect, nor do they need to be physically connected to them. Nonetheless, there are constraints on how psychological events can be transmitted. Adults for instance, understand that visual access is often critical to psychological outcomes; if a person cannot see an event, she cannot laugh in response to it. Although we know that even infants understand many aspects of informational access (Onishi & Baillargeon, 2005) we do not know whether they integrate their understanding of informational access into their understanding of psychological causation. For example, if the puppet's visual access to the blocks were occluded (e.g., the puppet were blindfolded) would the toddlers' recognize that the block could not have caused the puppet to laugh? In this context, would they know not to not intervene on the block and look up predictively? We are currently investigating constraints on toddlers' understanding of psychological transmission relationships in our laboratory.

The current study adds to a growing body of research suggesting that children may develop rich abstract inferences in tandem with or even before they have an accurate understanding of concrete details or specific mechanisms (Wellman & Gelman, 1992; Schulz, Jenkins, Goodman, & Tenenbaum, 2008; Goodman, Ullman, & Tenenbaum, in press). These studies suggest that, although children may have an adult-like abstract understanding of the concept of causation that binds prediction and action very early in development, their ability to recognize any particular event sequence as an instance of causation may depend on domain-specific constraints and develop in a piecemeal manner, in which they must learn viable means of causal transmission event by event.

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