You can't change the past:

Children's recognition of the causal asymmetry between past and future events

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Abstract

Children's temporal and causal reasoning skills improve substantially during early childhood, but it remains unclear when they fully understand the conceptual distinction between the past and the future. Here we explored U.S. 3- to 6-year-old children's ($n = 228$) and adults' ($n = 60$) understanding that acting in the present can change the future but not the past. To do so, we told participants 3-step causal stories, e.g., "(1) When Sally flips the light switch, (2) the light turns on, (3) so she can see to find her toy," and asked about the effects of an action at event 2, e.g., "What if John turned off the light?". When asked about the effects of the change on the future consequent event (3), only 3-year-olds responded at chance, while 4- to 6-year-olds became increasingly likely to judge that the future event would also change. However, when asked about the effects of the change on the past antecedent event (1), children of all ages, like adults, consistently judged that the past event still occurred. This suggests that children have an early-developing understanding that the past cannot be changed. Using a similar paradigm, we also explored children's reasoning about the implications of the non-occurrence of event 2, in which the cause was not specified, e.g., "What if the light *didn't* turn on?". Both children and adults reasoned differently about these scenarios than they did about those involving actions by external agents. In particular, adults and 6-year-olds inferred that the antecedent event also had not occurred. Implications for theoretical accounts of causal and temporal reasoning are discussed.

Keywords: cognitive development; temporal cognition; causal inference; counterfactual reasoning; backtracking

1. 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 relationships improves during the preschool and early school years (for reviews, see Gopnik & Wellman, 2012; Hoerl & McCormack, 2019), few studies directly explore the relationship between children's causal reasoning and their knowledge of the distinctions between past and future (McCormack & Hoerl, 2017a). 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 both (1) whether children believe actions can retroactively change antecedent events in the past and (2) whether children use information they observe about a current event to retrospectively infer that antecedent events have changed in the past.

Despite the central role of the past vs. 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, 2017a). 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/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 vs. future status of events, relative to the present. Nevertheless, children’s early use of grammatical tense is inconsistent and often inaccurate (e.g., Andersen & Shirai, 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, i.e., which events come first in time, does not necessarily imply a causal relationship 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 past and future.

Suggesting that even preverbal infants intuitively understand the relationship 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 chose 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 relationships 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 the future is changeable but the past is not. 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 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 relationships are defined in terms of their counterfactual dependency: i.e., if event A causes event B, then an intervention on event A (e.g., preventing it from occurring) will also lead to a change in event B (Pearl, 2000; Schulz et al., 2007; Schulz & Gopnik, 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 different¹ (Beck et al., 2006; German & Nichols, 2003; Guajardo & Turley-

¹The 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). In the present

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 a focus of the current study.

Bringing together the existing literature about causal reasoning and the past/future distinction, we hypothesize that if participants have a unidirectional view of how causality operates over time, when given a 3-step causal chain of events $A \rightarrow B \rightarrow C$, 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, e.g., an intervention at B will *not* retroactively alter antecedent event A (Sloman & Lagnado, 2005). Consider the following scenario (see Figure 1): When (A) Sally 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

paper, we take a broad view of counterfactual reasoning, which encompasses hypothetical questions about the past, present, and future, as well as conditionals.

off the light at event B, adults may reasonably predict that Sally will no longer be able to see at event C. However, they should *not* infer that Sally 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.

In addition to exploring children's beliefs about the possibility of changing the past, we were also interested in whether they can use information about the present to reason “back in time” and make inferences about what has already happened, which we refer to as *retrospective reasoning*. As discussed above, a unidirectional model of time dictates that changing an effect cannot change its causes. However, observing an effect *can* be diagnostic of its causes, following the logical principle modus tollens (*if A, then B, not B, therefore, not A*) (see Sloman & Lagnado, 2015 for discussion).

Indeed, prior work shows that adults generate different causal predictions 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 did not move (Sloman & Lagnado, 2005). Thus, if an expected event does not occur—and no other explanation for this 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 didn't turn on at point B (i.e., that event B was not observed), an adult might indeed conclude that Sally never flipped the light switch at point A. While some work suggests that children also engage in diagnostic reasoning about causal antecedents from observed outcomes (Erb & Sobel, 2014), children are typically less accurate in reasoning from effects to causes than they are at reasoning from causes to effects (Hong et al., 2005).

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 Sally flip the light switch?") and future event C ("Will Sally see to find her toy?"). See Appendix and <https://osf.io/ztdnv/> for complete set of stimuli.

Here, to explore the development of reasoning about time and causality, we presented 3- to 6-year-old children and adults with stories involving 3-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). 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 provided no explanation for the change to event B. Here, we also hypothesized that participants with a linear concept of time would judge that the future event (C) would not occur. However, if children (like adults) engage in retrospective reasoning about antecedent causes, we hypothesized that they would judge that the past event (A) had also changed (Sloman & Lagnado, 2005). In contrast, if children do not make the inference that a changed effect implies a changed cause, we predicted that they would perform similarly in the two conditions.

2. Method

2.1 Participants

A total of 288 subjects participated, including 30 3-year-olds ($M_{age} = 3.6$ years, range = 3;2–4;0 years), 65 4-year-olds ($M_{age} = 4.5$ years, range = 4.0–5.0 years), 70 5-year-olds ($M_{age} = 5.5$ years, range = 5.0–6.0 years), 63 6-year-olds ($M_{age} = 6.4$ years, range = 6.0–7.0 years) and 60 adult controls ($M_{age} = 21.6$ years, range = 18.2–31.1 years). 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.² Subjects were recruited from the west coast ($n = 258$) and the southwestern ($n = 30$) United States. Adult participants and parents of children provided informed consent to their participation. All

² 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.

study procedures were approved by the Institutional Review Boards of the universities at which data were collected.

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.

2.2 Materials

Study materials included eight 3-panel storyboards illustrating sequences of events from left to right. One example story is shown in Fig. 1, and all critical trial stories are shown in Appendix Figure 1. Each panel was 2.8 in. $\times$ 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 at <https://osf.io/ztdnv/>.

2.3 Procedure

Children were tested 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 3 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 child “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*³ 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

³ Under some definitions of counterfactual reasoning, our use of the simple past tense rather than the pluperfect subjunctive, e.g., “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 follow-up experiment ($n = 55$) using the pluperfect subjunctive tense. This study, reported in the Supplemental Materials, revealed the same pattern of results discussed here, consistent with previous work (Nyhout & Ganea, 2019a).

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 at <https://osf.io/ztdnv/>.

Data from children who responded incorrectly on more than one of the catch trials, i.e., 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 reasoning⁴.

2.4 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.

Experimental sessions were video-recorded, except in cases where parents did not provide consent to record. Responses from 171 children (59% of the total sample), including 3006 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).

3. Results

We began with two primary questions about our dataset: (1) Do participants reason differently about the implications of interventions by an external agent vs. negations without a specified cause? and

⁴ Although children who answered ‘yes’ on every trial (i.e., indicating that they thought none of the interventions/negations would have any effect) were not excluded, this pattern was very rare ($n = 7$).

(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, as well as random intercepts for subjects and stories. This analysis revealed a significant main effect of age, $\beta = 0.41$, $p = 0.001$, which improved the fit of the model compared to a reduced model that did not include this factor, $\chi^2(1) = 10.4$, $p = 0.001$. 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, $\beta = 1.87$, $p < .001$, $\chi^2(1) = 58.96$, $p < .001$. Given the evidence that children's behavior differed between conditions, we proceeded to analyze the data from the two conditions separately.

3.1 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, i.e., 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%, 95% CI [80%-100%].

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, $\chi^2(1) = 27.05$, $p < .001$. There was also a significant effect of event time (past vs future), $\beta = 1.9$, $p = 0.007$; $\chi^2(1) = 7.35$, $p = 0.007$, as well as a significant interaction, $\beta = -0.94$, $p < .001$; $\chi^2(1) = 42.48$, $p < .001$. As shown in Fig. 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 vs. future effect was significant in all age groups, including 3-year-olds, who reported that 60%, 95% CI [40%-80%] of future events changed, but only 20%, 95% CI [20%-40%] of past events did, $V = 335$, $p < 0.001$. 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 ($S = 83$, $p = 0.22$), though 4-year-olds, and all older groups, did ($S = 105$, $p < .001$).

Figure 2. Distributions of responses to questions about whether past (blue) and future (red) 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, e.g., 80% = 4 of 5 events changed. Gray areas indicate overlap of the two distributions. Vertical lines are medians. Three-year-olds were not tested in the negation condition.

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 wouldn't 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 4 out of 5 future events would change, and that at least 4 of the 5 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. Subjects who didn't follow a linear pattern

typically reported fewer than 4 changes to future questions, resulting in a mixed pattern. Subjects very rarely judged that both the past and future events changed, or that neither changed.

Figure 3. Percentage of subjects in each age group who demonstrated each of 4 response patterns across stories, in the (A) intervention and (B) negation conditions. “Same” indicates that the participant judged that at least 4 of 5 events did not change. “Change” indicates that the participant judged that at least 4 of 5 events changed. “Mixed” indicates inconsistent responding. Three-year-olds were not tested in the negation condition.

3.2 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, retrospectively, that there had been a change to antecedent event A.

As shown in Figure 2 (bottom row), when adults were told that event B didn't 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, $\beta = 1.09$, $p = 0.004$; $\chi^2(1) = 8.16$, $p = 0.004$. 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, $\beta = 0.35$, $p = 0.79$; $\chi^2(1) = 0.07$, $p = 0.791$, and no interaction, $\beta = -0.29$, $p = 0.24$; $\chi^2(1) = 1.36$, $p = 0.243$. In other words, we did not detect evidence that children were treating past and future events differently in this condition.

We predicted that participants capable of mature retrospective reasoning would judge that event A (like event C) had changed in the negation condition. This was 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, $S = 89$, $p = 0.18$). Five-year-olds, on the other hand, judged that past events would change on 40%, 95% CI [20%-60%] of trials, which was significantly lower than chance, $S = 71$, $p = 0.04$, 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.

In our individual-subjects analysis, an adult-like reasoning pattern was operationalized as one in which at least 4 of 5 past events *and* 4 of 5 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.

4. General Discussion

We set out to explore whether 3- to 6-year-old children, like adults, understand that future events can be changed, but past events cannot. By testing children’s reasoning about three-step causal chains, $A \rightarrow B \rightarrow C$, 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. 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 judged that both past event A and future event C must have also changed.

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. For example, 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). Here, we add to this work by showing that children who are the same age (and even younger) also know that past states of the world cannot be retroactively determined by present events. This finding suggests that even young preschoolers intuitively understand that time is irreversible.

Somewhat surprisingly, we found that adult-like reasoning about the effects of interventions on future events lagged behind children's reasoning about past events. While even 3-year-olds in the intervention condition judged that past events wouldn't change at greater than chance levels, children didn't 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 et al., 2006; Beck & Riggs, 2014; Perner et al., 2004; Rafetseder et al., 2010; Riggs et al., 1998), and that both children and adults tend to be more successful at conditional reasoning from causes to effects than at diagnostic reasoning from effects to causes (Hong et al., 2005). Moreover, in contrast to the present findings, 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).

What might account for the discrepancy between our results in the intervention condition and previous studies of children's conditional reasoning about the future? Notably, this prior success typically involved inferences about 2-step, rather than 3-step causal chains (Harris et al., 1996). Indeed, 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). Moreover, 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. On the other hand, 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 might 3-year-olds in the present study have had more difficulty with questions about the effects of an intervention on event B on the future event C than on past event A? One possibility is that children in our task 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 relationships 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). This difference may have contributed to the improved performance observed on past-related questions in the present study.

Children of all ages treated scenarios in which an explicit 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 Supplemental Materials), they were no more likely to judge that future events would change than past ones. Four- and 5-year-old children showed more varied response patterns on both the past- and future-event questions in this condition relative to the intervention condition, which is more 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 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.

By age 6, 65% of children (like most adults) consistently judged that a negation of event B implied changes to *both* past event A and future event C. One intriguing possibility is 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, or “parent,” causal variables (Gerstenberg, Bechlivanidis, & Lagnado, 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 interventionist accounts of causal reasoning (Woodward, 2005). Specifically, since under the interventionist framework, evaluating the effects of an intervention on a given variable requires “cutting off” that variable from its causal antecedents, backtracking should

not be possible (Pearl, 2000; see also Lucas & Kemp, 2015). However, given the methodological differences between our negation condition and the backtracking tasks that have been used with adults (e.g., Han et al., 2014; Lucas & Kemp, 2015), additional work is needed to further explore this potential developmental effect.

It is also possible that children's inferences about event A in the negation condition represent a form of diagnostic reasoning (i.e., the process of reasoning about the possible antecedent causes of an observed effect), rather than backtracking. As noted above, diagnostic reasoning from causes to effects may be more difficult than reasoning from effects to causes, for both children and adults (Erb & Sobel, 2014; Hong et al., 2005; Tversky & Kahneman, 1974). We found evidence for this in the negation condition, in which 4-year-olds responded at chance on future but not past questions, and 5-year-olds were more likely to infer that the antecedent event had not changed.

Unlike backtracking, diagnostic reasoning does not require that the participant treat the scenario in the test trial as a counterfactual alternative to the original story (see Lucas & Kemp, 2015 for a discussion). In other words, the child might simply consider a new, hypothetical event in which a lightbulb didn't turn on and consider its possible antecedent causes. This would not necessarily require them to revise a previous mental representation of a scenario in which the light *did* turn on. Notably, we did not find a different pattern of results when we changed the wording of our task to use the pluperfect subjunctive tense, which should be more likely to encourage children to mentally revisit the original story (see Supplemental Material; Nyhout & Ganea, 2019a). Again, however, additional work is needed to further explore the developmental trajectories of diagnostic reasoning and backtracking, which presents an important avenue for future research.

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 all 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, 2017b). 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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Appendix

Event A past	Event B present	Event C future	Intervention <i>What if...</i>	Negation <i>What if...</i>
When Sally flips the light switch	The light turns on	So she can see to find her toy	John turned off the light	The light didn't turn on

When Chris drops the plate	It breaks into lots of pieces	So Chris sweeps up the floor	Jenny caught the plate while it was falling	The plate didn't break

When Elizabeth plants a seed	A little sprout comes up from the ground	So a flower grows up	A bird ate the sprout	The sprout didn't come up from the ground

When Max falls down	He hurts his knee	So his mom takes him to the doctor	His sister gives him a band-aid that makes his knee better	Max didn't hurt his knee

When it starts raining	The kids get all wet	So they go inside to change into dry clothes	Someone gives them an umbrella to stay dry	The kids didn't get wet

Appendix Figure 1. Storyboards and pictures demonstrating interventions and negations of event B used on critical trials. Stimuli used in catch trials can also be found at <https://osf.io/ztdnv/>

Supplemental Materials

1. Follow-up experiment using pluperfect subjunctive tense

1.1 Method

1.1.1 Participants. We planned to test a total of 90 children between 4 and 7 years of age. However, the COVID-19 pandemic required us to cease in-person data collection in March of 2020. We therefore discontinued data collection and analyzed the data we had collected. A total of 55 subjects participated, including 19 4-year-olds ($M_{age} = 4.41$ years, range = 4.03–4.95 years), 14 5-year-olds ($M_{age} = 5.59$ years, range = 5.11–5.95 years), 14 6-year-olds ($M_{age} = 6.43$ years, range = 6.07–6.89 years), and 8 7-year-olds ($M_{age} = 7.51$ years, range = 6.07–6.89 years). Children were recruited from the west coast ($n = 3$) and southwestern ($n = 52$) areas of the U.S. Parents of children provided informed consent to their participation. The Institutional Review Boards at both universities approved all study procedures. An additional 6 children participated, but their data were excluded from analysis due to failing more than one catch trial ($n = 5$, including 1 4-year-old, 2 5-year-olds, and 2 6-year-olds) and having participated in a previous version of the experiment ($n = 1$).

1.1.2 Materials and methods were identical to those used in the negation condition of the main experiment, with the exception that the test questions were reworded to use the pluperfect subjunctive (*had not*), rather than the simple past tense (*did not*) (see Supplementary Table 1).

Supplementary Table 1: Past and future negation questions in main experiment vs. follow-up experiment

Event	Main experiment	Follow-up experiment
	<hr/>	
	<i>In the story, if the light didn't turn on...</i>	<i>In the story, if the light had not turned on...</i>
Past	Did Molly flip the flight switch, or not flip the light switch?	Did Molly still flip the light switch, or not flip the light switch?
Future	Will Molly see to find her toy, or not see to find her toy?	Would Molly see to find her toy, or not see to find her toy?
	<hr/>	
	<i>In the story, if the plate didn't break...</i>	<i>In the story, if the plate had not broken...</i>
Past	Did Chris drop the plate, or not drop the plate?	Did Chris still drop the plate, or not drop the plate?
Future	Will Chris sweep the floor, nor	Would Chris sweep the floor, or not sweep the floor?

1.2 Results

As in the negation condition of the main experiment, a logistic regression model of the children's data revealed only a main effect of age, $\beta = 1.21$, $p = 0.001$, $\chi^2(1) = 10.49$, $p = 0.001$. Older children were more likely to judge that events changed. There was no significant effect of the past vs. future status of the event, $\beta = -1.09$, $p = 0.45$, $\chi^2(1) = 0.57$, $p = 0.45$, and no significant interaction, $\beta = -0.01$, $p = 0.96$; $\chi^2(1) = 0$, $p = 0.96$. This indicates that, as in the negation condition of the main experiment, and unlike the intervention condition of the main experiment, children appeared to be reasoning similarly about both past and future events.

Given the smaller sample size in the follow-up experiment, we examined the age effects by performing a median split on the sample based on the children's age, creating a younger group of 28

children ($M_{age} = 4.7$ years, range = 4–5.8 years), and an older group of 27 children ($M_{age} = 6.7$ years, range = 5.9–7.8 years).

As in the negation condition of the main experiment, we were particularly interested in children's retrospective reasoning about the past. As shown in Supplementary Figure 1, we found that the older group of children in the follow up experiment judged the past had changed on 80% [80%-100%] of trials, which was significantly higher than chance, one-sample sign test, $S = 102$, $p < .001$), while the younger group did so on only 50% [20%-60%] of trials, which was not different from chance, one-sample sign test, $S = 61$, $p = 0.15$. This replicates the pattern of results we found in the negation condition of the main experiment, where 6-year-olds and adults consistently judged that past events had changed, but 4- and 5-year-olds were more mixed in their responses (see main text, Figure 2).

Moreover, as shown in Supplementary Figure 2, a reasoning pattern in which both the past and the future event were judged to change on at least 4 out of 5 trials was found in 78% [58%–91%] of older children, but only 25% [11%–45%] of younger children, paralleling our main findings.

Supplementary Figure 1. Distributions of responses to questions about whether past (blue) and future (red) events would change. Height of shaded areas indicates the proportion of participants who responded at each level of consistency, e.g., 80% = 4 of 5 events changed. Gray areas indicate overlap of the two distributions.

Supplementary Figure 2. Percentage of participants in each age group who demonstrated each of 4 response patterns across stories in the follow-up experiment. “Same” indicates that the participant judged that at least 4 of 5 events did not change. “Change” indicates that the participant judged that at least 4 of 5 events changed. “Mixed” indicates inconsistent responding.