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EMPIRICAL ARTICLE

CHILD DEVELOPMENT

You can't change the past: Children's recognition of the causal asymmetry between past and future events

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Abstract

This study explored children's causal reasoning about the past and future. U.S. adults ($n = 60$) and 3-to-6-year-olds ($n = 228$) from an urban, middle-class population (49% female; ~45% white) participated between 2017 and 2019. Participants were told three-step causal stories and asked about the effects of a change to the second event. Given direct interventions on the second event, children of all ages judged that the past event still occurred, suggesting even preschoolers understand time is irreversible. However, children reasoned differently when told that the second event did not occur, with no specific cause. In this case, 6-year-olds and adults inferred that the past event also did not occur. In both conditions, inferences that future events would change emerged gradually between 4 and 6.

KEYWORDS
backtracking, causal inference, cognitive development, counterfactual reasoning, temporal cognition

INTRODUCTION

You can change the future, but you can't change the past. This fundamental causal asymmetry between the past and future is central to a linear concept of time and has profound effects on adults' everyday behaviors. We make decisions in the present with their future consequences in mind and assess the role our past actions have played in shaping our present circumstances. Although philosophers and physicists have argued about the ultimate reality of a past and future which are fundamentally distinct (see Bardon, 2013), adults from industrialized societies typically find it difficult, if not impossible, to conceive of a world in which this is not the case. Is a unidirectional understanding of causality distinguishing past, present, and future a "built-in" feature of human cognition? If it isn't, when and how does this way of thinking develop? While we know that children's reasoning about before-and-after, past-and-future, and cause-and-effect relations improves during the preschool and early school years (for reviews, see Gopnik & Wellman, 2012; Hoerl & McCormack, 2019), few studies directly explore the relation between children's causal reasoning and their knowledge of the distinctions between past and future (McCormack & Hoerl, 2017). Here, we ask how children use information about an event to make causal inferences about related events in the past and future. In particular, we explore (1) whether children understand that actions cannot retroactively change antecedent events in the past and (2) whether children use information they observe to retrospectively infer that antecedent events have changed.

Despite the central role of the past versus future distinction in adults' reasoning about events, it remains unclear to what extent young children possess this understanding, and at what point in development it emerges (Hoerl & McCormack, 2019; McCormack & Hoerl, 2017). While it is difficult to test whether preverbal infants have a concept of the past or future, children begin to produce language related to the past versus future distinction early in development. For example, English-speaking 2-year-olds use the past-tense verb marking *-ed* (Brown, 1973), and 3-year-olds produce time words like "tomorrow" and "yesterday" to reference events that are not ongoing (Busby Grant & Suddendorf, 2011). Early production of temporal language has historically been taken as evidence that very young children understand the past versus future status of events, relative to the present. Nevertheless, children's early use of grammatical tense is inconsistent and often inaccurate (e.g., Andersen, 1996), and their understanding of deictic time words like “yesterday” becomes gradually more adult-like until at least age 7 or 8 (Hudson & Mayhew, 2011; Tillman et al., 2017). Together, these studies are consistent with the idea that past-future reasoning initiates early, followed by a prolonged period of development. However, it remains possible that children's understanding of the differences between the past and the future develops prior to their ability to express these differences in language.

How else might we test whether young children understand the difference between the past and future? One fundamental distinction between past and future events is their causal status in relation to the present. Temporal ordering, that is, which events come first in time, does not necessarily imply a causal relation between events: We wake up in the morning *before* eating breakfast, but we don't eat *because* we have awakened. However, causal chains always operate unidirectionally over time: If we wake up *because* an alarm went off, we must have woken up *after* the alarm went off. Effects can never precede their causes in time. Therefore, by testing children's understanding of how causality operates over time, we can also gain insight into their understanding of the distinctions between past and future.

Suggesting that even preverbal infants intuitively understand the relation between temporal order and physical causality, 4-month-olds look longer when presented with impossible causal chains of events, including those with apparent breaks in temporal continuity, indicating that such events violate their expectations about the world (Cohen & Amsel, 1998). However, recognizing the temporal-causal structure of a simple physical event, like one ball striking another, does not imply that infants have a *concept* of the past or the future (see Hoerl & McCormack, 2019). Later in development, when asked which of two possible events caused another event to happen, 3-year-olds choose the antecedent, rather than the subsequent, event (Bullock & Gelman, 1979). By age 4, children also recognize that past, but not future, events determine present physical and mental states (Busby & Suddendorf, 2010). However, even 5-year-olds often struggle to use information about the relative ordering of multiple past events to make inferences about the state of the present, and routinely fail to solve temporal reasoning tasks in which the order they receive information about events doesn't match the order in which those events actually occurred (e.g., McCormack & Hoerl, 2007). These findings suggest that, although even infants are able to mentally represent ongoing temporal and causal events, young children may lack the flexible temporal perspective-taking skills that allow adults to reason about the relations between events in the past, present, and future (Hoerl & McCormack, 2019).

Critically, however, none of these prior studies have directly tested whether children understand that future events can be changed by actions in the present but past events cannot. Indeed, researchers exploring temporal cognitive development have pointed out the need for “[f]uture studies … to address directly when children initially understand that the past and future differ in terms of their alterability” (McCormack, 2015). Relevant to this question, a separate literature has explored the development of children's causal and counterfactual reasoning skills (see Gopnik & Wellman, 2012 for a review). Despite the related subject matter, however, this literature has progressed largely independently from the work on the development of temporal cognition.

Within the causal reasoning literature, some accounts suggest that causal relations are defined in terms of their counterfactual dependency: that is, if event A causes event B, then an intervention on event A (e.g., preventing it from occurring) will lead to a change in event B (Pearl, 2000; Schulz & Gopnik, 2007; Schulz et al., 2007). A large body of work suggests that preschool-aged children can reason about these counterfactual scenarios, making inferences about what else would have happened if one event in a causal chain had been different (Beck et al., 2006; German & Nichols, 2003; Guajardo & Turley-Ames, 2004; Harris et al., 1996; Kavanaugh & Harris, 1999; Nyhout & Ganea, 2019a; Perner et al., 2004; Riggs et al., 1998; Robinson & Beck, 2000 but see Beck et al., 2006, 2010; Rafetseder et al., 2013). For example, in seminal work by Harris and colleagues (1996), 3- and 4-year-olds were asked to reason about a two-step causal sequence. In one story, a character walked across the floor with muddy boots [A], causing a mess on the floor [B]. When asked questions about what would have happened had A not occurred (e.g., “What if Carol had taken her shoes off—would the floor be dirty?”), children accurately judged that B also would not occur. Later, Guajardo and Turley-Ames (2004) also tested whether children were able to generate alternative antecedent events (at A) that would cause a change to B (e.g., “What could you have done so that the kitchen floor would not be dirty?”), and found that this ability improved between ages 3 and 5. Researchers have questioned to what extent children's performance on counterfactual reasoning tasks is limited by their ability to “think back in time” to imagine alternative possibilities (Beck et al., 2006; Burns & McCormack, 2009; Frosch et al., 2012). However, to our knowledge, none of these paradigms have addressed whether children believe that an action at event B could *retroactively* change its antecedent cause, A, which is the primary focus of the current study.

Bringing together the existing literature about causal reasoning and the past versus future distinction, we hypothesize that if participants have a unidirectional view of how causality operates over time, when given a three-step causal chain of events A → B → C, they should judge that an intervention at A can alter future events B and C, and that an intervention at B can alter future event C, as previous studies have found (e.g., German & Nichols, 2003; Rafetseder et al., 2013; Schulz et al., 2007). Importantly, however, they should also judge that, an intervention at B will *not* retroactively alter antecedent event A (Sloman & Lagnado, 2005). Consider the following scenario (see Figure 1): When (A) Molly flips the light switch, then (B) the light turns on, so (C) she can see to find her toy. If told that another character, John, turned off the light at event B, adults may reasonably predict that Molly will no longer be able to see at event C. However, they should *not* infer that Molly never turned the light on at event A, because John's actions at time B cannot retroactively change what has already happened at time A. Here we test whether 3- to 6-year-old children make these same inferences.

Importantly, although it is impossible to directly change past events via our actions in the present, it is nevertheless possible for our beliefs about past events to change given information about the status of present events. This distinction is critical to adultlike reasoning about the past, since strictly adhering to the principle that "past events cannot change" would deny the possibility that new evidence in the present could inform our

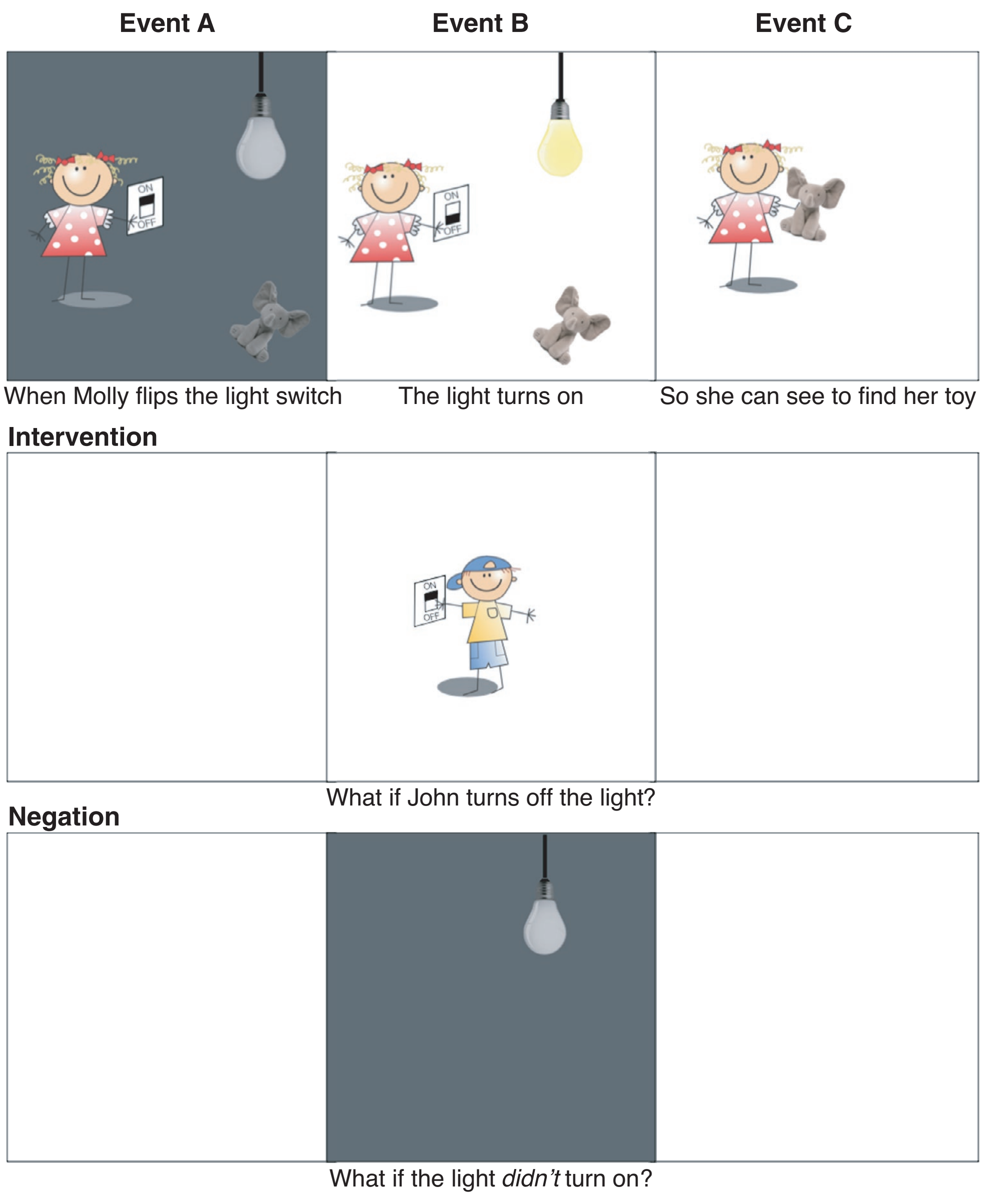

FIGURE 1 Example stimuli. The experimenter recited the story on the front of the card (top row), then flipped it to reveal three empty boxes. In the test phase, according to the child's condition, the experimenter placed either an intervention (middle row) or negation (bottom row) card in the center box, and then asked questions about the effects of this event on the past event A ("Did Molly flip the light switch?") and future event C ("Will Molly see to find her toy?"). See Appendix for complete set of stimuli

knowledge of prior events. In other words, although a unidirectional model of time dictates that *changing* an effect cannot *change* its causes, it is possible that *observing* an effect can be *diagnostic* of its causes (Sloman & Lagnado, 2015). That is, reasoners can use information about the present to reason "back in time" and make inferences about what has already happened. Indeed, prior work shows that adults generate different causal judgments about antecedent event A after simply *observing* that event B did not occur than they do following an intervention on B that *prevents* it from occurring (Sloman & Lagnado, 2005; Waldmann & Hagmayer, 2005). For example, in one study, when adults were told that moving gear A causes gear B to move, but B has been prevented from moving (i.e., an intervention on B), 80% of adults said A was still moving. In contrast, when they were told that A causes B to move and B was *observed* as not moving, 80% of adults said that A also had not moved (Sloman & Lagnado, 2005). Thus, if an expected event does not occur—and no other explanation for its nonoccurrence is provided—an adult may reasonably infer that the event's typical antecedent cause must not have occurred. Applying this logic to the scenario from Figure 1, when simply told that the light did not turn on at point B (i.e., that event B was not observed), an adult might indeed conclude that Molly did not flip the light switch at point A (i.e., that event A did not occur.)

Here, to explore the development of reasoning about time and causality, we presented 3- to 6-year-old children and adults with stories involving three-step causal chains, and then asked them to consider scenarios in which the second event (B) does not occur. Importantly, we asked both about the effects of this change on the future event (C) and on the past event (A). Additionally, paralleling prior work with adults, we also varied whether the change at B was a direct action by an outside agent or an observation without a specified external cause. In the *intervention condition*, an agent acted to change event B. In this case, if participants have a unidirectional concept of time, we hypothesized that they would judge that the future event (C) would change, but that the past event (A) would still occur. In the *negation condition*, we gave participants identical information, except that the cause of the change to event B was left unspecified. Here, we also hypothesized that participants with a linear concept of time would judge that the future event (C) would not occur. Critically, however, if children (like adults) reason about antecedent causes of observed effects, they should judge that the past event (A) *had also changed* (Sloman & Lagnado, 2005). This is because, in this case, the observed change to event B is diagnostic of its cause, and warrants inferences about both events A and C. Moreover, because the negation condition (unlike the intervention condition) does not specify that a causal action occurred at a specific point, the inference that a change occurred earlier in the narrative does not violate unidirectional time.

This contrast allowed us to assess whether children infer that (1) you cannot change the past by acting in the present, but (2) you *can* infer a change to the past by observing present events and reasoning about their causes. Furthermore, by comparing children's responses across both types of events, we can rule out the possibility that children apply a general strategy when reasoning about the past—either inferring that antecedent events are always fixed or that they always change. If they do, children should perform similarly across conditions on both past and future questions.

In addition to assessing whether children have an adult-like understanding of the relation between present and past events, the negation condition also allows us to consider the role of children's diagnostic reasoning abilities (i.e., their ability to reason from effects to causes) in the development of their understanding of the past and future. While some work suggests that, by 6 years of age, children can reason about the most likely causal antecedents from observed outcomes (Erb & Sobel, 2014), preschool-aged children are generally less accurate in reasoning from effects to causes than they are at reasoning from causes to effects (Hong et al., 2005), paralleling findings with adults (Fenker et al., 2005). Prior work also suggests that while children are able to represent and reason about alternative possibilities in the future by age 4, they are not able to consider how alternative past events could have impacted present circumstances until at least age 6 (e.g., McCormack et al., 2018; Redshaw & Suddendorf, 2016; see Redshaw & Suddendorf, 2020 for discussion). This asymmetry may reflect a general bias to privilege inferences that travel *forward* in time (Tversky & Kaheman, 1974). If so, then reasoning about the past may develop more slowly than future thinking, or require additional capacities that go beyond representing causal dependencies (Fernbach et al., 2010, 2011; Sloman & Lagnado, 2005).

It has been suggested that, for children, understanding that past and future events differ in their alterability may be a prerequisite for more sophisticated forms of counterfactual reasoning (McCormack & Hoerl, 2017). However, it remains unclear whether these represent separate developmental milestones. If we find that children succeed in the intervention condition but fail in the negation condition, this might suggest that although they have an understanding that the past and future are fundamentally distinct, they nevertheless struggle to consider alternative possibilities in the past.

METHOD

Nature of findings

This research was confirmatory in the sense that it was hypothesis-driven and guided by specific questions about whether children can differentiate the effects of present changes on past versus future events. However, it was exploratory in the sense that the method was novel and we did not have specific predictions about whether individual age groups would succeed or fail. Given the novelty of the method and the fact that our study was not pre-registered, we recommend confirmation through future replication efforts.

Participants

Data collection took place between November 2017 and July 2019. A total of 288 subjects (49% female) participated, including 30 3-year-olds (M_{age} = 3.6 years, range = 3.1–4.0 years; 13 girls), 65 4-year-olds (M_{age} = 4.5 years, range = 4.0–5.0 years; 42 girls), 70 5-year-olds (M_{age} = 5.5 years, range = 5.0–6.0 years; 26 girls), 63 6-year-olds (M_{age} = 6.4 years, range = 6.0–7.0 years; 30 girls), and 60 adult controls (M_{age} = 21.6 years, range = 18.2–31.1 years; 41 women). Participants in each age group were randomly assigned to either the intervention or negation condition, except for 3-year-olds, who were all assigned to the intervention condition. Three-year-olds were tested subsequently to the other age groups, and only on the intervention condition, as a follow-up to the results we obtained with 4-year-olds. As the procedures were identical for all ages, these data are discussed together. Subjects were recruited from the greater San Diego, CA, (n = 258) and Austin, TX, (n = 30) areas, in the United States. Adults were recruited from a pool of undergraduates at UC San Diego and were given course credit in exchange for participation. Children were recruited from local preschools, museums, and a university subject pool. While individual demographics for all participants were not collected, a plurality of the west-coast population from which subjects were recruited was white (44.5%) and middle-class (median household income $73,900), and a plurality of the southwestern population was also white (48.8%) and middle-class (median household income $71,543).

Adult participants and parents of children provided informed consent to their participation. All study procedures were approved by the Institutional Review Boards of UC San Diego and The University of Texas at Austin.

An additional 55 children participated, but their data were excluded from analysis due to experimenter or technical error (n = 5), failure to complete the entire task (n = 6), insufficient fluency in English (n = 2), incomplete age information (n = 2), or for failing two or more "catch" trials (n = 40), as explained further below.

Materials

Study materials included eight 3-panel storyboards illustrating sequences of events from left to right. One example story is shown in Figure 1, and all critical trial stories are shown in Appendix Figure A1. Each panel was 2.8 in. × 2.8 in. Single images corresponding to event B in each story were also used during test trials, which represented either identical pictures (catch trial stories), interventions, or negations, depending on condition. Each individual image was square with a black outline, and on the reverse side of each storyboard were three empty black squares positioned in the same format as the filled images on the front of the card. All stimuli are available via the Open Science Framework.

Procedure

All participants were tested in person, one-on-one. The experimenter began the session by placing a demonstration storyboard in front of the participant, saying "I'm going to tell you some stories. There are three things that happen in each story, see?" She then pointed to each image in the story while reciting the corresponding part of the narrative, which, in the demonstration, was "When Julie opens the door, then her dog runs outside, so he smashes up all the flowers in the garden."

The experimenter then flipped over the storyboard, revealing the three empty boxes, and initiated a demonstration catch trial. While placing a duplicate of the center image from the front of the card in the empty center square, she asked the participant "tell me, *just like in that story*, if the dog ran outside …," and then pointed to the empty third (event C) box while completing the question with a forced choice: "will he smash all the flowers in the garden or not smash the flowers in the garden?" After receiving a verbal response from the participant, the experimenter repeated the procedure again, instead pointing to the first (event A) box and asking, "did Julie open the door or not open the door?."

Next, the experimenter flipped the card back over, repeated the original story, and explained that she would now be asking the participant to think about what would happen in the story if something had been *different*. In this demonstration critical trial, the experimenter placed a modified image B in the empty center square on the back of the card. This image showed either the intervention, "What if the dog were on a leash and couldn't get out?," or the negation, "What if the dog *didn't* run outside?," according to condition. The test concluded with the past and future test questions, as above. No feedback was given on either the control or critical trials using the demonstration story.

After this demonstration phase, the experimenter told the participant that she would tell some other stories, sometimes asking if things had been the same (catch trial stories), and sometimes asking if things had been different (critical trial stories), and sometimes asking about the first event of the story (A), and sometimes about the last event (C). The remainder of the task included seven new stories, five of which were used on critical trials and two of which were catch trial stories. The ordering of the stories (other than the demonstration story), the past and future questions about each story, and the positive and negative response options in each question were counterbalanced across participants. The third and sixth stories were catch trials. Procedures used in the intervention and negation conditions were identical, apart from the different test questions and corresponding images used during the test. One example story is shown in Figure 1, all five stories used in critical trials are shown in the Appendix, and the complete scripts and stimuli for all stories can be found on OSF.

The use of the 3-panel storyboards, along with the pointing behavior of the experimenter, was intended to help children keep track of which point in the 3-step narrative was being described or queried. For example, by placing the intervention or negation card in the second of three boxes, the same location in which event B had previously been shown on the front of the card, the experimenter signaled that this new event happened at the same time. Likewise, by pointing to the first (before B) and third (after B) boxes, in addition to using the past and future tense as appropriate, the experimenter signaled that she was asking about events that were in the past and future, relative to event B.

Data from participants who responded incorrectly on more than one of the catch trials, by denying that an event from the story they had just heard had occurred in that story, were excluded due to their failure to comprehend the task instructions (total $n = 40$; $n = 14$ 3-year-olds, 15 4-year-olds, 8 5-year-olds, 2 6-year-olds, and 1 adult). This exclusion criterion was particularly important because the predicted "adult-like" response pattern in the negation condition was one in which the participant judged that *none* of the events in either past or future critical trials had occurred. We, therefore, aimed to minimize the chances of confusing a "no" bias in children who failed to comprehend the task with adult-like conditional reasoning. Although participants who answered "yes" on every trial (i.e., indicating that they thought none of the interventions or negations would have any effect) were not excluded, this pattern was very rare ($n = 7$).

Coding

During testing, the experimenter recorded whether the participant affirmed or denied that each past or future event would occur. Yes responses were coded as 1, no responses as 0. These were later reverse-coded, as described below. Data from the demonstration story were not included in analysis. All data appear on OSF.

Experimental sessions were video-recorded, except in cases where parents did not provide consent to record. Responses from 160 children and 45 adults (71% of the total sample), including 3690 trials, were coded a second time. Inter-rater reliability was 99%. Discrepancies were resolved by a third coder. All analyses were conducted in R, using the *lme4* package for mixed-effects modeling (Bates et al., 2014).

Follow-up experiment

The precise definition of counterfactual reasoning, and thus the age at which it emerges in childhood, is the subject of much debate (e.g., Beck, 2016; Nyhout & Ganea, 2019a, 2019b; Weisberg & Gopnik, 2013). Under some definitions of counterfactual reasoning, our use of the simple past tense in the negation condition, for example, "What if the dog *didn't* run outside?," rather than the pluperfect subjunctive "What if the dog *hadn't* run outside?," implies that these questions were conditional rather than counterfactual (see Beck et al., 2006; Iatridou, 2000; Lucas & Kemp, 2015). To explore this distinction, we conducted a small follow-up experiment ($n = 55$) using the pluperfect subjunctive tense. This study, reported in the Supporting Information, revealed the same pattern of results discussed here, consistent with previous work (Nyhout & Ganea, 2019a).

RESULTS

We began with two primary questions about our dataset: (1) Do participants reason differently about the implications of interventions by an external agent versus negations without a specified cause? and (2) In each case, do participants differentiate the effects of a change to an event (B) on a subsequent future event (C) versus an antecedent past event (A)?

We first asked whether children's performance differed between the intervention and negation conditions. Because our DV was a binary choice (either an event would occur or not), we conducted a mixed-effects logistic regression. For ease of exposition, the data were reverse-coded, such that answers indicating that events would not occur in the test scenario were considered "changes" (1), while answers indicating that events would still occur were considered non-changes (0). We modeled the likelihood that a child would say an event changed as a function of their age (continuous; between-subjects), condition (intervention vs. negation; between-subjects), and event time (past vs. future; within-subjects). We also included an interaction between event time and condition in this model, and random intercepts for subjects and stories. For additional details regarding differences in performance across stories, refer to Figure S1 and Table S1.

This analysis revealed a significant main effect of age, $\beta = 0.41$, $p = .001$, which improved the fit of the model compared to a reduced model that did not include this factor, $\chi^2(1) = 10.4$, $p = .001$. There was also a significant effect of event time (past vs. future), $\beta = -2.92$, $p < .001$,

$\chi^2(1) = 301.41$, $p < .001$, as well as a significant interaction between event time and condition, $\beta = 1.87$, $p < .001$, $\chi^2(1) = 58.96$, $p < .001$.

To further explore this interaction between event time and condition, we examined children's responses to questions about past events and future events separately. In each case, we modeled the likelihood that a child would say an event changed as a function of their age and condition. In the case of future events, we found a significant effect of age, $\beta = 0.92$, $p < .001$; $\chi^2(1) = 22.3$, $p < .001$, but no significant effect of condition. Children were equally likely to say that a future event would change as a result of an intervention on or a negation of an antecedent event. In the case of past events, however, we found a different pattern: Children in the negation condition were more likely to say that past events had changed than children in the intervention condition, and this was particularly true for older children (interaction of age and condition, $\beta = 0.90$, $p = .005$; $\chi^2(1) = 8.0$, $p = .005$.)

Given the evidence that children's behavior differed between conditions, we proceeded to analyze the data from the two conditions separately.

Intervention condition

Our goal in the intervention condition was to test whether participants differentiate the effects of a change to one event in a causal chain on a consequent event versus an antecedent event. In other words, do they know that you can change the future, but not the past? The distributions of responses to past- and future-event questions, that is, the percentage of events that each group said would change, are shown in the top row of Figure 2, with medians represented by vertical lines. As expected, and in line with prior work, adults strongly distinguished past from future: the median percentage of antecedent events they said would change was 0%, 95% CI [0%–0%], while the median percentage of future events they said would change was 100%, [80%–100%]. (Because not all distributions were normal, we report medians as a measure of central tendency throughout the Results section. For comparison, Table S2 shows the mean percentages for each age group, condition, and event time.)

A mixed-effects logistic regression model examining children's likelihood of saying that an event changed revealed a significant effect of age, $\beta = 0.71$, $p < .001$, which improved the fit of the model compared to a reduced model that did not include this factor, $\chi^2(1) = 27.04$, $p < .001$. There was also a significant effect of event time (past vs. future), $\beta = 1.9$, $p = .007$; $\chi^2(1) = 7.35$, $p = .007$, as well as a significant interaction, $\beta = -0.94$, $p < .001$; $\chi^2(1) = 42.47$, $p < .001$. As shown in Figure 2, children were more likely to judge that interventions would change the future than the past, and the difference between responses to past and future questions increased with age. Wilcoxon signed-rank tests confirmed that the past versus future effect was significant in all age groups, including 3-year-olds, who reported that 60% [40%–80%] of future events changed, but only 20% [20%–40%] of past events did, $V = 335$, $p < .001$. The median percentage of past events judged to have changed remained at 20% for the 4-, 5-, and 6-year-old groups. The median percentage of future events judged to change increased to 80% for the 4- and 5-year-old groups, and to 100% for the 6-year-old group. When asked questions about the past, children from all age groups were less likely to judge that events would change than would be expected if they were randomly guessing (one-sample sign test, for 3-year-olds, $S = 41$, $p < .001$). On the future questions, 3-year-olds did not respond differently from chance ($S = 83$,

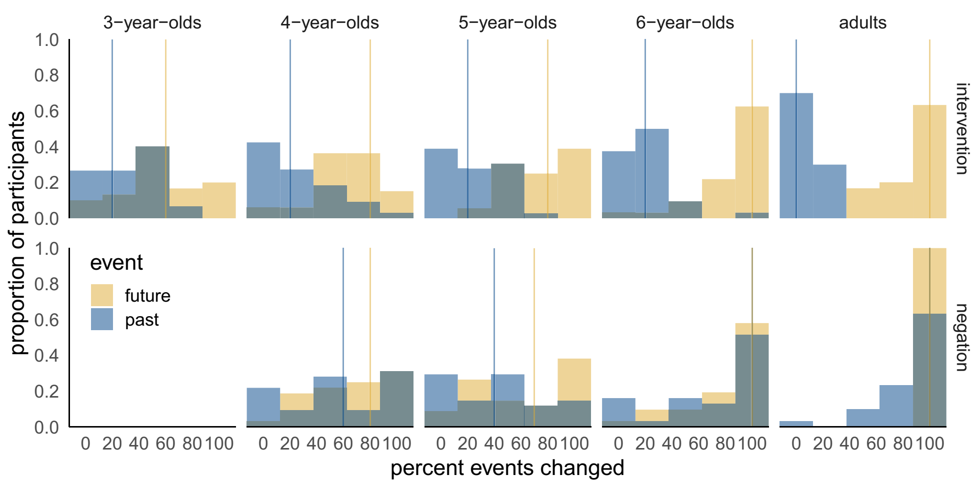

FIGURE 2 Distributions of responses to questions about whether past (blue) and future (yellow) events would change, in the intervention (top) and negation (bottom) conditions. Height of shaded areas indicates the proportion of participants who responded at each level of consistency, for example, 80% = 4 of 5 events changed. Darker gray areas indicate overlap of the two distributions. Vertical lines are medians. Three-year-olds were not tested in the negation condition

p = .22), though 4-year-olds, and all older groups, did (S = 105, p < .001).

In addition to group-wise performance, we were interested in the patterns of responses provided by individual subjects. For instance, did children who said the antecedent event would not change still say that the consequent event *would* change, as a linear model of time would predict? For the purpose of this analysis, we operationalized a "linear" pattern as one in which the participant judged that at least four of five future events would change, and that at least four of the five past events would not. As shown in Figure 3a (darkest bars), we found that 83% [65%–94%] of adults conformed to this pattern, as did 72% [53%–86%] of 6-year-olds, 36% [21%–54%] of 5-year-olds, 27% [13%–46%] of 4-year-olds, and 7% [1%–22%] of 3-year-olds. Thus, although even 3-year-olds (as a group) distinguished past and future, very few of them (n = 2) were behaving in an "adult-like" manner on the task. Participants who did not follow a linear pattern typically reported fewer than four changes to future events, resulting in a mixed pattern. Participants very rarely judged that both the past and future events changed, or that neither changed.

Negation condition

Unlike in the intervention condition, in which participants were told that an agent acted to change event B, in the negation condition, participants were simply told that event B did not occur. They were then asked about events A and C. We were particularly interested in whether children would infer that there had been a change to antecedent event A.

As shown in Figure 2 (bottom row), when adults were told that event B did not occur, in addition to reasoning that the subsequent event, C, would not occur on a median of 100% [100%–100%], of trials, adults also judged that the antecedent event, A, had not occurred on 100% [80%–100%] of trials. These findings are in line with prior adult work (Waldmann & Hagmayer, 2005).

A logistic regression model of the children's data in the negation condition, with the same effects structure as the one used in the intervention condition, revealed only a main effect of age, $\beta = 1.09$, $p = .004$; $\chi^2(1) = 8.15$, $p = .004$. Older children were more likely than younger children to judge that events changed. However, unlike in the intervention condition, there was no significant effect of event time, $\beta = 0.35$, $p = .79$; $\chi^2(1) = 0.07$, $p = .79$, and no interaction, $\beta = -0.29$, $p = .24$; $\chi^2(1) = 1.36$, $p = .24$. In other words, we did not detect evidence that children were treating past and future events differently in this condition.

The finding that children treated past and future events similarly in the negation condition makes sense if they understand that, in this case, it is possible to use information about the present to make inferences about both past and future events. We predicted that participants capable of reasoning about antecedent causes of observed effects would judge that event A (like event C) had changed in the negation condition. This was indeed the case for both 6-year-olds and adults: the median percentage of trials on which they judged event A had changed was 100%, significantly higher than chance S = 110, p < .001. However, this pattern was much less common across the 4- and 5-year-old groups, as can be seen in the flatter distributions in Figure 2. Four-year-olds judged that past events changed on a median 60%, 95% CI [40%–80%], of trials, which was not significantly different from what would be expected if these children were randomly guessing (one-sample sign tests, S = 89, p = .18). Five-year-olds, on the other hand, judged that past events would change on 40%, 95% CI [20%–60%] of

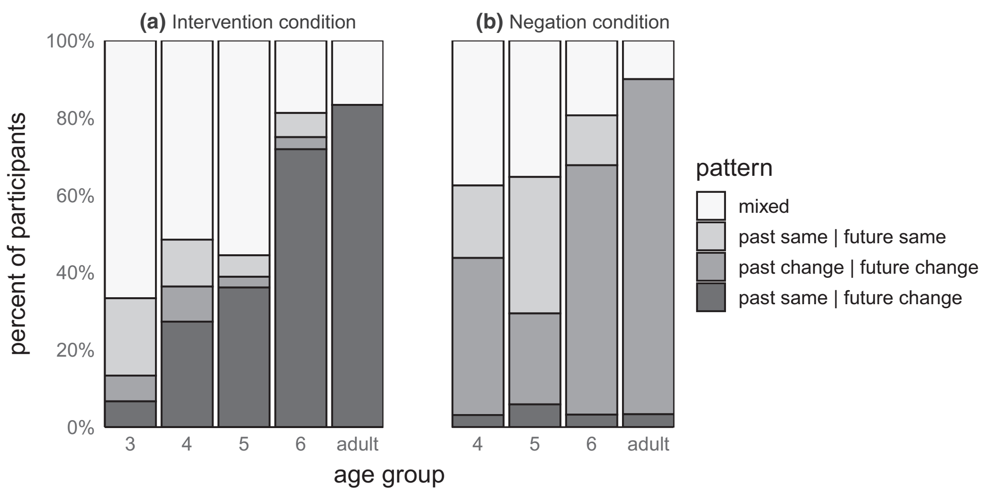

FIGURE 3 Percentage of subjects in each age group who demonstrated each of four response patterns across stories, in the (a) intervention and (b) negation conditions. "Same" indicates that the participant judged that at least four of five events did not change. "Change" indicates that the participant judged that at least four of five events changed. "Mixed" indicates inconsistent responding. Three-year-olds were not tested in the negation condition

trials, which was significantly lower than chance, $S = 71$, $p = .04$, indicating that (in contrast to older children) they were more likely to infer that event A had *not* changed than that it had.

Importantly, although 4-year-olds were performing at a level that was not significantly different from chance on questions about past event A, they did perform better than chance on questions about future event C, $S = 105$, $p < .001$, as did all older age groups. This suggests that 4-year-olds were not simply failing to comprehend the task, but were less consistent in their reasoning about the implications of the negation on the past event than on the future one. Moreover, the low levels of success on past-related questions among 4- and 5-year-olds in the negation condition stands in contrast to our results in the intervention condition, where even 3-year-olds performed better than chance. This suggests that children's tendency to deny that past events changed in the intervention condition reflects their understanding of linear time, and not their use of a general strategy to infer that the past is always fixed.

In our individual-subjects analysis, an adult-like reasoning pattern was operationalized as one in which at least four of five past events *and* four of five future events changed. As shown in Figure 3b (second-darkest bars), we found that 87% [69%–96%] of adults; 65% [45%–81%] of 6-year-olds; 24% [11%–41%] of 5-year-olds; and 41% [24%–59%] of 4-year-olds displayed this pattern. Linear response patterns, like those frequently generated in the intervention condition, were very rare in participants in the negation condition. Children of all ages treated scenarios when event B was not observed differently from scenarios in which an external causal agent was named, particularly with respect to their reasoning about the past. This was true despite the fact that the task was otherwise identical.

GENERAL DISCUSSION

We set out to explore whether 3- to 6-year-old children, like adults, understand that past and future events differ in terms of their alterability in the present. By testing children's reasoning about three-step causal chains, A → B → C, we discovered that children as young as 3 were more likely to judge that an action changing event B will also change consequent event C than antecedent event A. Thus, even young preschoolers appear to understand that there is an asymmetry between the past and future, such that the past cannot be retroactively altered by an action in the present. Nevertheless, children's reasoning became increasingly adultlike across the developmental period we explored. In particular, although children of all ages rarely judged that acting on B would retroactively change past event A, between ages 4 and 6, children became increasingly likely to judge that future event C would change. We also found that children, like adults, reasoned very differently when the cause of the change to event B was unspecified, indicating that they do not rely on a general strategy when reasoning about past events. When they were simply told that B did not occur (rather than that a specific outside agent stopped it from occurring), 4- and 5-year-olds were no less likely to infer a change to the past than they were to infer a change to the future. By age 6, most children (like adults) consistently inferred from the nonoccurrence of B that both past event A and future event C must have also changed. In sum, although children recognize the causal asymmetry between the past and future by as early as age 3, it takes several additional years for them to reliably identify circumstances that warrant inferences from the present to the past.

This work falls at the intersection of several literatures, extending what is known about the development of temporal cognition, causal and counterfactual thinking, and diagnostic reasoning. Historically, the literature on the development of temporal cognition has focused largely on capacities that are present from early infancy (e.g., duration perception) and those that do not emerge until around age 5 or later (e.g., temporal reasoning). It is less well understood how children conceive of time in the intervening years, particularly when their use of temporal language is still limited (Weist, 1989). One proposal made by McCormack and colleagues is that, prior to having a unified linear model of time, young preschoolers nevertheless distinguish between events that can be changed and those that cannot (McCormack & Hoerl, 2017). Previous work on children's understanding of past and future events showed that 4-year-olds know that present states of the world are determined by antecedent events, not by future ones (Bullock & Gelman, 1979; Busby & Suddendorf, 2010), but did not directly address whether children believe past events are alterable. Here, we provide the first direct evidence that even 3-year-olds distinguish past and future events with respect to their causal properties. In particular, our findings indicate that preschoolers know that past states of the world cannot be retroactively determined by present events, suggesting that they intuitively understand that time is irreversible.

The present data also contribute to a growing body of research on the later development of temporal cognition that indicates that an important conceptual shift occurs around age 5, as children become able to flexibly reason about the timing and relative order of events in the past, present, and future (see Hoerl & McCormack, 2019; McCormack & Hoerl, 2017). Prior work has shown that, at about age 5, children become able to infer the current state of affairs when they receive information about past events, even when those events are presented out of order (e.g., McCormack & Hoerl, 2005; Povinelli et al., 1999). Importantly, such tasks require children to go beyond a primitive strategy in which they simply serially update their mental model of the present as new information comes in. Instead, children must engage in what is known as "temporal decentering" or "temporal perspective-taking"—thinking about the relations between events that obtained at a time point other than the present moment. For example, if the event series A, B, C has already occurred, temporal decentering is required to reason that, at the time of event B, event C had still not yet occurred, and therefore could have been different (for discussion, see McCormack & Hoerl, 2017). Our finding that children in both conditions became increasingly likely to say that future events changed with age may reflect the development of temporal perspective-taking skills.

On the other hand, our result that adult-like reasoning about the effects of interventions on future events lagged behind children's reasoning about past events is surprising in light of prior work on the development of causal reasoning. While even 3-year-olds in the intervention condition judged that past events wouldn't change at greater than chance levels, children did not judge that future events *would* change until age 4 (see also Beck et al., 2010). This pattern is somewhat at odds with the prior literature showing that children are better able to predict a future outcome than to reason counterfactually about what might have happened in the past (Beck, 2016; Beck & Riggs, 2014; Beck et al., 2006; Perner et al., 2004; Rafetseder et al., 2010; Riggs et al., 1998). Additionally, some prior research has found evidence for successful conditional reasoning about the effects of a change to an antecedent event on a subsequent one, even in 3-year-olds (German & Nichols, 2003; Harris et al., 1996). Notably, this prior success typically involved inferences about two-step, rather than three-step causal chains (Harris et al., 1996). Some have suggested that the length of the causal chain and the complexity of the reasoning scenarios presented may lead to increased processing demands, impacting the age of success (German & Nichols, 2003; Perner et al., 2004; Riggs et al., 1998; but see Beck et al., 2010). In addition to reasoning about three-step scenarios, children in the present study were tasked with switching back and forth between questions about prior and subsequent events, which may have further increased cognitive load. However, if 3-year-olds' failure on the future trials was due to general memory limitations or issues with task comprehension, they should have also struggled with the past trials, and they did not.

Why else might 3-year-olds in the present study have had more difficulty with questions about the effects of an intervention at event B on the future event C than on past event A? One possibility is that children provided more variable predictions about the future than the past because the future is intrinsically more open-ended. In linear time, a given intervention (e.g., turning off a light) may or may not be effective at generating a particular future outcome (e.g., preventing a child from finding a lost toy), due to a host of other situational factors (e.g., whether the room had another light source). However, an intervention will *never* retroactively change what has already occurred. Moreover, prior work investigating children's understanding of before-after relations has shown that they are better able to reason about the temporal order of events in the past compared with those in the future (McCormack & Hanley, 2011). Indeed, children tend to perform better on past-related items relative to future-related ones on a wide variety of temporal cognitive and linguistic tasks, providing evidence that children's understanding of the past and future may follow different developmental trajectories (Busby Grant & Suddendorf, 2009; Friedman, 2000, 2002, 2005; Harner, 1975; McCormack & Hanley, 2011).

We also found evidence that children were not simply applying a general strategy in which they always judged that past events do not change, but were sensitive to which causal scenarios involved a possible violation of linear time. In particular, children of all ages treated scenarios in which an agent caused the change to B (in the intervention condition) differently from those in which the cause of the change was unspecified (in the negation condition). In the latter case, when children were simply told that event B *didn't* occur (or, in the follow-up experiment, that it *hadn't* occurred, see Supporting Information), they were no more likely to judge that future events would change than past ones. Children appeared to distinguish ambiguous scenarios that could license changing one's beliefs about the past (in the negation condition) from impossible interventions on past events. Four- and 5-year-old children showed more varied response patterns on the past-event questions in the negation condition relative to the intervention condition, which is in line with the results of other studies in which children showed impairments in counterfactual reasoning well beyond the age of 3 (Beck et al., 2006; Nyhout et al., 2019; Rafetseder et al., 2013). This difference in performance between the intervention and negation conditions is notable considering how similar the two conditions were to one another. Given children's high performance in the intervention condition, and the lack of a bell curve centered around random responding in the negation condition, we do not believe these results can be simply attributed to their confusion about the negation task. Instead, the present results indicate that even 4-year-old children reason differently from observing the non-occurrence of an event than from an intervention.

It is not until age 6 that children (like adults) consistently judged that a negation of event B implied changes to *both* past event A and future event C. Children's inferences about event A in the negation condition may reflect their developing diagnostic reasoning skills. As noted above, diagnostic reasoning from effects to causes has been found to be more difficult than conditional reasoning from causes to effects (Erb & Sobel, 2014; Hong et al., 2005; Tversky & Kahneman, 1974). It is also possible that children who perform like adults in the negation condition are deploying what the adult counterfactual reasoning literature has termed *backtracking*. Backtracking refers to a specific type of counterfactual reasoning that involves an inference about upstream causal variables (Gerstenberg et al., 2013; Rips, 2010; Rips & Edwards, 2013; Sloman & Lagnado, 2005). There has been substantial debate surrounding the type of counterfactuals and learning contexts that consistently lead to backtracking inferences in adults (Han et al., 2014). However, to our knowledge, no previous research has investigated whether children make these inferences. If backtracking *is* present in a majority of children by the age of 6, this might have important implications for existing accounts of causal reasoning (Woodward, 2005) and represents an important avenue for future work.

Taken together, the findings from both conditions show that although children differentiate past from future events from a young age, there is protracted developmental change in children's reasoning about each of these types of events. This likely reflects improvements in temporal perspective-taking, counterfactual reasoning, or diagnostic reasoning. Additionally, there might be specific sources of input that contribute to children's learning about the relations between past, present, and future events between ages 3 and 6. For example, several authors have suggested that language acquisition may play a key role in the development of a linear concept of time: during the preschool and early school years, children frequently engage in a shared conversation about past and future autobiographical events with adults (Harner, 1982; Hudson, 2002, 2006), and gradually learn to use time-related language (e.g., words like "before" and "yesterday") to identify time points in the past and future (Blything et al., 2015; Busby Grant & Suddendorf, 2011; Clark, 1971; Tillman et al., 2017; Zhang & Hudson, 2018).

In sum, the current study brings together literatures on the development of causal reasoning and temporal cognition in a new way, by leveraging a causal reasoning task to explore children's understanding of the past and future. The results of the intervention condition provide evidence that children are able to recognize the causal asymmetry between past and future as early as age 3, consistent with the early development of a linear view of time. Nevertheless, we found a protracted developmental trajectory for reasoning about the future in both the intervention and negation conditions, as well as for reasoning about the past in the negation condition. In these cases, children's inferences about the implications of changes in the present on events in the past and future did not approach adult-like levels until age 6 or later. As researchers have speculated, mature counterfactual reasoning may hinge on the development of an abstract, event-independent concept of time (McCormack & Hoerl, 2017). In other words, to consider different possible worlds, one must decouple the time-point at which an event occurred from the event itself. Linear time thus provides a framework in which events can be organized and even mentally "switched out," so that the causal consequences of these events can be considered. By studying children's understanding of the causal and temporal relations between events in tandem, we hope that future researchers will be able to shed new light on one of the most fundamental questions about the human condition: How is time represented in the mind?

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available via the Open Science Framework at https://osf.io/ztdnv/.

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SUPPORTING INFORMATION

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APPENDIX

FIGURE A1 Storyboards and pictures demonstrating interventions and negations of event B used on critical trials. The ordering of the past and future event questions about each story and the positive and negative response options to each question were counterbalanced. Control trial stimuli are not shown. Complete scripts and stimuli can be found on OSF