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Mind the Gap: Dispositional Agency Facilitates Toddlers' Causal Representations

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Abstract

Toddlers readily learn predictive relations between events (A predicts B); however, they intervene on A to *cause* B in few contexts (e.g., when an agent initiates the event.) The current studies look at whether toddlers' failures are due to the difficulty of initiating interventions or to constraints on the events they causally represent. Toddlers saw a block slide towards a base, but an occluder prevented them from seeing whether the block contacted the base; after the block disappeared, a toy did or did not activate. We predicted if toddlers construed the events causally, then they would expect contact when the toy activated but distance when the toy did not activate. In Experiment 1 toddlers predicted the contact relations only when an agent was potentially present. Experiment 2 confirmed that toddlers believed a hidden agent was present. These findings suggest that dispositional agency facilitates toddlers' ability to represent causal relationships.

Keywords: causal reasoning; prediction; dispositional agency; looking-time measures.

Human adults recognize that events that predict each other sometimes cause each other. This allows us to generate novel actions to cause an event (hereafter referred to as "interventions"), distinguish spurious associations from genuine causes, and engage in effective exploration (see Glymour, Spirtes, and Scheines, 2001; Gopnik et al., 2004; Pearl, 2000; Schulz, Gopnik & Glymour, 2007; Woodward, 2002, 2007). However, many researchers have speculated that this recognition might emerge relatively late in both phylogeny and ontogeny (see Bonawitz et al., 2010; Gopnik et al., 2004; Meltzoff 1995; Meltzoff & Blumenthal, 2007; Waisman, Cook, Gopnik & Jacobs, 2009a, 2009b; Woodward, 2007). There is no evidence that non-human animals spontaneously intervene after observing novel predictive relationships (see Tomasello & Call, 1997) and surprisingly, there is some evidence that this insight may be absent even in early childhood: Although preschoolers readily move from observing predictive relationships among physical events to trying causal interventions, toddlers do not (Bonawitz et al., 2010).

Specifically, in a study upon which the current work is based, children were familiarized to a predictive event in which (1) a block moved across a stage and contacted a base, and (2) a spinning toy airplane, connected by a visible wire to the base, immediately activated upon contact. Preschoolers (mean: 47 months) and toddlers (mean: 24 months) were equally successful at learning the predictive relationship: in a catch trial, in which the toy did not activate, virtually all children spontaneously looked to the toy. However, when asked to make the toy go, although almost all the preschoolers pushed the block towards the base and looked to the toy, none of the toddlers did so. That is, no toddler spontaneously intervened, and when prompted to do so, all toddlers pushed the block to the base but none then predictively looked to the toy.

These results were not due to the toddlers' unwillingness to interact with the block (all of them engaged in object-directed play) nor their disinterest in the plane (all of them did so repeatedly when later shown how). Rather, Bonawitz et. al (2010) found that the presence of a dispositional agent[1] appeared to affect toddlers' ability to move from prediction to intervention. If instead of the block moving by itself during the familiarization phase, the experimenter pushed the block into the base, toddlers performed the action themselves and anticipated the outcome.

Given the wealth of research documenting the sophistication of children's causal reasoning (for review, see Schulz, Kushnir, & Gopnik, 2007), toddlers' failure in the non-agentive context may seem surprising. However, previous developmental studies of causal reasoning have almost always included dispositional agents (puppets or people). Thus, little is known about whether children spontaneously recognize the possibility that non-agentive

[1] By dispositional agent we mean an agent capable of intentional action. We use the term dispositional agent rather than just "agent" in order to distinguish dispositional from causal agents (which include objects or forces). We use the term dispositional rather than intentional agent because our experiments do not specifically test the distinction between the intentional and accidental actions.

predictive relations are causal.[2] By contrast, the importance of dispositional agency to infants' causal representations has been widely documented. Infants represent dispositional agents, but not objects, as potential causes of both object motion and change of state events (Muentener, under review; Muentener & Carey, 2010; Saxe, Tenenbaum, & Carey, 2005; Saxe, Tzelnic, & Carey, 2007; but see Sobel & Kirkham, 2007 for potential evidence against this claim). Arguably then, in the absence of dispositional agency, toddlers, like infants, might fail to represent predictive relations as potentially causal.

Alternatively, toddlers' failure to intervene and anticipate the outcome of their interventions might not be due to any difficulty representing non-agentive events as causal but to the difficulty of initiating causally relevant actions. Researchers have suggested that intentional action might, *in general*, lag behind predictive looking either because the demands of planning and executing motor responses interfere with children's ability to access task-relevant information (Baillargeon et al, 1990; Diamond & Goldman-Rakic, 1989; Thelen & Smith, 1994), or because stronger representations might be necessary for acting than for looking (see Munakata, 2001 for review). Although there are important theoretical distinctions between these claims, they are united in suggesting that a gap between children's ability to make successful predictions and their ability to perform effective actions might reflect changes not in children's conceptual understanding but in their ability to manifest their knowledge under complex task demands. If so, any additional information that strengthens the representation of a causal relationship might boost performance. That is, toddlers may recognize deliberate actions by dispositional agents as likely causes, and therefore may identify sequences involving agent actions as causal relations. Thus, the presence of a dispositional agent in Bonawitz et. al. (201) may have improved toddlers' performance because it provided information about the type of action that could be performed with the block at the time the toddler encoded the predictive relation.

By assessing toddlers' causal understanding independent of their ability to initiate actions, we can learn whether dispositional agency merely facilitates children's ability to move from prediction to intervention, or whether it affects children's underlying representations. In order to distinguish these accounts, we look at children's expectation that physical causation requires contact between causal agents and patients (e.g., Ball, 1973; Kotovsky & Baillargeon, 2000; Leslie & Keeble, 1987; Oakes & Cohen, 1990). For example, research suggests that infants expect objects to move when contacted and not to move when not contacted (Kotovsky and Baillargeon, 2000). Recently, these findings have been extended to non-motion state change events, such that infants expect a hand to have contacted the box when it breaks but not when it does not, but they do not have these expectations when the candidate cause is not an agent (Muentener & Carey, 2010).

In the current study, we look at whether dispositional agency affects toddlers' causal representations by using a violation of expectation looking-time paradigm. Inspired by previous work (Bonawitz et al., 2010), we show children a block that slides towards a base; a toy connected to the base either does or does not activate. An occluder prevents children from seeing whether the block contacts the base. On test, we remove the occluder and measure looking time. If toddlers form causal representations of non-agentive events and the failure to intervene suggested by previous work (Bonawitz et al., 2010) is due only to the difficulty involved in initiating motor responses, then children should both (1) expect contact when the effect occurs, and (2) expect a gap when the effect does not occur. By contrast, if toddlers require dispositional agents to represent the events as causal, they should make differential predictions about contact causality in the presence of these cues, but not in their absence. This paradigm thus allows us to investigate whether developmental change occurs merely at the level of performance or at the level of conceptual representations.

Experiment 1

We predicted that toddlers would expect contact causality for events initiated by a dispositional agent, but have no expectations for otherwise identical non-agentive events. However, because toddlers might selectively attend to events initiated by dispositional agents, we compared two closely matched conditions: one in which a block began to move spontaneously (the Spontaneous Motion condition) and one in which a block emerged from off-stage already in motion (the Inferred Agent condition). We were inspired by previous research (Saxe et al., 2005) suggesting that infants posit hidden agents when an object emerges in motion. If for instance, a beanbag emerges from the right side of a stage, 7-month-olds look longer when a previously hidden hand is revealed on the left side of the stage than the right. If toddlers similarly represent hidden agents when objects emerge in motion and represent agent-initiated but not spontaneously occurring events as causal, they should expect spatial relations consistent with contact causality in the Inferred Agent but not the Spontaneous Motion condition.

Methods

Participants Ninety-six toddlers (mean: 24.1 months, range –18 - 30 months) were recruited at a Children's Museum. An additional 9 toddlers were recruited but not included in the final sample due to: inability to complete the session (n = 3), parental interference (n = 1), or failure to predictively look during the familiarization trials (n = 5). 12 toddlers were assigned to each of eight conditions crossing three factors: Agency (Inferred Agent or Spontaneous Motion), Activation (Toy On or Toy Off), and Spatial Relation

[2] Michottean launching events, where one object strikes another and sets it in motion, are an important exception. Many researchers however, have suggested that causal perception of launching events is distinct from other causal inference (e.g., Scholl & Tremoulet, 2000). See General Discussion.

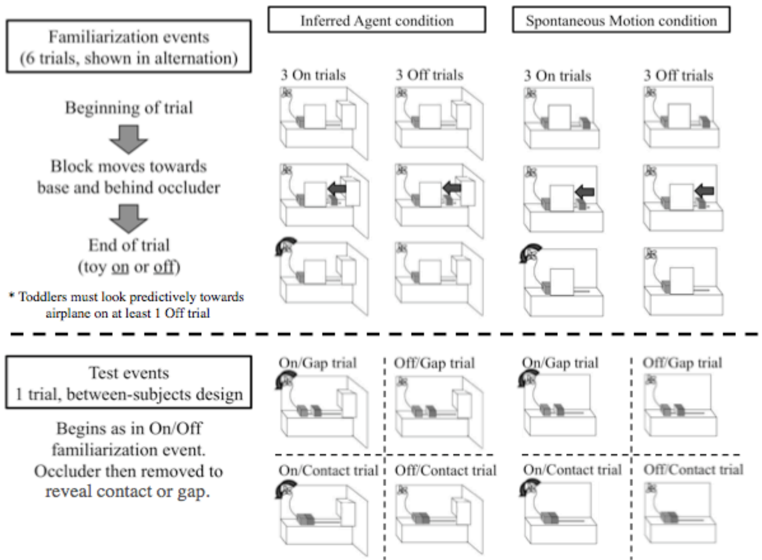

Figure 1: Procedure for Experiment 1. In the Inferred Agent condition, toddlers viewed 6 familiarization trials (3 On, 3 Off, in alternation) in which a block emerged from behind the right side barrier and travelled towards the base, disappearing behind the screen. Toddlers then viewed only one of four test events. Following the initial motion of the block, as during the Familiarization trials, the experimenter removed the screen to reveal the block in contact or at a distance from the base, and the toy either on or off. The Spontaneous Motion condition followed the same procedure, except that the right side barrier was not present during any portion of the experiment.

(Contact or Gap). There were no age differences across conditions ($F(1, 88) = 1.08$, $p > .05$).

Materials All events occurred on a white stage (60 cm^2 x 50 cm) that blocked a confederate from view. A barrier was positioned to the far right of the stage. (See Figure 1.) An orange block (the base) and a purple block (both 6 cm^3) were on opposite ends of the stage. The purple 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. A toy airplane, visibly attached to the base by an orange wire, was located on the back stage wall. During familiarization, a screen (22x28 cm) occluded the spatial relationship between the block and base.

Procedure

Familiarization The block began at the far right of the stage in the Spontaneous Motion condition and behind the right side barrier in the Inferred Agent condition. The experimenter drew the toddlers' attention to the stage saying, "Watch my show." Toddlers viewed an *On trial* and then an *Off trial*. In the *On trial*, the block moved towards the base and disappeared behind the screen. Once the block disappeared, the airplane began to spin. At the end of the trial the stage was covered by a curtain and the scene was reset. The *Off* trials were identical, except that the airplane did not spin. The length of the familiarization trials were experimenter-controlled. The experimenter ended the trial after the airplane spun for 3 s (*On* trial) or (*Off* trial) after the toddler predictively looked towards the airplane or 3 s, whichever came first. This procedure was repeated twice, for a total of 6 familiarization trials. In order to proceed to the test phase, toddlers had to predictively look to the airplane on at least one *Off* trial.[3]

Test The start of each test event was identical to the familiarization: the block moved towards the base, disappearing behind the screen. Toddlers either saw events in which the airplane activated during the test event (On conditions) or did not (Off conditions). The experimenter then said, "Look at this!" and removed the screen, revealing the block either touching (Contact conditions) or at a distance (Gap conditions) from the base. The length of the test trial was toddler-controlled. The experimenter ended the trial when he judged that the child looked away for 2 consecutive seconds.

Two coders, blind to the test event, coded from video toddlers' looking times after the experimenter said "Look at this!". Inter-rater reliability, conducted on 1/3 of the toddlers' looking time, was high, $r > .9$.

[3] For all experiments, there were no significant differences across conditions in the number of toddlers who were dropped from subsequent analysis because they failed to predictively look during one of the *Off* familiarization trials.

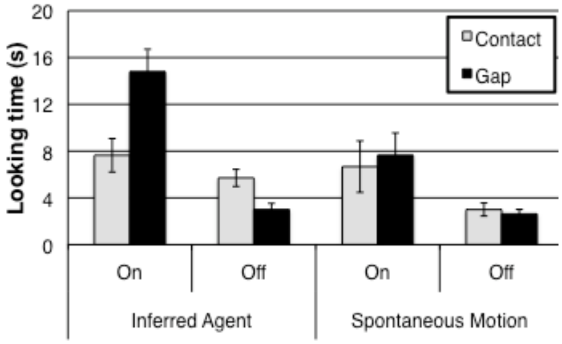

Figure 2: Looking time (±1 SD) to the final test events in Experiment 1.

Results

To evaluate toddlers' looking time to the test events (see Figure 2), we conducted an analysis of variance (ANOVA) with Agency (Inferred Agent vs. Spontaneous Motion), Activation (On vs. Off), and Spatial Relation (Contact vs. Gap) as between-subjects factors. This analysis yielded a main effect of Activation, F(1, 88) = 32.69, p <.0001. Toddlers looked longer at the test event when the airplane moved (9.19 s) than when it did not (3.58 s). There was also a 3-way interaction between the factors, F(1, 88) = 4.19, p = .044, which was qualified by a 2-way interaction between Activation and Spatial relation, F(1, 88) = 8.88, p = .004. There were no other main effects or interactions.

We conducted separate ANOVAs in each condition to follow-up this analysis. In the Inferred Agent condition, there was a main effect of Activation; F(1, 44) = 28.95, p < .0001. Toddlers looked longer when the airplane moved (11.22 s) than when it did not (4.35 s). There was also an interaction between Activation and Spatial Relation, F(1, 44) = 14.94, p < .0001. This interaction reflected the fact that toddlers looked longer at the gap event when the airplane moved, t(22) = 3.00, p = .007, but longer at the contact event when the airplane did not move, t(22) = 3.00, p = .007.

A different pattern emerged in the Spontaneous Motion condition. There was a main effect of Activation, F(1, 44) = 8.53, p = .005. Toddlers looked longer when the airplane moved (7.2 s) than when the airplane did not (2.8 s). No other main effects or interactions approached significance. In the Spontaneous Motion condition, toddlers did not discriminate among the test events.

Discussion

These results suggest that only toddlers in the Inferred Agent condition represented the block as the cause of the airplane's motion. These children looked longest when the test event violated contact causality: (1) when the block stopped short of the base but the toy activated or (2) when the block contacted the base but the toy did not activate. By contrast, when the block moved spontaneously, toddlers had no differential expectations. These results are consistent with the hypothesis that dispositional agency facilitates toddlers' ability to represent predictive relations as causal.

However, while consistent with this possibility, we have no *positive* evidence that toddlers' success in the Inferred Agent condition in Experiment 1 was due to inferring the presence of a hidden agent. To test this, we present the same familiarization events in Experiment 2 as in Experiment 1 but at test, we remove the barrier on the right of the stage to reveal a person's hand. Following the logic of Saxe, Tenenbaum, & Carey (2005), if toddlers expect a hidden agent only when the block emerges in motion, then toddlers in the Spontaneous Motion condition should look longer at the hand than those in the Inferred Agent condition.

Experiment 2

Methods

Participants Twenty-four toddlers were recruited at a Children's Museum. An additional 2 toddlers were recruited but were not included in the final sample due to: inability to complete the session (n = 1), or failure to predictively look during the familiarization trials (n = 1). Toddlers were assigned to an Inferred Agent (mean age: 22.18 months, range: 18 – 30 months) or a Spontaneous Motion condition (mean age: 23.22, range: 18 – 30 months). There were no differences in age (t(22) = .6, p > .05).

Materials The same materials used in the Inferred Agent condition of Experiment 1 were used in this experiment.

Procedure In the Inferred Agent condition, the block emerged from off-stage already in motion. In the Spontaneous Motion condition, the block began moving spontaneously. Toddlers viewed 6 familiarization events identical to those in Experiment 1. Following familiarization, all toddlers viewed the same test event. The block moved across the stage towards the base, disappearing behind the occluder. Then, the experimenter said, "Look at this!" and lowered the far right barrier, revealing a hand at rest, palm facing towards the block. Two coders, blind to the test event, coded toddlers' looking times from video. Inter-rater reliability, conducted on 1/3 of the toddlers' looking time, was high, r > .9.

Results

An analysis of toddlers' looking time to the test event revealed that toddlers looked significantly longer in the Spontaneous Motion (17.62 s) than the Inferred Agent condition (9.96 s), $t(22)$ = 3.43, p = .002.

Discussion

Toddlers inferred that there was a hidden dispositional agent when the block emerged in motion but not when it moved spontaneously. This is consistent with our hypothesis that toddlers represented the events causally in the Inferred Agent condition of Experiment 1 because they believed that a dispositional agent initiated the events. Strikingly therefore, merely occluding the onset of the block's motion allowed toddlers to make predictions about contact causality that they failed to make when the onset of motion was visible.

General Discussion

The current study suggests that toddlers have expectations consistent with contact causality when they can infer the presence of a dispositional agent. Prior research (Bonawitz et al., 2010) showed that dispositional agency facilitates toddlers' ability to spontaneously intervene on predictive relations. Together with the current findings, it appears that dispositional agency affects not merely whether toddlers initiate causal interventions, but whether they represent events causally.

Why did toddlers fail to make differential predictions in the Spontaneous Motion condition? We have suggested that toddlers do not readily represent objects as potential causes; they thus failed to represent the non-agentive event causally. However, the spontaneous movement of the block itself violated the expectation that physical objects move only when they are contacted (Kotovsky & Baillargeon, 2000). Thus, the initial spontaneous movement of the block might have confused the toddlers and disrupted any further expectations they might have had. Mitigating against this possibility, note that there was no difference between conditions in the number of toddlers who met the inclusion criteria (i.e,. who predictively looked to the plane during the familiarization phase). This suggests that children did not find the spontaneous movement of the block particularly disruptive.

However, if, as we have suggested, the absence of a dispositional agent, rather than the presence of spontaneous movement, interferes with children's expectations of contact causality, then even in the face of spontaneous movement, children should represent contact causality given other cues to the causal relationship. Previous research (Bonawitz et al., 2010) suggests that causal language acts as such a cue. When spontaneously occurring events are described causally, toddlers intervene and anticipate the target outcome. Recent work from our lab suggests that toddlers also have expectations consistent with contact causality only when events are described with causal language (Muentener, Bonawitz, Horowitz, & Schulz, under review; Bonawitz, Horowitz, Ferranti, & Schulz, 2009). Therefore, considering that toddlers' succeeded in these causal language conditions, when the blocks spontaneous movement was identical to the spontaneous condition here, we believe this provides additional support ruling out the hypothesis that toddlers' failure in the Spontaneous Motion condition was due to the block's unexpected spontaneous motion.

The results from the current study are consistent with previous research showing that infants accept dispositional agents, but not objects, as candidate causes of physical motion (see Saxe & Carey, 2006, for review) and change of state events (Muentener & Carey, 2010). Michottian launching events remain an important exception; infants as young as 6-months distinguish causal agents and causal patients in launching events, even though no dispositional agents are present (e.g., Leslie & Keeble, 1987). However, such "perceptual causality" depends on the precise spatio-temporal properties of the events (Scholl & Tremoulet, 2000), suggesting it might be encapsulated from other kinds of causal reasoning (Blakemore et al., 2001; Leslie & Keeble, 1987; Michotte, 1947; Schlottman, 2000; Scholl & Tremoulet, 2000; though see Saxe & Carey, 2006). The current findings suggest that, outside of arguably modular processes, children might not represent the causal structure of non-agentive events until relatively late in development.

Prior research suggests that infants use a variety of cues to recognize an entity as a dispositional agent, ranging from the presence of a face or hand to the demonstration of self-propelled motion. In the current paradigm, Bonawitz et al. (2010) used the full presence of a human, and we used toddlers' inference that entities seen already in motion are typically caused to move by an external agent. The extent to which other agency cues facilitate toddlers' causal representations merits further investigation.

Finally, we note that the use of infant looking time as a measure of conceptual understanding has been subject to debate (e.g. Haith, 1998; Kidd, Piantadosi, & Aslin, 2010; Munakata, 2001). This study establishes a convergence between looking time measures (used here) and the action measures used in closely matched previous work (Bonawitz et. al., 2010). This convergence may help validate sensitivity to contact causality as an index of causal understanding in infancy research (Ball, 1973; Kotovsky & Baillargeon, 2000; Luo, Kaufman, & Baillargeon, 2009; Muentener & Carey, 2010; Muentener, under review; Woodward, Phillips, & Spelke, 1993).

These findings highlight the importance of dispositional agency in the development of causal reasoning. Although further research is needed to uncover the trajectory of causal representations in early childhood, the current study helps fill the gap between research on infants' restricted causal representations and the sophisticated causal reasoning of later childhood.

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