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How children map causal verbs to different causes across development

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Although collision-like causes are fundamental in philosophical and psychological theories of causation, humans conceptualize many events as causes that lack direct contact. Here we argue that how people think and talk about different causes is deeply connected, and investigate how children learn this mapping. If Andy hits Suzy with his bike, Suzy falls into a fence and it breaks, Andy 'caused' the fence to break but Suzy 'broke' it. If Suzy forgets sunscreen and gets sunburned, the absence of sunscreen 'caused' Suzy's sunburn, but the sun 'burned' her skin. We tested 691 children and 270 adults. Four-year-old children mapped 'caused' to distal causes and 'broke' to proximal causes (Experiment 1). Although 4-year-old children did not map 'caused' to absences until later (Experiment 2), they already referred to absences when asked 'why' an outcome occurred (Experiment 3). Our findings highlight the role of semantics and pragmatics in developing these mappings.

Some say that causation is the cement of the universe[1]. Others say that it is the glue between observed events[2]. Whatever your views on adhesion, determining what causes what underlies many of the most profound cultural and scientific achievements, from the discovery of fire to the discovery of germs. The capacity for causal reasoning is a fundamental building block of cognition, with some aspects of causal cognition being unique to humans (for example, ref. 3), including that we use different causal expressions to refer to different types of causes (for example, ref. 4).

Linguists distinguish between lexical and periphrastic causatives. Lexical causatives encode causal relationships in a single verb, such as 'break', 'burn' and 'crack'. Periphrastic causatives are two-clause expressions, such as 'caused to break' (for example, ref. 5). Lexical causatives can refer only to direct causes while periphrastic causatives can also refer to indirect causes[5–12]. Linguists usually characterize direct causes as those that contact their effects (for example, refs. 8,9,13–16; see also ref. 12 for discussion). For instance, in determining what caused what when Andy hits Suzy with his bike, Suzy falls into a fence, and the fence breaks, it seems appropriate to say that Andy 'caused' the fence to break and that Suzy 'broke' it[4,12].

The linguistic distinction between lexical and periphrastic causatives relates to the philosophical distinction between productive and dependence-based causes[17,18]. Productive causes bring about effects via a spatiotemporally continuous process[12,19,20]. This can involve direct contact between a single cause and effect, such as Suzy kicking a fence and breaking it, but can also involve chains of events. In the fence-breaking scenario where Andy hits Suzy with his bike, she falls into the fence and it breaks, the distal cause, Andy, initiates the chain and the proximal cause, Suzy, makes contact with the effect. Dependence-based causes can be defined in terms of counterfactuals, such as 'if the cause had not occurred, then the effect would not have occurred'[21]. Accordingly, absences can also be causes. Not watering plants can cause them to die. Here, there is no production but there is dependence: if the plants had been watered, they would not have died[21–26].

These linguistic and philosophical distinctions are reflected in adults' language use[4]. For example, if Suzy goes to the beach, forgets her sunscreen and gets a sunburn, adults judge that the sun 'burned' her skin and that the absence of sunscreen 'caused her skin to burn'. Lexical causatives, such as 'burn' tend to be used for productive causes, whereas 'caused' tends to be used for non-productive causes, such as absences.

Here we investigate how children learn to map different causal expressions to different causes. To do so, they need to master two

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challenges: a semantic challenge of learning the meaning of different causal expressions, and a pragmatic challenge of understanding what expression is most appropriate to use in context. The semantic challenge includes realizing that lexical causatives have a narrow domain of application, whereas periphrastic causatives apply more broadly. For example, it is literally true that in the fence-breaking scenario, both Andy and Suzy 'caused' the fence to break. But only Suzy 'broke' it. Children need to learn that 'caused' can refer not only to direct causes but also to indirect causes and absences. The semantic overlap between lexical and periphrastic causatives creates the pragmatic challenge. When someone asks 'Who caused the fence to break?', it is more appropriate to say that it was Andy (rather than Suzy). Suzy not only caused the fence to break, but she also broke it. Because there is a more specific expression that one could have used to refer to Suzy, the less specific expression points to Andy. By examining how children map causal expressions to causes across development, we gain insight into how they address the semantic and pragmatic challenge, revealing the psychological mechanisms underlying the connection between the causal expressions that linguists recognize and the causal relations that philosophers characterize. Before turning to our experiments, we briefly discuss previous work on how children's causal cognition and causal language develop.

Development of causal cognition

Direct and indirect causes. Direct contact matters for how infants perceive causation. Infants perceive causation when one object makes contact with another and stops moving at the same time as the other one starts to move. If there is no contact, or a temporal delay, but the second object moves anyhow, infants do not perceive causation[27–29].

Direct contact, although not the only thing that matters, also plays a role in how children reason about causation[30]. When 2-year-old children are shown that a toy airplane lights up when a block comes into contact with its base, they will touch the base with the block when asked to make it go. In contrast, when the airplane is connected to the base by a long wire, they do not touch the base with the block when asked to make it go[31]. Children appear to understand direct causal relationships earlier than indirect ones.

Absent causes. Around the age of 3 to 4, children grasp that causation does not always require contact. For instance, they will hold an object over a detector (without touching it) after seeing that doing so makes the detector light up[31–35]. Around 5 years of age, children recognize that absences can be causes. For instance, they understand that not salting an icy sidewalk can cause someone to fall[36]. Because absences do not produce effects, treating absences as causes suggests an understanding of dependence-based causation.

Development of causal language

Lexical and periphrastic causatives. Lexical causatives, such as 'break', 'drop', 'dry' and 'open', are included in the vocabulary of most English-speaking children between the ages of 2 and 2½ (ref. 37). Around this time, children use them in adult-like ways both in their transitive form (for example, 'Andy broke the fence.') and intransitive form (for example, 'The fence broke.')[38,39].

At this same age, children understand novel verbs used in transitive, but not intransitive sentences, as having causal meaning. Naigles[40] showed 2-year-old children scenes where two actions were performed at the same time. In the causal scene, a bunny pushed down on a duck's head, making the duck tilt its head. In the non-causal scene, the duck and bunny twirled their arms in synchrony. Children heard novel verbs in either transitive form ('The duck is krading the bunny.') or intransitive form ('The duck and the bunny are krading.'). When asked to find 'krading', children looked longer at the causal scene when hearing the transitive sentence and longer at the non-causal scene when hearing the intransitive sentence (see also refs. 40–46). When hearing a novel verb in a transitive sentence, children expect that verb to encode a causal relationship that involves spatiotemporal continuity (for example, refs. 47–51).

What about periphrastic causatives? Between the ages of 2 and 2½, children acquire one of their first periphrastic causatives, 'made'. Children then do two things. They 'overlexicalize', using a lexical causative when an adult would use a periphrastic construction (for example, 'Water bloomed these flowers' (=made these flowers bloom)) and 'overanalyse', using a periphrastic construction where a lexical causative is called for (for example, 'Then I'm going to sit on him and made him broken.' (=break him); ref. 52). This suggests that young children have difficulty distinguishing between what kinds of causes lexical and periphrastic causatives refer to.

Semantics and pragmatics. While transitivity might help children distinguish statements that refer to causes from those that do not, it does not help with distinguishing what kinds of causes lexical and periphrastic causatives refer to. However, causatives differ in their specificity[53]. For example, 'caused to break' is more general in that it is true of many possible ways in which breaking can happen, including directly and indirectly breaking something. In contrast, 'break' is more specific—it picks out the subset of direct causes.

Because of the semantic overlap between lexical and periphrastic causatives, understanding causal verbs may be related to understanding scalar terms. For instance, 'some' is less specific than 'all'. Although it is not literally false to say 'some' even when 'all' is true, using 'some' pragmatically implies that 'all' is not true (because the speaker could have said 'all'). Consequently, adults do not find it acceptable for a speaker to say that 'Some of the horses jumped over the fence.' when in fact all of the horses did (see for example, ref. 54, for discussion).

In contrast, 5- to 6-year-old children say that a puppet 'answered well' when all horses jumped over a fence and the puppet said 'some of the horses jumped over the fence'[54–56]. Although young children engage in various forms of pragmatic inference[57–60], it seems that they understand 'some' and 'all' in ways that accord with their literal semantics. Across development, children learn the pragmatic implicature that is associated with using each expression, and they begin to understand them like adults.

Adults think it is less appropriate to say that 'Suzy caused the fence to break' than 'Suzy broke the fence', in the fence-breaking scenario[4]. But much like younger children think it is fine to say 'some of the horses jumped over the fence' when all of the horses jumped over the fence, they might think the same for 'Suzy caused the fence to break'. Older children might realize that while this sentence is true, it is potentially misleading since a more specific and informative expression is available, namely, that 'Suzy broke the fence'. Once children know that 'caused to break' and 'broke' can mean different things, they need to consider what pragmatic inferences a listener will make based on what they say.

Our question

As children develop, they first understand that causes directly produce effects, then that causes can be indirect, and finally that absences can also be causes[3]. How do children learn what causal expressions map onto these different kinds of causes?

How children map 'caused' to different kinds of causes is of particular interest since we know so little about it. The word 'caused' is almost never used in developmental work, although it is commonplace in work on adult causal judgement (for example, refs. 61–71). Children are instead asked what 'made' an outcome occur, whether they can 'make' it happen (for example, refs. 31,34,72–77), or whether something happened 'because' of something else (for example, refs. 78–82). It is understandable that 'caused' does not feature prominently in developmental work. 'Caused' is much less frequent than 'made' in adult speech. According to the Corpus of Contemporary American English[83], 'caused' is ranked 563 while 'made' is ranked 50. Young children may not hear or produce the word 'caused' very often.

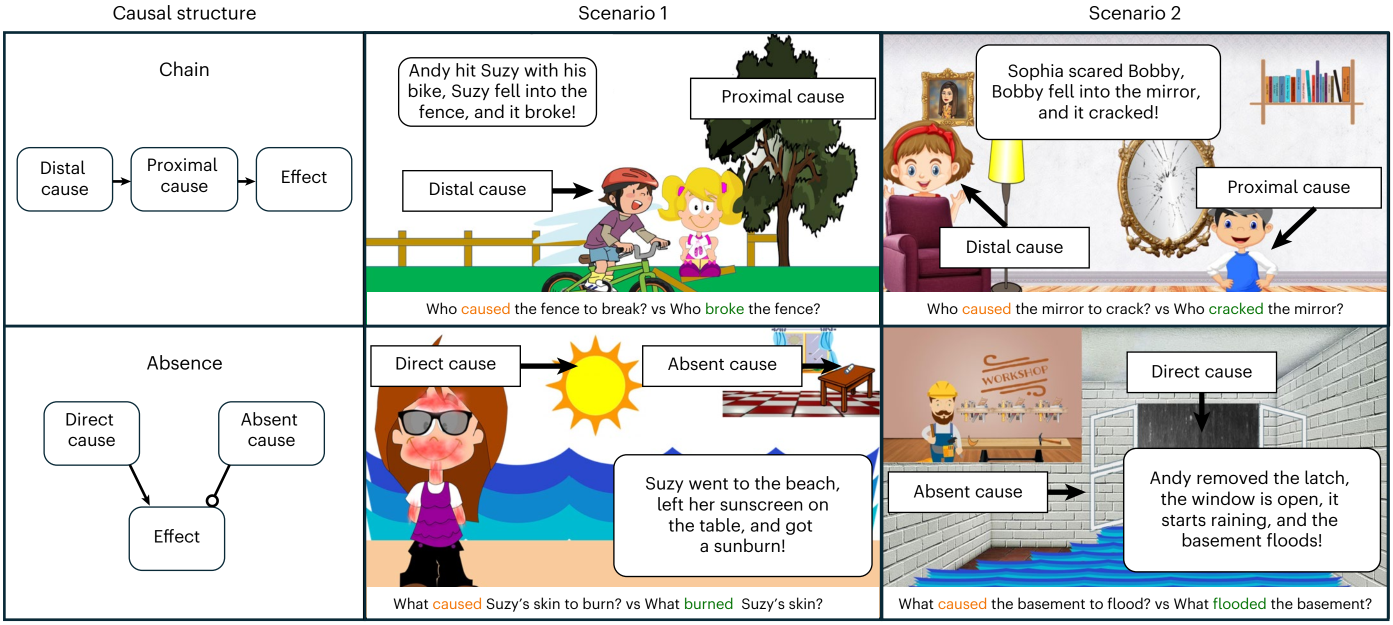

Fig. 1 | Experiment overview. Causal structures and illustrations of the final scene in different scenarios. Top row: the chain cases from Experiment 1. Bottom row: the absence cases from Experiments 2 and 3. Participants were asked questions that either used a periphrastic causative (for example, 'caused to break') or a lexical causative (for example, 'broke'). In one condition, the periphrastic causative was 'caused' (shown here), and in the other it was 'made'.

Do children understand that 'caused', 'made' and lexical causatives can refer to different kinds of causes? There are two separate questions here. First, do children distinguish lexical and periphrastic causatives? Second, do children distinguish different periphrastic causatives? To draw different inferences about what lexical and periphrastic causatives refer to, children need to understand both the semantics of these verbs and the pragmatics of their use. For instance, in the fence-breaking scenario, children need to know that while it is true that both Andy and Suzy caused the fence to break, it is only true that Suzy broke it. If asked 'Who caused the fence to break?', the better answer is Andy since the speaker could have used a more specific question—'Who broke the fence?'—if they wanted to hear about Suzy. Before children understand the semantics of these verbs and the pragmatics of their use, they might treat them as only referring to direct productive causes.

Children also need to understand that there are subtle semantic differences between periphrastic causatives, such as 'caused' and 'made' (see for example, ref. 84). By examining both 'caused' and 'made' as periphrastic alternatives to lexical causatives, we ask whether children simply think any periphrastic causative refers to whatever the lexical causative does not, or whether they think that 'made' and 'caused' mean something different.

Results

To investigate how children develop their understanding of different causal expressions, we conducted three experiments examining their interpretation of lexical and periphrastic causatives across different causal scenarios. Before presenting the specific findings, we outline our statistical approach and preregistration procedures.

Statistical approach and preregistration

For all results reported in this paper, we analysed the data using Bayesian logistic mixed-effects models, using the default priors as specified by the brms package in R[85]. We will refer to a statistical result of interest as 'credible' when the 95% credible interval excludes 0 (or 1 when reporting odds ratios).

Figure 1 and Table 1 show an overview of the experiments. We preregistered separate analyses for each selected referent (for example, 'Andy'–distal cause; 'Suzy'–proximal cause) and report these results in the Supplementary Information. Here we directly compare which referent was selected for a given causal verb, using the phrase 'as predicted' to explicitly mark where our preregistered hypotheses apply. All experiments, data, analyses and links to preregistrations are available on GitHub[86].

Experiment 1: Causal chains

The goal of this experiment was to determine whether adults and children understand 'caused', 'made' and lexical causatives ('broke', 'cracked') to refer to different events in causal chains, such as the fence-breaking scenario (see Fig. 1 top and Table 1). Who will children and adults refer to when asked 'Who caused the fence to break?' and 'Who broke the fence?', and who will they refer to when asked 'Who made the fence break?' and 'Who broke the fence?'? Figure 2 shows the results.

'Caused' versus lexical causatives. As predicted, we found that children were more likely to select the distal cause (for example, the person on the bike) when asked 'Who caused the fence to break?' compared with 'Who broke the fence?' (caused: 67%, 95% confidence interval (CI) [61%, 72%]; lexical: 20%, CI [16%, 25%]; odds ratio: 13.8, 95% credible interval (CrI) [7.8, 22.4]). The same was true for adults (caused: 74%, CI [67%, 82%]; lexical: 28%, CI [20%, 36%]; odds ratio: 18.2, CrI [6.27, 40.7]). There was no credible effect of age on children's selections of the distal cause (0.07, CrI [−0.11, 0.26]), and there was no interaction between causal verb and age (0.21, CrI [−0.07, 0.48]).

'Made' versus lexical causatives. As predicted, children were more likely to select the distal cause for 'made' compared with 'lexical' (made: 47%, CI [41%, 52%]; lexical: 22%, CI [17%, 27%]; odds ratio: 4.8, CrI [2.8, 7.4]), and the same was true for adults (made: 52%, CI [43%, 61%]; lexical: 28%, CI [19%, 36%]; odds ratio: 4.6, CrI [2.0, 8.7]). There was no credible effect of age on selecting the distal cause (0.05, CrI [−0.14, 0.25]), but there was an interaction between causal verb and age (0.58, CrI [0.31, 0.86]) where selection of the distal cause decreased with age for 'lexical' (−0.24, CrI [−0.49, 0.00]) but increased for 'made' (0.34, CrI [0.12, 0.56]).

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Table 1 | Overview of experiments

Experiments	Condition	Scenarios	Questions	Response coding	Age (children)	*N* (children)	*N* (adults)
Experiment 1	'Caused' versus lexical causatives ('broke', 'cracked')	fence	'Who caused the fence to break?' and 'Who broke the fence?'	Andy (distal), Suzy (proximal)	4–9	150	60
		mirror	'Who caused the mirror to crack?' and 'Who cracked the mirror?'	Sophia (distal), Bobby (proximal)			
	'Made' versus lexical causatives ('broke', 'cracked')	fence	'Who made the fence break?' and 'Who broke the fence?'	Andy (distal), Suzy (proximal)	4–9	150	60
		mirror	'Who made the mirror crack?' and 'Who cracked the mirror?'	Sophia (distal), Bobby (proximal)			
Experiment 2	'Caused' versus lexical causatives ('burned', 'flooded')	sunburn	'What caused Suzy's skin to burn?' and 'What burned Suzy's skin?'	sun (direct), sunscreen (absent)	4–9	150	60
		flood	'What caused the basement to flood?' and 'What flooded the basement?'	rain/water (direct), latch/window (absent)			
	'Made' versus lexical causatives ('burned', 'flooded')	sunburn	'What made Suzy's skin burn?' and 'What burned Suzy's skin?'	sun (direct), sunscreen (absent)	4–9	150	60
		flood	'What made the basement flood?' and 'What flooded the basement?'	rain/water (direct), latch/window (absent)			
Experiment 3	Absence with explanation	sunburn	'Why did Suzy get a sunburn?'	sun (direct), sunscreen (absent)	4–6	61	30
		flood	'Why did the basement flood?'	rain/water (direct), latch/window (absent)			

The scenario order was randomized in all experiments. In Experiments 1 and 2, the question order was also randomized. In Experiment 1, we counterbalanced which character appeared in which causal role (for example, either Andy or Suzy was the one on the bike).

'Caused' versus 'made'. We found that children were overall more likely to select the distal cause for 'caused' compared with 'made' (odds ratio: 2.61, CrI [1.76, 3.68]). The same was true for adults (odds ratio: 4.17, CrI [1.86, 7.63]).

Discussion. Similar to adults, 4-year-olds chose different referents in causal chain scenarios when a speaker uses 'caused' versus a lexical causative. When Andy hits Suzy with his bike, she falls into the fence and it breaks, they think Andy, the distal cause, 'caused' the fence to break and that Suzy, the proximal cause, 'broke' it. In contrast, 'made' is treated more like a lexical causative early on. Children become less likely to think that 'made' refers to proximal causes over development. But even adults do not think that 'made' clearly refers to distal causes. In contrast, both children and adults think that 'caused' refers to distal causes.

The fact that children already understand 'caused' to refer to causes that are more remote from their effects raises the possibility that they might even understand 'caused' to refer to causes that are disconnected from their effects, such as absences. We examine this in Experiment 2.

Experiment 2: Absences

This experiment investigates whether children understand 'caused', 'made' and lexical causatives to refer to different causes when presented with situations involving causation by absence, such as Suzy going to the beach, forgetting her sunscreen and getting a sunburn (see Fig. 1 bottom and Table 1). What will children and adults answer when asked 'What caused Suzy's skin to burn?' and 'What burned Suzy's skin?', and when asked 'What made Suzy's skin burn?' and 'What burned Suzy's skin?'? Will they refer to an absence, such the sunscreen, or a direct cause, such as the sun? Figure 3 shows the results.

'Caused' versus lexical causatives. As predicted, we found that children were more likely to select the absent cause when asked 'What caused Suzy's skin to burn?' compared with 'What burned Suzy's skin?' (caused: 35%, CI [30%, 41%]; lexical: 13%, CI [9%, 17%]; odds ratio: 3.8, CrI [2.2, 5.6]). The same was true for adults (caused: 57%, CI [49%, 65%]; lexical: 10%, CI [5%, 16%]; odds ratio: 12.4, CrI [5.0, 23.2]). There was a credible effect of age on children's selections of the absent cause (0.14, CrI [0, 0.31]), and there was an interaction between causal verb and age (0.39, CrI [0.08, 0.65]). Older children were more inclined to select the absent cause for 'caused' (0.33, CrI [0.17, 0.49]) but not for 'lexical' (−0.05, CrI [−0.29, 0.22]).

'Made' versus lexical causatives. In contrast to what we predicted, we found that children were more likely to select the absent cause for 'made' compared with 'lexical' (made: 27%, CI [22%, 32%]; lexical: 12%, CI [8%, 16%]; odds ratio: 3.4, CrI [1.9, 5.5]). The same was true for adults (made: 53%, CI [45%, 61%]; lexical: 18%, CI [11%, 25%]; odds ratio: 5.5, CrI [2.9, 9.4]). There was a credible effect of age on children's selections of the absent cause (0.21, CrI [0.02, 0.43]) but no interaction between causal verb and age (0.15, CrI [−0.15, 0.44]).

'Caused' versus 'made'. We found that children were not more likely to select the absent cause for 'caused' compared with 'made' (odds ratio: 1.4, CrI [0.93, 1.94]). The same was true for adults (odds ratio: 1.17, CrI [0.67, 1.81]).

Discussion. When Suzy went to the beach, forgot her sunscreen and got a sunburn, young children almost never referred to an absence of sunscreen when asked what 'caused' her skin to burn, 'made' it burn, or 'burned' it. Instead, they referred to the sun. With increasing age, children were more inclined to refer to an absence of sunscreen when they heard a periphrastic causative and were somewhat more likely to do so when the periphrastic causative was 'caused' compared with 'made'.

While young children already have available a mapping of 'caused' to distal causes in chains, the mapping of 'caused' to absences shows protracted development. Why might this be the case? They might find it more challenging to draw a connection between the use of this

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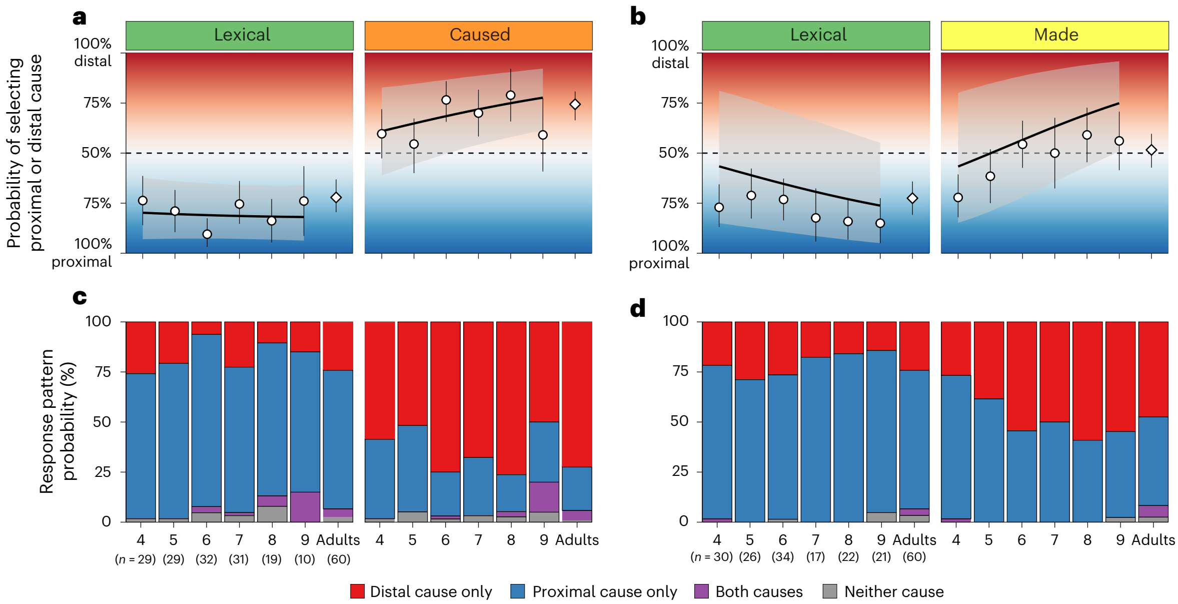

Fig. 2 | Experiment 1. Top row (**a**,**b**): the relative proportion with which participants selected the distal cause (red shading) versus the proximal cause (blue shading) depending on whether the speaker used a lexical causative or a periphrastic causative. For these we included all responses except for those where participants selected neither a distal nor a proximal cause. **a**,**b**, The probability of selecting a proximal or distal cause in the (**a**) 'caused versus lexical' and (**b**) 'made versus lexical' conditions. Regression lines show the fits of Bayesian logistic mixed-effects models with 80% credible intervals. Large points show the percentage with which each age group selected either referent. Error bars show 95% bootstrapped confidence intervals. Bottom row (**c**,**d**): the full response patterns. **c**,**d**, The response patterns in the (**c**) 'caused versus lexical' and (**d**) 'made versus lexical' conditions for each age group along with the number of participants. Very few participants provided 'both causes' or 'neither cause' responses and most participants selected only a distal or a proximal cause.

word and this kind of cause. Or they might not even consider absences as causes. In Experiment 3, we ask whether children can conceive of absences as causes by simply asking them why something happened.

Experiment 3: Absences and explanation

Experiment 3 explores whether children and adults are more likely to refer to absences when simply asked 'why' an outcome occurred. 'Why' questions are often answered with 'because', and adults are more likely to agree with sentences referring to absences when those sentences use 'because' compared with 'caused'[87]. Here we test whether children might refer to absences when asked 'why' an outcome occurred. Figure 4 shows the results.

As predicted, when asked 'Why did Suzy get a sunburn?', we found that children were more inclined to select absences, such as the sunscreen, than direct factors, such as the sun (absence: 73%, CI [66%, 79%]; direct: 19%, CI [13%, 25%]; odds ratio: 11.8, CrI [6.7, 18.7]). So were adults (absence: 93%, CI [87%, 100%]; direct: 27%, CI [15%, 38%]; odds ratio: 53.5, CrI [9.1, 183]). Indeed, as the results show, even the youngest children in our sample were more likely to select absent than direct factors when asked a 'why' question.

Discussion. When young children are told that Suzy goes to the beach, forgets her sunscreen and gets a sunburn, and are asked 'What caused Suzy's skin to burn', they tend to say 'the sun'. But when they are asked 'Why did Suzy's skin burn?', they say 'because she forgot her sunscreen'. This suggests that although children can conceive of absences, they do not refer to absences when hearing the word 'caused' until later.

General discussion

Linguists distinguish two kinds of causal expressions, lexical causatives and periphrastic causatives. Philosophers distinguish two kinds of causal relations, production and dependence. Recent work has found that adults use lexical causatives, such as 'burn', for productive causes that have a direct spatiotemporal connection to their effects and periphrastic causatives, such as 'cause', for dependence-based causes such as absences[4]. This suggests a deep connection between the different causal expressions that linguistics recognize and the different causal relations that philosophers have characterized. How do children learn to map different causal verbs to different kinds of causes?

Our findings reveal that young children understand that causal language picks out different causes. When considering a situation where Andy hits Suzy with his bike, Suzy falls into the fence and it breaks, 4-year-old children already refer to the proximal cause, Suzy (Experiment 1), when asked 'Who broke the fence?'. Likewise, when considering a situation where Suzy goes to the beach, forgets her sunscreen and gets a sunburn, they refer to the direct cause, the sun (Experiment 2), when asked 'What burned Suzy's skin?'. This suggests that young children treat lexical causatives, such as 'broke' and 'burned', as picking out causal relations involving direct spatiotemporal contiguity.

Young children show an adult-like understanding of 'caused' even though 'caused' is rarer and less familiar than lexical causatives and other periphrastic causatives such as 'made'. 4-year-old children already map 'caused' to distal causes in a chain. When asked 'Who caused the fence to break?', they refer to Andy, the person on the bike who hit Suzy (Experiment 1). So while children understand more frequent and familiar lexical causatives such as 'broke' to refer to proximal causes in chains, they also understand that 'caused' can refer to distal causes in chains. At the same time they appreciate this, they do not distinguish 'made' from lexical causatives, despite 'made' being more frequent and familiar than 'caused'. Not even adults understand 'made' to clearly refer to distal causes. Only 'caused' does.

While young children map different causal verbs to different productive causes in chains, situations that involve absences are more challenging. When Suzy goes to the beach, forgets her sunscreen and gets a sunburn (Experiment 2), young children almost never refer to Suzy's having forgotten the sunscreen when asked 'What caused her skin to burn?' or 'What made her skin burn?'. With increasing age, children become more inclined to do so and do so more readily for

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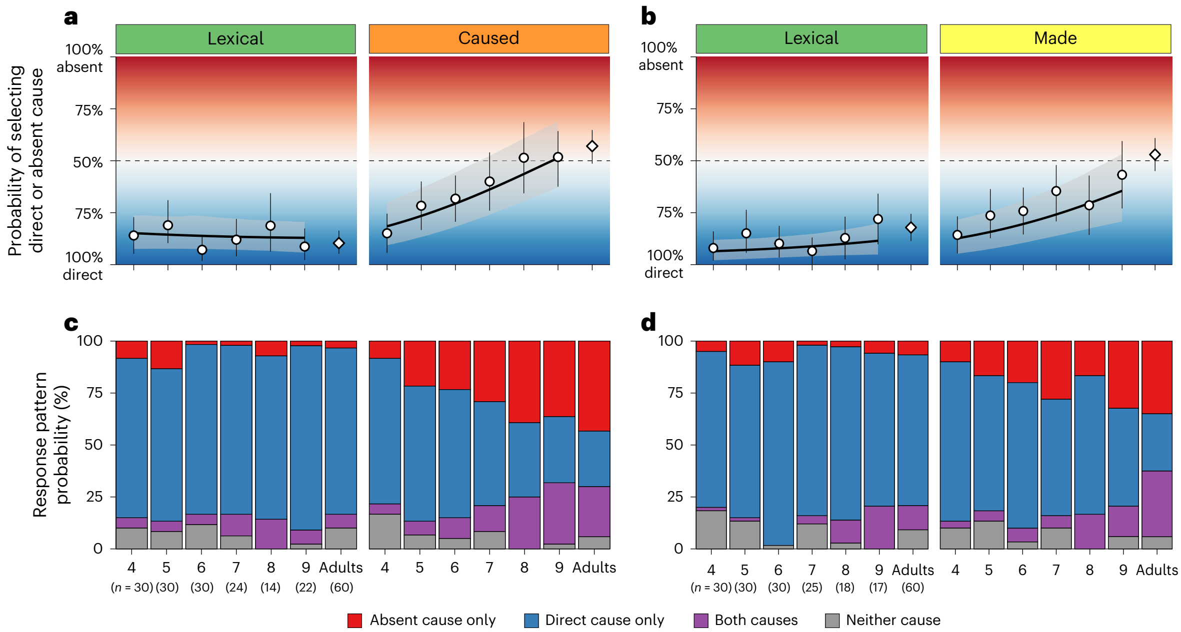

Fig. 3 | Experiment 2. Top row (**a**,**b**): the relative proportion with which participants selected the absent (red shading) versus the direct cause (blue shading) depending on whether the speaker used a lexical causative or a periphrastic causative. For these we included all responses except for those where participants selected 'neither' an absent nor a direct cause. **a**,**b**, Probability of selecting a direct or absent cause in the (**a**) 'caused versus lexical' and (**b**) 'made versus lexical' conditions. Regression lines show the fits of Bayesian logistic mixed-effects models with 80% credible intervals. Large points show the percentage with which each age group selected either referent. Error bars show 95% bootstrapped confidence intervals. Bottom row (**c**,**d**): the full response patterns. **c**,**d**, Response patterns in the (**c**) 'caused versus lexical' and (**d**) 'made versus lexical' conditions for each age group along with the number of participants. The majority of participants selected only an absent or direct cause.

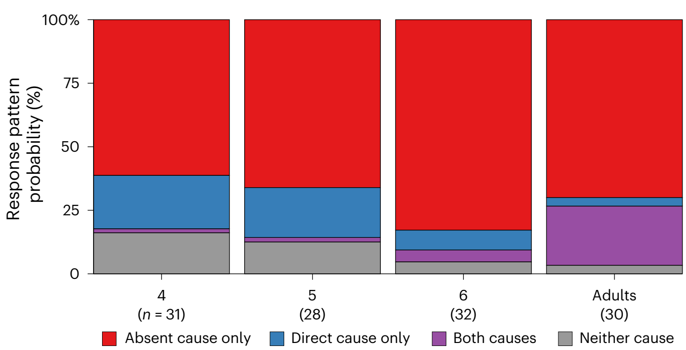

Fig. 4 | Experiment 3. Response patterns for each age group along with the number of participants. 'Both causes' means that they mentioned both the absent and direct cause, 'neither cause' means they mentioned neither. Overall, adults and children tended to refer to an absence when asked 'why' the outcome occurred. In contrast to children, adults were somewhat inclined to select 'both causes', and children were somewhat more inclined than adults to select 'neither cause'.

'caused' compared with 'made'. Yet children do think that absences can be causes before mapping 'caused' to them. While 4-year-old children do not refer to an absence when asked 'What caused Suzy's skin to burn?', they do when asked 'Why did Suzy's skin burn'?' (Experiment 3).

Together, our findings show that lexical causatives, such as 'broke' and 'burned', and periphrastic causatives, such as 'made' and 'caused' map to different causes over the course of development. What explains this developmental shift? We propose that both semantic and pragmatic mechanisms are at play.

Semantic development

Causal verbs differ in their specificity. Lexical causatives are more specific than 'made', and 'made' is more specific than 'caused'.

Lexical causatives refer to ways of directly causing particular outcomes. They specify many different direct, productive relations, such as burning and breaking, that even young children understand. Across development, lexical causatives maintain a narrow scope—they only refer to direct productive causes and not to indirect causes or absences. As such, they provide an early emerging, stable set of meanings that allow reference to many different and specific ways of producing outcomes.

Young children understand 'made' much like they do 'broke' or 'burned': 'made' refers to direct productive causes. Yet unlike lexical causatives, 'made' undergoes some semantic expansion across development. Even though neither adults nor children tend to reliably refer to distal or absent causes when asked what 'made' something happen, they are nonetheless more inclined to refer to these than when considering lexical causatives. But in contrast to the many different productive relations specified by lexical causatives, 'made' provides a more general way to refer to productive causes, one that does not specify the particular manner in which the effect was produced. In this way, 'made' might express a generic kind of production.

'Caused' has a more general meaning than 'made'—one that goes beyond referring to productive causes. One possibility is that the meaning of 'caused' is closely tied to that of counterfactual necessity, such that one event 'caused' another to happen when it would not have happened without it (see also for example, ref. 84). This may be something 4-year-old children already recognize when selecting distal causes. So when 4-year-old children refer to Andy as the one who 'caused' the fence to break, they might appreciate that if Andy hadn't hit Suzy with his bike, the fence would not have broken. Even if children have this meaning available for 'caused' it may initially have a relatively narrow domain of application: it can refer to distal causes but not absences. So while 4-year-olds can think of absences—they cite Suzy forgetting her sunscreen when asked 'why' she got a sunburn—they do not refer to them when asked what 'caused' her skin to burn. They do so later, once the semantics of 'caused' expands to include absences.

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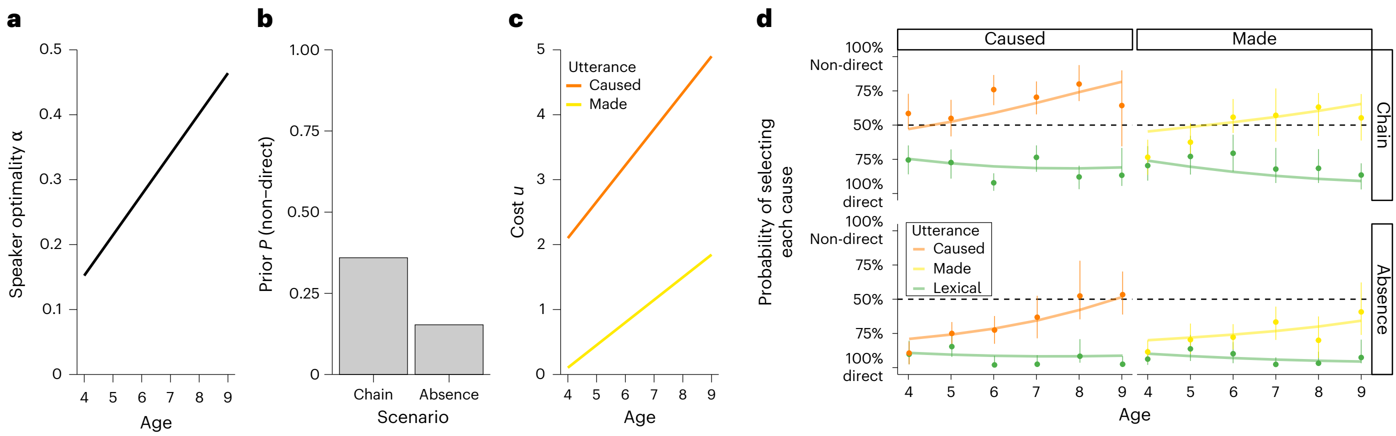

Fig. 5 | Rational Speech Act (RSA) model. a–c, Model parameters and how they change with development. **a**, The speaker optimality parameter *α* increases with age, meaning that older children assume that speakers are more likely to produce more informative utterances. **b**, The prior over the two referents is assumed not to change with age. The values show the prior probability of referring to the 'non-direct' referent. This means that in the chain scenario, a speaker is more likely to refer to the 'proximal cause' than the 'distal cause'. In the absence scenario, a speaker is even more likely to refer to the 'direct cause' than the 'absent cause'. **c**, The (relative) cost of using a periphrastic causative increases with age and is greater for 'caused' than for 'made'. The cost for producing the lexical causative is assumed to be 0. **d**, Empirical data and model predictions. The points denote the proportion of participants who chose the direct cause or non-direct cause (that is, the indirect or absent cause) as a referent depending on the utterance. The lines show the model predictions. Left side: the possible utterances were 'caused' vs 'lexical'. Right side: 'made' vs 'lexical'. Top row: the 'chain' scenarios. Bottom row: the 'absence' scenarios. Error bars show 95% bootstrapped confidence intervals.

Pragmatic development

Semantic expansion is one key mechanism that can help explain how children learn to map causal verbs to different causes across development. Another mechanism is children's ability to draw pragmatic inferences about the use of different causal expressions in context. Here we suggest a few factors that might change across development, using the Rational Speech Acts (RSA) framework as a guide[88–90].

Let us suppose for now that lexical causatives can only refer to direct causes, and that periphrastic causatives can refer to any kind of cause. Within the RSA framework, there are three factors that can help explain the patterns we observe: speaker optimality, utterance cost and reference prior. Here we outline the general idea and provide a concrete implementation in the Supplementary Information. Figure 5a–c shows the model parameters (and how they are assumed to change across development), and Fig. 5d shows how well this model captures the data in Experiments 1 and 2.

'Speaker optimality' captures how likely a speaker is to use more informative utterances. If older children assume that speakers are more likely to be informative, then this helps explain the general pattern that they are more likely to differentiate between the referents than younger children depending on whether they hear a lexical or periphrastic causative (Fig. 5a).

The 'reference prior' captures how likely a speaker is to refer to specific events. By assuming that speakers are more likely to refer to direct causes than distal causes and even less likely to refer to absences, the model captures some of the differences between the scenarios (Fig. 5b). Specifically, it accounts for the fact that when a periphrastic causative was used, participants were more likely to refer to distal causes in chains, than to absences in the other scenarios. Unlike the other factors in the model, the reference prior doesn't change with age.

Finally, the 'utterance cost' captures how costly it is for a speaker to say something. An utterance is more costly when it is more difficult to say and when it comes to mind less easily[88,91]. Periphrastic causatives are longer expressions than lexical causatives (for example, 'caused to break' versus 'broke'), so their utterance cost is higher. 'Caused' is rarer than 'made', so 'caused' is more costly than 'made'. This difference in utterance cost between the expressions accounts for the fact that listeners are more likely to infer that the distal or absent cause was referred to when a speaker used 'caused' compared with 'made'. If a speaker was willing to incur a greater cost, they must have wanted to be particularly informative (Fig. 5c). The model assumes that, as children get older, they realize the greater relative cost of a periphrastic causative compared with a lexical causative. This could be because children need to first learn which expressions are rare and which ones are more common. The model predictions and empirical data are shown in Fig. 5d. The model accounts well for participants' responses, $r = 0.94$, RMSE = 7.55.

This model shows that even if the semantics of 'caused' and 'made' were identical, differences in their interpretation could arise from pragmatic effects such as the ones we have outlined here. In reality, it is likely that both semantic and pragmatic factors jointly produce the changes in children's causal language understanding that we observed in our experiments. While the semantics of the model we consider here is fixed, the RSA framework can also model situations where the meaning of an expression needs to be learned and might change over time[92]. In the Supplementary Information, we also look at how children's answers are affected by which causal expression they hear first. Order effects can provide further evidence for the role of pragmatic inference in language understanding (for example, refs. 93–96).

Other verbs, other languages

Our experiments featured a small number of lexical causatives, and 'caused' and 'made' as periphrastic causatives. Of course, the English language features many more causatives. For example, in addition to 'caused' and 'made', English speakers can also say 'enabled', 'allowed', 'let' and so on (see for example, refs. 53,97). It is possible that participants would be more inclined to refer to absences when asked what 'allowed' it to happen rather than what 'caused' it[97,98]. If participants were instead asked 'What allowed Andy's basement to flood?' when he left the window open and it rained or if they were asked 'What allowed Suzy's skin to burn?' when she went to the beach, forgot her sunscreen and got a sunburn, they may have been more inclined to refer to an absence than when asked what 'caused' these outcomes. Indeed, even though children show protracted development in mapping 'caused' to absences, they have no trouble referring to them when asked 'why' an outcome occurred, spontaneously using 'because' to do so. It is possible that they map periphrastic causatives such as 'allowed' and 'let' to absences earlier than they do so for 'caused' or 'made'.

While we drew on the distinction between lexical and periphrastic causatives to explore how the connection between different causal verbs and relations arises, not all languages afford lexical and periphrastic constructions for expressing causation[99]. For instance, Mayan languages have morphological causatives (for example, a suffix can be added to a verb to give it a causal meaning) and periphrastic causatives, and Swahili has two kinds of morphological variants. Across languages, more direct kinds of causes are usually referred to by either lexical or morphological causatives. Indirect causes are typically referred to by periphrastic causatives or else by morphological causatives when the language uses lexical causatives for direct causes (for example, Japanese). In cases where the language only has morphological causatives (for example, Swahili) distinct types of morphological causatives are used for direct and indirect causes. While a number of languages use lexical or morphological causatives to refer to direct causes, an exception is Charu: periphrastic causatives refer to more direct causes. Indirect causes are referred to with morphological and periphrastic causatives (for example, refs. 11,15). Children who speak languages with different causal constructions from English, such as Charu, might show different developmental patterns in mapping verbs to different causes (see for example, ref. 100, for work comparing German and Turkish-speaking children).

Conclusion

We examined how children develop a mapping from different causal verbs to different kinds of causes. They understand that lexical causatives, such as 'burned', refer to direct causes that produce their effects, that periphrastic causatives, such as 'caused', can refer to causes that are more remote from their effects, and eventually come to understand that 'caused' can also refer to absences. We argued that both semantic and pragmatic mechanisms contribute to this development. While more work is needed to tease these contributions apart, our findings suggest that semantic and pragmatic mechanisms support a distinction between causal verbs that involves mapping them to different causes. Our findings offer insight into the psychological mechanisms underlying the connection between the causal expressions that linguists recognize and the causal relations that philosophers characterize.

Methods

This research was approved by the Stanford Institutional Review Board (protocol no. IRB-59627). All participants were asked to carefully read a consent form which included information about the study and the anonymity of the data. Adult participants read the form online and clicked a button indicating consent before proceeding to the experiment. Children were accompanied by a parent or guardian who verbally gave (recorded) consent and confirmed that the child assented to the study before it began. In addition, before the study began, children were given a description of the study, told that there were no right or wrong answers, and then decided to proceed to the study by clicking a button on the screen. Between test trials, children were also given a description of what was to come next, and decided to proceed by clicking a button on the screen. Children and parents (or guardians) were told that they could stop the study at any time, for any reason, and that there was no penalty for doing so. At the end of the study, parents or guardians also indicated their level of consent for how the video recording could be used (for example, whether the video should be kept private or could be made public).

We preregistered sampling data from adults through Prolific (see ref. 101 for details on demographics) and data from children through Lookit (see ref. 102 for details on demographics) because these samples tend to be geographically and demographically diverse. For children, we preregistered that they would be included in the sample if they provided their own answers on all test trials, without input from parents, siblings and so on.

In Experiments 1 and 2, children and adults were randomly assigned to the 'caused' versus lexical causatives condition or the 'made' versus lexical causatives condition. Each experiment included two scenarios and two questions that were presented in random order. In Experiment 3, children and adults read two scenarios and answered a single question. The scenarios were presented in random order. In all experiments, we counterbalanced which character was in which causal role.

We collected data in Experiments 1 and 2 from 150 children for the 'caused' versus lexical causatives condition and 150 children for the 'made' versus lexical causatives condition, with 30 children in each age group from 4–6 and 60 in the 7–9-year-old range. For Experiment 3, we preregistered that we would collect data from 60 children who were 4–6 years old. For adults, we preregistered that we could collect data from 60 participants in the 'caused' versus lexical causatives condition and in the 'made' versus lexical causatives condition in both Experiments 1 and 2 (240 participants in total). In Experiment 3, we preregistered that we would collect data from 30 participants. For both children and adults, we recruited participants until the preregistered sample size was achieved. We did not conduct power analyses to determine sample sizes. Our sample sizes were based on those of similar previous studies. For all experiments, data were collected from October 2021 to September 2023. Exclusions are reported in each study described below. All data were analysed using R v.4.3.3.

Experiment 1: Causal chains

The 'caused versus lexical' version for adults was preregistered on 28 October 2022. The version for children was preregistered on 1 November 2022. The 'made versus lexical' version for adults was preregistered on 2 December 2022. The version for children was preregistered on 6 December 2022.

Participants. We recruited 120 adult participants (age: M = 35 years, s.d. = 13; gender: 55 female, 56 male, 8 non-binary, 2 no response/other; race: 12 Asian, 7 Black, 93 White, 9 no response/other) and 300 children (gender: 128 female, 135 male, 37 no response/other). We preregistered that we would collect data from 30 4-year-olds, 30 5-year-olds, 30 6-year-olds and 60 7–9-year-olds for each of the 'caused' versus lexical causatives and the 'made' versus lexical causatives conditions. Our final sample included only children who met our preregistered inclusion criteria. For all experiments, each video was watched, and it was confirmed whether the participants were children and whether they completed it without interference from parents or siblings. A total of 63 participants were excluded due to technical issues (no video, no audio) or failing to meet our preregistered inclusion criteria (interference or incomplete). Adults were recruited through Prolific and paid at a rate of US$12 an hour. Children were recruited through Lookit[102] and families were paid $5 for their participation.

Procedure. Children were tested asynchronously and began with warm-up trials, which were included to help them become comfortable with saying their answers out loud. After being introduced to Maggie and being told that they would help her learn English, children were presented with two pairs of sentences: "I live in Maple Street/I live on Maple street" and "I put socks on my feet/I put socks on my feets". For each one, they were asked whether it is right or wrong for Maggie to say that. Children were asked to say their answers out loud.

Children then proceeded to the test scenarios (see Fig. 1 top row and Table 1). In one, Andy hits Suzy with his bike, she falls into a fence and it breaks; in the other, Sophia hides behind a chair, jumps out, scares Bobby, he falls into a mirror and it cracks. In the 'caused' versus lexical causatives condition, children were asked in the fence scenario 'Who caused the fence to break?' and 'Who broke the fence?'. In the 'made' versus lexical causatives condition, they were asked 'Who made the fence break?' and 'Who broke the fence?'. In the mirror scenario, they were asked either 'Who caused the mirror to crack?' (in the 'caused' versus lexical causatives condition) or 'Who made the mirror crack?' (in the 'made' versus lexical causatives condition) as well as 'Who cracked the mirror?'. Children said their responses out loud.

The procedure for adults was the same except that they did not complete warm-up trials, and instead of saying responses out loud, they wrote them in a text box. The adult version of the experiment was programmed in jsPsych[103].

Design. Participants were randomly assigned to the 'caused' versus lexical causatives or 'made' versus lexical causatives condition. In both conditions, the scenario and question order was randomized. We also counterbalanced which character was in which causal role (for example, either Suzy or Andy was the one on the bike).

Response coding. We preregistered coding responses into two categories: 'distal' if the character on the bike (or behind the chair) was mentioned and 'proximal' if the character who fell into the fence (or the mirror) was mentioned. Our coding scheme was not mutually exclusive. It was possible for a participant to refer to both a distal and proximal cause in the same response, or to neither of the two.

Experiment 2: Absences

The 'caused' versus 'lexical' version for adults was preregistered on 6 October 2021. The version for children was preregistered on 7 March 2022 (for 4–6-year-olds) and on 8 January 2022 (for 7–9-year-olds). The 'made' versus 'lexical' version for both adults and children was preregistered on 16 May 2022.

Participants. We recruited 120 adult participants (age: M = 30 years, s.d. = 10; gender: 68 female, 49 male, 2 non-binary, 1 no response/other; race: 12 Asian, 12 Black, 83 White, 13 no response/other) and 300 children (gender: 147 female, 153 male). We preregistered that we would collect data from 30 4-year-olds, 30 5-year-olds, 30 6-year-olds and 60 7–9-year-olds for each of the 'caused' versus lexical causatives and the 'made' versus lexical causatives conditions. Our final sample included only children who met our preregistered inclusion criteria. A total of 70 participants were excluded due to technical issues or failing to meet our preregistered inclusion criteria. Adults were recruited through Prolific and paid at a rate of $12 an hour. Children were recruited through Lookit[102] and families were paid $5 for their participation.

Procedure. The procedure was the same as in Experiment 1. However, this time participants saw different scenarios (see Fig. 1 bottom row and Table 1). In one of the scenarios, Suzy goes to the beach, forgets her sunscreen and gets a sunburn. In the other, Andy removes the latch from his basement window, the window is open when it starts to rain, and the basement floods. In the 'caused' versus lexical causatives condition, children were asked in the sunburn scenario 'What caused Suzy's skin to burn?' and 'What burned Suzy's skin?'. In the 'made' versus lexical causatives condition, they were asked 'What made Suzy's skin burn?' and 'What burned Suzy's skin?'. In the flood scenario, they were asked 'What caused Andy's basement to flood?' (in the 'caused' versus lexical causatives condition) and 'What flooded Andy's basement?', or 'What made Andy's basement flood?' (in the 'made' versus lexical causatives condition) and 'What flooded Andy's basement?'. Children said their responses out loud.

Design. Participants were randomly assigned to the 'caused' versus lexical causatives or 'made' versus lexical causatives condition. In both conditions, the order of the scenarios and questions were randomized.

Response coding. We preregistered coding responses into two categories: 'absence' (for example, if the sunscreen was mentioned) and 'direct' (for example, if the sun was mentioned). As in Experiment 1, our coding scheme was not mutually exclusive.

Experiment 3: Absences and explanation

This experiment, for both adults and children, was preregistered on 3 April 2023.

Participants. We recruited 30 adult participants (age: M = 34 years, s.d. = 12; gender: 10 female, 16 male, 3 non-binary, 1 no response/other; race: 6 Asian, 3 Black, 20 White, 1 no response/other) and 91 children (gender: 53 female, 38 male). We preregistered that we would collect data from 30 4-year-olds, 30 5-year-olds and 30 6-year-olds. Eighteen participants were excluded due to technical issues or failing to meet our preregistered inclusion criteria. Adults were recruited through Prolific and paid at a rate of $12 an hour. Children were recruited through Lookit[102] and families were paid $5 for their participation.

Procedure and design. The procedure was the same as in Experiment 2. However, this time participants were asked different questions. In the sunburn scenario, participants were asked 'Why did Suzy's skin burn?', and in the flood scenario, they were asked 'Why did the basement flood?'. The order of the scenarios was randomized.

Response coding. We preregistered the same coding scheme as in Experiment 2. As in our previous experiments, our coding scheme was not mutually exclusive.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

All data are available on GitHub at https://doi.org/10.5281/zenodo.17572955 (ref. 86).

Code availability

All code is available on GitHub at https://doi.org/10.5281/zenodo.17572955 (ref. 86).

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Author contributions

D.R., S.Z., S.N., E.M.M. and T.G. conceptualized the project and designed the methodology. D.R. S.Z. and T.G. developed software. D.R. and T.G. performed validation and conducted formal analysis. D.R. and S.Z. conducted investigation and curated data. D.R. wrote the original manuscript draft. D.R., S.N., E.M.M. and T.G. reviewed and edited the manuscript. D.R. and T.G. performed visualization. D.R., E.M.M. and T.G. supervised and administered the project. E.M.M. and T.G. acquired funding.

Competing interests

The authors declare no competing interests.

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Sampling strategy	We preregistered sampling data from children through Lookit and sampling data from adults through Prolific. For children, we preregistered that they would be included in the sample if they provide their own answers, without input from parents, siblings, etc., on all test trials. We collected data in Experiments 1 and 2 from 150 children for the "cause vs. lexical" version and 150 children for the "made vs lexical" version with 30 in each age group from 4- 6 and 60 in the 7 - 9 year old range. For Experiment 3, we preregistered that we would collect data from 60 children who were 4 - 6. We sampled until we met the relevant n. For adults, we preregistered that we could collect data from 60 participants in the "cause vs lexical" version and 60 in the "made vs lexical" version in both Experiments 1 and 2. In Experiment 3, we preregistered that we would collect data from 30 participants. Data collection stopped when we reached these ns. We didn't conduct a power analyses to determine sample sizes. Our decision for adults and children was based on sample sizes usually used in these kinds of experiments.
Data collection	The adult version of the experiment was programmed in jsPsych and data was collection online through Prolific. The version for children was programmed in Lookit and data was collected in Lookit as well. Children were accompanied by a parent.
Timing	Data was collected from October 2021 to September 2023.
Data exclusions	In experiment 1, 63 children were excluded due to technical issues (no video, no audio) or failing to meet our pre-registered inclusion criteria (interference or incomplete). In experiment 2, 70 children were excluded due to technical issues or failing to meet our pre-registered inclusion criteria. In experiment 3, 18 children were excluded due to technical issues or failing to meet our pre-registered inclusion criteria.
Non-participation	We didn't record non-participation.
Randomization	In Experiments 1 and 2 children and adults were assigned to a "cause v lexical" version or a "made v lexical" version. Each experiment included two scenarios and two questions that were presented in random order. In Experiment 3, children and adults read two scenarios and answered a single question. The scenarios were presented in a random order. In all experiments, we counterbalanced which character was in which causal role.

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