

Beyond causality: Heuristics for inferring possibility

by

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The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

I am either the majority contributor or sole contributor to all of the work presented in this thesis.

This includes Chapters 2, 3, and 4 of my thesis which are publications co-authored with my supervisor Dr. Ori Friedman. Citations and information regarding these publications can be found in the relevant chapters.

Abstract

Deciding what is possible is an essential human ability, and our judgments about possibility often appear effortless and straightforward. But how do we actually decide whether something is possible or impossible? This dissertation explores two strategies that children might use to infer the possibility of strange or improbable events. The first posits that children think about the causal circumstances that could enable an event when judging whether it could happen. The second instead suggests that children's inferences about possibility are guided by a memory-based heuristic that compares potential events to known events. Children's ($N = 1,068$) use of these strategies are explored across three papers. Chapter 2 investigated 4- to 7-year-old's beliefs about the possibility of improbable events and impossible events in dreams and stories, finding that children judged more events to be possible in these fantastical worlds than in real life. However, across all worlds children more often judged improbable events possible than impossible events, and children only affirmed impossible events if the events were especially dream- or story-like. The findings suggest that children's beliefs about fantastical worlds are partly constrained by their real-world intuitions, and partly driven by what they know to have occurred in each kind of world. Chapter 3 explored whether 4- to 6-year-old children use a memory-based similarity heuristic to infer possibility, in which events are judged possible if they are similar to a known event. The findings provide evidence for a similarity heuristic in 5- and 6-year-olds possibility judgments: children judged similar improbable events possible, but did not affirm dissimilar improbable events or similar impossible events. Finally, Chapter 4 examined whether providing 4- to 7-year-old children with information about enabling causal circumstances would lead them to affirm the possibility of improbable events. It also contrasted the effect of this kind of causal information with information about similar events. The findings

show that causal information alone did little to alter children's beliefs about possibility. However, the findings again show evidence for a similarity heuristic in 5- and 6-year-olds possibility judgments, as children more often affirmed improbable events if they were first told about a similar event. Further, this study provides tentative evidence that a combination of enabling causal knowledge and information about a similar event has the greatest positive impact on children's possibility judgments for improbable events. Together, this work suggests that our beliefs about possibility are largely driven by our familiarity with, and memory of, past events.

Acknowledgements

The following is mostly an exercise in exclusion, since I couldn't possibly thank everyone I'm grateful towards on a single page. So I'll keep it brief.

First I should thank Ori. If I have a successful career after this, it's because of his guidance and the work we've done together. He helped make this work something I'm genuinely proud of. I couldn't have asked for a better mentor. I lucked out. (He would probably tell me to be less humble, but I don't feel like it.)

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Dedication

To mom and dad. Sorry I moved away. I think it'll work out.

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Chapter One: General Introduction

“If we call prodigies or miracles whatever our reason cannot reach, how many of these appear continually to our eyes! Let us consider through what clouds and how gropingly we are led to the knowledge of most of the things that are right in our hands; assuredly we shall find that it is rather familiarity than knowledge that takes away their strangeness...”

—Michel de Montaigne

Determining what's possible is an essential human ability, and something we often do without much effort. We look for doors because we know we cannot walk through walls; we avoid running into traffic because we know we are not immortal; we prepare for tomorrow but believe we can never revisit yesterday; we speak our thoughts aloud because we know our minds are private and inaccessible. Each of these judgments reflect everyday behaviours that show a clear orientation towards the possible over the impossible.

Such distinctions often seem easy to intuit, but not all possibility judgments are so straightforward—and the consequences of mistaken possibility judgments can be severe. Sometimes we are unable to see possibilities—or dismiss them as impossibilities—and therefore fail to adequately anticipate the future. People have confidently bet against the possibility of radio signals crossing the Atlantic Ocean, flying machines ever leaving the ground, and the viability of nuclear energy—only to be proved wrong within their lifetimes (“Keep up”, 1893; Foresight Institute, 2021). On the other hand, we sometimes mistake impossibilities for possibilities, and waste time and resources working towards unattainable goals. For instance, the field of alchemy spent centuries working towards the discovery of a substance that could turn lead into gold, despite this being atomically impossible (Matson, 2014). And many inventors worked tirelessly towards the creation of a functional perpetual motion machine, despite the machine’s mere existence being a clear violation of the laws of thermodynamics (Angrist, 1967).

We also use others' ability to distinguish between possible and impossible events as an especially important social cue. For instance, imagine a friend calls you on the phone to tell you they see people with the bodies of horses and objects levitating above the ground. You cannot be certain about what is *actually* happening around them, but you might reasonably worry that your friend is hallucinating since the things they are perceiving cannot be real. Further, imagine your doctor casually informs you that they believe the earth is flat and that cell phone towers serve to exert power over our thoughts. You might begin to seriously question the quality of the care you are receiving, since your doctor clearly struggles to use available evidence to figure out what is really going on. Even young children are skeptical of claims made by people who appear to have a faulty view of reality (Harris et al., 2018; Sobel & Kushnir, 2013). We usually do not expect people to come to unique conclusions about possibility, and any surprising conclusions we do encounter often signal misperception, faulty reasoning, or even trickery.

But *how* do we infer what's possible and impossible? One might expect that our beliefs about possibility are driven by a rich understanding of how the world works, and knowledge of the deeper principles that render certain outcomes possible or impossible (Schult & Wellman, 1997; Sobel, 2004). Despite often seeming effortless and ubiquitous in nature, possibility judgments appear to rely on an understanding of disparate domains of knowledge. Our belief that we can never walk through walls or fall upwards seems to indicate knowledge of physics. We also know that cats can never birth puppies or transform into tigers, which appears to reflect an understanding of biology. And we know that days can never last forever or pass more slowly in some places than others, which suggests a basic grasp of the properties of time. But these judgments may be less disparate, and less principled, than they seem.

This dissertation seeks to investigate possibility judgment as a domain-general phenomenon. It explores simple strategies that we may deploy when reasoning about the possibility of events in diverse domains, rather than addressing how our understanding of different domains or processes might shape our beliefs. Here, I test two separate accounts that broadly explain how children and adults may reason about possibility. The first posits that we consult our knowledge of *how* events might happen before deciding whether they can or cannot. For instance, before deciding whether giraffes can possibly swim, we might consider the awkward size and shape of the animal and whether its limbs could reasonably propel its weight upwards and forwards. The second proposes that we use our memories of what *has* happened as a direct jumping off point for our inferences about possibility. For instance, we might just remember that elephants, hippos, and zebras can swim, and decide that giraffes can probably swim, too.

While this work serves as the first to test these accounts directly, the accounts themselves are not entirely new. They have been proposed, in one form or another, in previous work on beliefs about possibility, though solid evidence in favour of either remains weak or absent entirely (see Shtulman & Carey, 2007; Woolley & Ghossainy, 2013). They were also raised much earlier by Michel de Montaigne, who penned an essay in the 16th century addressing two very similar accounts for inferring possibility. Regarding how we come to understand which events are possible rather than impossible, he asserted that “assuredly we shall find that it is rather familiarity than knowledge that takes away their strangeness” (Montaigne, 1958). Here, I will argue that I find just that.

Before further outlining these two accounts, though, it is essential to explain my approach to understanding possibility, and why it is informative. While my work aims to pinpoint general

mechanisms that enable reasoning about possibility, the studies in this dissertation solely explore the beliefs of young children rather than adults. Specifically, my work seeks to understand how beliefs about possibility develop over time, and to identify the kinds of information that drive belief revision. This is a fruitful approach to understanding how we reason about possibility, as it allows me to test manipulations that may serve to foster more mature reasoning among children, thereby pinpointing the mechanisms that shape adults' beliefs. And it is *especially* fruitful because children's and adults' beliefs about possibility differ so dramatically.

A naïve reader might expect this difference to involve diminishing credulity: young children believe that almost anything is possible, and only grow to realize that some outcomes are actually impossible as they learn more about how the world works. However, that reader will be surprised to learn that the complete opposite is true: children are remarkably skeptical about the possibility of events. Below, I describe the recent body of developmental work that shows how children's beliefs about possibility differ markedly from those of adults, and how these findings have contributed to our understanding of possibility judgment.

What do children think is possible?

Could a person find an alligator under their bed, grow a beard down to their toes, or drink onion juice? The truth is that these events *are* possible, albeit highly strange and improbable. Adults acknowledge this, and affirm that such things are as possible as completely ordinary events, like washing a car or wearing a baseball cap. However, young children feel differently. When 4- to 6-year-olds are asked these questions, they usually say the events cannot happen. Indeed, 4-year-olds have been found to deny them almost as often as truly impossible events, such as walking through a brick wall or travelling through time (Shtulman & Carey, 2007).

This finding is robust: young children usually deny the possibility of *any* strange and improbable event. This pattern of responding has emerged across different study designs and test questions (Bowman-Smith et al., 2019; Cook & Sobel, 2011; Danovich & Lane, 2020; Lane et al., 2016; 2018; Nancekivell & Friedman, 2017; Nolan-Reyes et al., 2016; Shtulman & Phillips, 2018), including questions that span multiple domains of knowledge (biology, physics, psychology; Shtulman, 2009). For instance, children not only reject the possibility of people engaging in strange behaviours (Shtulman, 2009; Shtulman & Carey, 2007), but also the possibility of strange and unfamiliar machines like motion detectors and voice changers (Cook & Sobel, 2011). They also continue to deny improbable events when someone tells them that they experienced the event firsthand or heard about the event from someone else (Lane et al., 2018), and they deny claims about improbable events learned from books or the internet (Danovich & Lane, 2020). They even deny improbable events after being asked to imagine the events occurring, even if they are successful at imagining them (Lane et al., 2016). Overall, their beliefs about improbable events are remarkably consistent, and appear resistant against manipulations that seek to change them.

However, it is worth noting that children *can* differentiate improbable events from impossible events when asked to explicitly differentiate between the two (Shtulman & Carey, 2007; Weisberg & Sobel, 2012). For instance, Shtulman & Carey (2007) provided children with a “possible” box and “impossible” box and asked them to sort improbable and impossible events into the appropriate boxes. Here, children overwhelmingly sorted improbable events as “possible” and impossible events as “impossible”, despite denying these same events in earlier experiments. In another study by Weisberg & Sobel (2012), children were heard a story filled with either improbable or impossible events and were asked to select pages to continue the story.

On each test trial, children were offered a page that had either improbable events or a page that had impossible events. Despite denying that all of these events were possible, children mostly selected the pages with events that matched the story; they chose improbable events for the improbable story, and impossible events for the improbable story. Finally, across all studies of children's beliefs about possibility children are almost always *more* likely to deny impossible than improbable events, despite mostly denying both. Together, these findings suggest that children represent improbability and impossibility differently. Yet very few studies show children outright affirming the possibility of improbable events—they mostly deny them instead.

This finding is analogous to children's reasoning about atypical events and behaviors in other domains. Children typically deny the possibility of events or objects that deviate from established social norms (Kalish, 1998; Komatsu & Galotti, 1986; Levy et al., 1995; Lockhart et al., 1977; Miller et al., 2000). For instance, they judge that a person could not wear pajamas to the grocery store (Browne & Woolley, 2004), and deny that school buses could be any color other than yellow (Cimpian & Steinberg, 2014). They also judge that people cannot choose to perform atypical actions or initiate atypical events, such as eating dinner alone rather than with their family (Chernyak et al., 2019). These findings may be partly driven by children's failure to distinguish between things that *should* happen (i.e., judgments about moral obligations) and things that *could* happen (i.e., true possibility judgments; Shtulman & Phillips, 2018). However, this failure cannot fully explain how children reason about possibility across the board, as they readily deny the possibility of amoral events that do not involve choice (e.g., finding an alligator under your bed, getting struck by lightning). Together, these findings highlight a general aversion among young children towards affirming atypical events and behaviors.

Surprisingly, similar patterns of judgment also emerge when children are asked to reason about fantastical worlds and events. While children can readily distinguish between reality and fantasy from at least age 5 (Boerger, 2011; Corriveau et al., 2009; Samuels & Taylor, 1994; Woolley & Ghossainy, 2013), their reasoning about fantasy appears remarkably reality-bound and mundane. For instance, when children are asked to select the next page in a clearly magical story, they prefer to select a page describing normal events over a page that fits the magical theme (Weisberg et al., 2013). They also usually offer mundane explanations for magical and impossible phenomena; they say that unicorns come from pet stores, and that beards as tall as towers were probably just grown to be that way (Nancekivell & Friedman, 2017; Woolley & Cornelius, 2017). Further, children report struggling to even *imagine* phenomena that cannot occur in the real world (Lane et al., 2016). In sum, children appear to have a global bias against affirming any event that is outside the norm—even when these events are embedded in patently unrealistic contexts.

How can we explain children's possibility judgments, and why they differ so drastically from those of adults? Below, I revisit the two potential strategies outlined above and look more closely at how they might operate. Importantly, these strategies may be used by both children and adults alike, and teasing them apart may help us better understand the mechanisms underlying the developmental shift outlined above. Also note that while these accounts are not mutually exclusive, they each make unique predictions regarding how beliefs about possibility should change throughout development, and the kinds of information that should drive these changes.

How could this happen? The causal-circumstances account

One way that children and adults might reason about possibility is by attempting to identify *how* events could occur. Specifically, they might seek to identify circumstances that would enable an event, only affirming events as possible if they succeed. For instance, people might affirm that a person could find an alligator under their bed if they decide that it could have crawled unseen through an open door or window. On this view, adults usually affirm the possibility of improbable events because they succeed at identifying circumstances that would enable them. Conversely, children usually deny the possibility of improbable events because they cannot think of any circumstances that would allow the event to occur.

This account has been favored in previous work on possibility judgment (Lane et al., 2016; Shtulman, 2009; Shtulman & Carey, 2007), and some evidence in support of the account can be found in how children and adults justify their beliefs. Adults often offer factual justifications, or justifications that identify circumstances that would enable an event (or the absence of such circumstances). Factual justifications essentially offer principles that would enable or disable outcomes. For instances, when asked if a person could live without a functioning heart, adults might deny the event with the justification that "You need a heart to pump blood" (Shtulman, 2009). Justifications pointing to causal circumstances instead aim to explain *how* the event might occur. For instance, an adult might state that a person *could* live without a heart if some alternative mechanism could pump their blood instead (Shtulman & Tong, 2013). Conversely, children usually offer neither of these kinds of justifications. Instead, they often respond hypothetically (e.g., a person without a heart would die), or redundantly (e.g., because you can't live without a heart; Shtulman, 2009). Taken at face value, these justifications suggest that causal concerns are top of mind when affirming that something is possible.

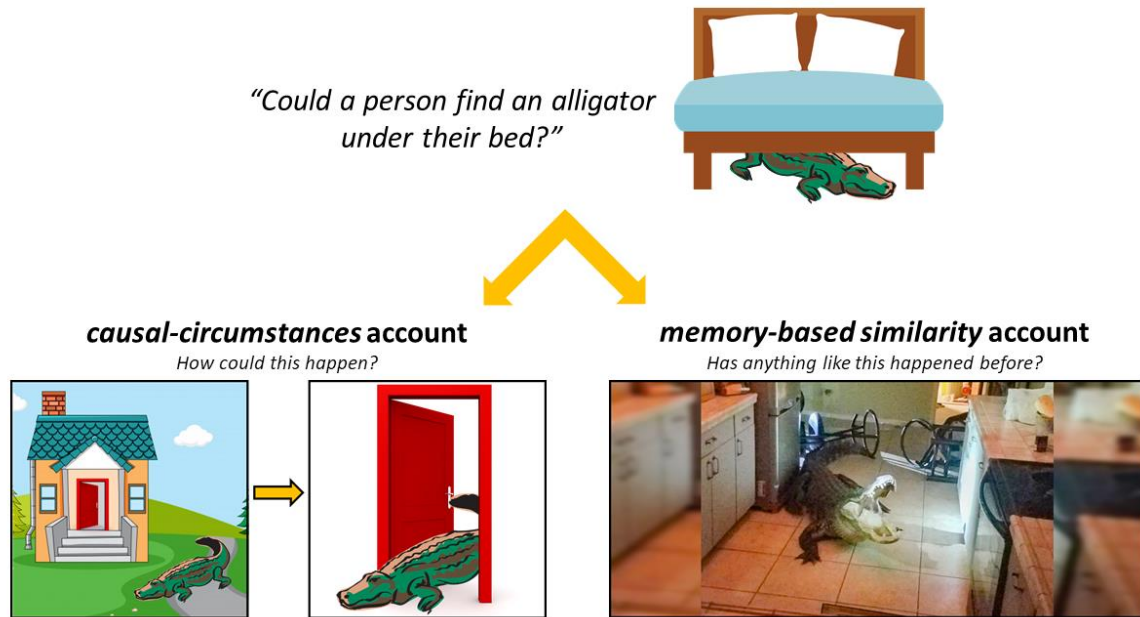


Figure 1. The two proposed strategies for inferring possibility. The causal-circumstances account proposes that people judge possibility by trying to think of circumstances that might allow events to happen. The memory-based similarity account proposes that people judge possibility by searching their memories for instances of similar events that have already occurred.

This causal-circumstances account might also explain how children reason about norm violations and fantasy. Regarding norm violations, children might not be able to envision *how* such violations could occur; for instance, they might know little about how a school bus could come to be painted differently. Regarding fantastical worlds, children might default to reasoning about how events could happen in the real world even when confronted with clearly fantastical events and contexts. Indeed, this account has been offered as an explanation for why children report failing to even *imagine* extraordinary events—they simply cannot envision *how* the events could happen (Lane et al., 2016).

Has anything *like* this happened before? The memory-based similarity account

Alternatively, people may reason about the possibility of events by searching for memories of similar events that they *know* to have happened in the past, only affirming events if

they can recall that something similar has already occurred. For instance, people might affirm that a person could find an alligator under their bed if they can recall instances of alligators being unexpectedly found in people's kitchens or bathrooms. This strategy does not require any knowledge of how outcomes might be enabled. Instead, it is akin to the use of an availability heuristic that searches for *similar* events rather than exact instances of the event in question (Bowman-Smith et al., 2019; Tversky & Kahneman, 1973). On this view, adults affirm improbable events because they have more memories to call on, or because they are better at retrieving relevant memories (see Levy & Anderson, 2002). Conversely, children fail because they do not know of similar events or are less able to retrieve them.

Note that this account differs from a mere-familiarity account, in which events are judged possible if they are already known (Woolley & Ghossainy, 2013). Previous work addressed whether mere familiarity could account for children and adults' beliefs about improbable events by asking whether they had already heard of the events in question. It could not—both groups had never heard of pickle-flavored ice-cream or alligators under beds, yet children denied these events while adults affirmed them (Shtulman, 2009; Shtulman & Carey, 2007). But the present similarity account instead only requires that a sufficiently similar event be identified, regardless of the familiarity of the target event.

While this account has little direct support, there are reasons to believe that it can explain previous findings better than a purely causal account. For instance, children judge events as more possible in distant lands than in the place they live (Bowman-Smith et al., 2019). It seems unlikely that children are somehow more familiar with *how* events might happen in distant lands than at home, so they may instead feel less confident in their memories when reasoning about unfamiliar events in unfamiliar places. Further, adults often judge possible certain events that are

currently *impossible*, such as performing a brain transplant or traversing the Milky Way (Shtulman & Tong, 2013). The circumstances that could enable these events are simply not known, so it is unlikely that adults' judgments are driven by knowledge of how they could happen. Instead, adults may affirm them because they appear similar to known events, such as performing a heart transplant or travelling to the Moon.

This similarity account can also explain children's beliefs about norm violations. Children may deny such violations for the same reason they deny improbable events: they have no memories of similar violations occurring. For instance, they may only know of yellow school buses, so they infer that buses must be yellow. This account may also help explain how children reason about fantasy. Children's reality-bound reasoning towards fantastical worlds and events may reflect a general bias towards familiar events, as children call upon their memories of what they know to have happened in reality. This could explain why they prefer to insert ordinary events into fantastical stories, and why they offer mundane explanations for impossible and extraordinary events.

Overview of Dissertation

The following three chapters advance our understanding of children's beliefs about possibility by adjudicating between the causal-circumstances account and memory-based similarity account of possibility judgment. Together, these chapters will report the results of eight experiments, in which I tested 1,068 children aged 4 to 7. Chapter 2 tests the limits of the causal-circumstances account by probing children's beliefs about the possibility of events in dreams and stories. Chapter 3 directly tests for the presence of a memory-based similarity heuristic in children's possibility judgments. Finally, Chapter 4 investigates whether knowledge of enabling causal circumstances leads children to affirm that improbable events are possible.

Are children reality-prone when reasoning about fantastical worlds?

Chapter 2 investigates children's beliefs about the possibility of improbable and impossible events across dreams, stories, and reality. In the first experiment, 4- to 6-year-olds were simply asked whether different improbable events and impossible events could happen in a dream or real life. The second experiment builds on the first by asking 4- to 7-year-olds whether the same kinds of events are possible in a dream or a story. In the third and final experiment, children were asked whether dream- and story-like impossible events could happen in a dream, a story, and reality.

This series of experiments provides insight into whether children hold nuanced beliefs about different fantastical worlds, and whether their reasoning about these worlds mirrors their understanding of the real world. It also provides insight into how children reason about possibility in general, as the findings point to mechanisms that may drive global inferences of possibility across contexts. Specially, this chapter explores whether children's beliefs about fantasy are in line with the causal-circumstances account, as this account predicts that judgments for events fantastical worlds should reflect intuitions about how events might occur in reality.

Do children use a memory-based similarity heuristic to infer possibility?

Chapter 3 directly investigates whether children rely on their knowledge of what *has* happened to determine what *can* happen. In the first experiment, 4- to 6-year-olds were told either improbable or ordinary facts and asked whether related improbable events can happen. In the second experiment, 5- and 6-year-olds were asked whether the same events are possible after hearing either related or unrelated improbable facts. In the third experiment, 5- and 6-year-olds were told improbable facts before judging whether related improbable and impossible could happen.

Together, these findings speak to two important aspects of children's reasoning about possibility. First, they show whether children will affirm improbable events as possible if they know of a similar event—even if the circumstances that could enable these events remain mysterious or unclear. Second, they probe the extent to which children are willing to deploy this heuristic by testing whether their judgments are constrained by knowledge of deeper principles rendering certain outcomes impossible.

Are children's beliefs about possibility explained by limitations in causal knowledge?

Chapter 4 turns to the causal-circumstances account for possibility inferences, and tests whether children will affirm improbable events as possible if they are told *how* they might happen. In Experiment 1, 4- to 7-year-olds were told either causal or noncausal information about ordinary events before being asked whether related ordinary events, improbable events, and impossible events could happen. In Experiment 2, 5- and 6-year-olds were told either 1) how ordinary events could happen, 2) how improbable events could happen, or 3) merely the fact that an improbable event occurred.

These findings directly address the role of enabling causal information in children's possibility judgments. They also explore the relative influence of causal information and knowledge of similar events, providing insight into how these strategies jointly work to shape children's beliefs about possibility.

Chapter Two: Children’s beliefs about possibility in dreams and stories are constrained by their beliefs about reality (Paper One)

A version of this paper is published:

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It is impossible for a person to soar through the air unaided by modern technology, or to gain and use magical powers. Yet many people experience these events firsthand, as both are common in the dreams of adults around the world (e.g., Canada, Germany, and China; see Nielsen et al., 2003; Schredl, Ciric, Götz, & Wittmann, 2004; and Yu, 2008 respectively). People regularly encounter these events in worlds of fiction as well. Some of the highest grossing books and films of all time (e.g., Harry Potter, The Avengers) feature characters that fly and use magic, and do so amidst a flurry of other equally reality-defying events. Adults easily affirm that such events are possible in dreams and fiction, but impossible in real life. This shows that adults hold restricted beliefs that are specific to the particular world (real, dream, or fictional) under consideration.

It is unclear, though, whether younger children also consider the world in which an event is embedded (dream, story, reality) when determining if it can occur in that world. Here we contrast two theoretical perspectives. One is that children are reality-prone and judge similar things to be possible in dreams, stories and reality. Children’s knowledge of familiar real events is believed to make them skeptical about counterintuitive entities and events (Shutlman, 2009; Shtulman & Carey, 2007), and constrains their reasoning about fiction (e.g., Sobel & Weisberg, 2014; Weisberg, Sobel, Goodstein, & Bloom, 2013), their enactment of pretense (e.g., Van de Vondervoort & Friedman, 2017), and even their imaginations (e.g., Lane, Ronfard, Francioli, & Harris, 2016). So perhaps children’s knowledge of familiar real events also limits their beliefs

about what is possible in dreams and stories. This theoretical perspective is inspired by Lane et al.'s (2016) *causal constraints* account, which contends that children often fail to imagine events when they are unaware of a causal mechanism that would enable it to occur.

The other perspective is that children consider the world in which an event occurs, and judge different events to be possible in fantasy worlds than in the real world. Differing judgments across worlds would show that children are not wholly constrained by their real-world knowledge when reasoning about fantastical worlds. It would also further demonstrate that children consider environment and context when deciding if an event is possible (Bowman-Smith, Shtulman, & Friedman, 2019; Dias & Harris, 1988; Richards & Sanderson, 1999).

Children as Reality-Prone Reasoners

We know that children are highly conservative in their judgments about what is possible in the real world. They deny the possibility of not only impossible events, but improbable events as well. For 4-year-olds, having a pet lion is almost as impossible as walking through a brick wall, while for adults it is almost as possible as wearing a baseball cap. Children adopt broader beliefs about whether events are possible as they age, but it is not until adulthood that people largely accept that improbable events can happen (Shtulman & Carey, 2007). This pattern of findings has proven robust (Cook & Sobel, 2011; Lane, Ronfard, & El-Sherif, 2018; Lane, Ronfard, Francioli, & Harris, 2016; Nancekivell & Friedman, 2017; Nolan-Reyes, Callanan, & Haigh, 2016; Shtulman, 2009; Shtulman & Phillips, 2018; Weisberg & Sobel, 2012).

Children's bias towards reality-prone reasoning may leave them insensitive to the world in which an event occurs. Children use their real-world causal knowledge to judge that some unfamiliar events are not possible (Schult & Wellman, 1997; Sobel, 2004; Cook & Sobel, 2011; Shtulman & Carey, 2007; Shtulman, 2009). But they might likewise use this knowledge to judge

these events cannot happen in stories and dreams. This would lead to possibility judgments that are similar across reality and fantasy. Broadly consistent with this, children are often reality-prone when reasoning about fantastical worlds. Whereas adults often continue an overtly fantastical story with more fantastical events, children instead continue the story with realistic events (Weisberg et al., 2013). Children offer realistic explanations for fantastical events (e.g., buying a pet unicorn at a pet store), despite also believing that the events are impossible (Nancekivell & Friedman, 2017). Even when asked to simply close their eyes and imagine an impossible event (e.g., walking through a brick wall), children often report that they are unable to do so, or that they imagined a possible event instead (e.g., walking around a brick wall; Lane et al., 2016). Together, these findings suggest that children might apply realistic principles indiscriminately across realistic and fantastical contexts.

Children as Differentiators Between Reality and Fantasy

Alternatively, children's judgments about what is possible may vary across worlds, and may be less conservative when the events are framed as occurring in a fantasy world rather than reality. Despite their tendency towards reality-prone reasoning, children draw a firm distinction between reality and fantasy (Samuels & Taylor, 1994; Woolley & Ghossainy, 2013). For example, from age 5 children judge characters who perform impossible feats to be fictional, rather than from history (Corriveau, Kim, Schwalen, & Harris, 2009), and from age 6, children judge that fantastical characters are more likely to perform acts that violate real-world causal principles (e.g., walking through a wall instead of using a door) than real people (Boerger, 2011). Further, children are less likely to view an antisocial event (e.g., kicking a friend) as unacceptable when it occurs in a fantastical context as compared to real life (Fast & Van Reet, 2018). So, while children may exhibit more reality-prone reasoning than adults, they do not

expect real and fantastical worlds to mirror each other. They may therefore accept that even impossible events can occur in fantastical worlds, while denying that improbable events can occur in the real world.

Previous work has shown that children show some appreciation that impossible events can be dreamt or imagined. For instance, Wellman & Estes (1986) and Woolley & Wellman (1992) found that 3- to 5-year-olds believed that they could both think and dream about impossible events such as a pencil that cries or an apple that dances. Importantly, however, all but one of the events featured anthropomorphism, and children may more readily accept anthropomorphic events than other violations of their real-world knowledge (Van de Vondervoort & Friedman, 2017; also see Lane, Wellman, & Evans, 2010). Indeed, this may explain why children accepted the possibility of thinking and dreaming about anthropomorphic impossible events, whereas Lane et al. (2016) found that children could not even visualize other impossible events.

We tested between these alternative theories in three experiments. Experiment 1 compares children's possibility judgments in reality and dreams; Experiment 2 compares judgments about dreams and stories; and Experiment 3 compares judgments across all three worlds.

Experiment 1

Method

Participants. We first asked 90 children about whether events could occur in dreams: 30 4-year-olds ($M = 4;5$ [years;months], range = 4;0-4;11, 16 girls), 30 5-year-olds ($M = 5;5$, range = 5;0-5;11, 14 girls), and 30 6-year-olds ($M = 6;5$, range = 6;0-6;11, 17 girls). We then asked a further 90 children whether the same events could occur in reality: 30 4-year-olds ($M = 4;8$,

range = 4;3-4;11, 10 girls), 30 5-year-olds (M = 5;5, range = 5;0-5;11, 13 girls), and 30 6-year-olds (M = 6;3, range = 6;0-6;9, 15 girls). One additional child did not respond to the questions and was therefore replaced.

For all experiments, we sought to test 30 children per age-in-years per between-subject condition; this number was in keeping with our lab-wide stopping rule when these data were collected. Children were recruited and individually tested at childcare centers and elementary schools. Demographics were not formally collected, but most children were from middle-class families in the region of Waterloo (Ontario, Canada). Approximately 85% of residents in this region are Caucasian, and the largest visible minority groups are of Chinese and South Asian descent. All studies received approval from the Office of Research Ethics at the University of Waterloo.

Materials and procedure. In all experiments, children heard descriptions of events that were each accompanied by a related photo shown on a laptop computer; see Figure 2 for all events and photos. For the dream condition, children were first asked if they were familiar with dreams (“Do you ever have dreams? And do you ever remember your dreams?”). Children then heard about twelve events and judged if the events could happen in a dream (“I’m going to tell you a bunch of things, and I want to know if they could happen in a dream. OK?”). We asked about three types of events (with four events per type): improbable events (e.g., “In a dream, could a person have a pet peacock?”), physically impossible events, hereafter called “impossible” events (e.g., “...walk through a brick wall?”), and logically impossible events,

hereafter called “illogical” events (e.g., “...draw a circle that’s also a square?”).¹ Events were presented in one of two pseudorandom orders.

Experiments 1 & 2

In [a dream, a story, real life], could a person...

Have a pet peacock?



Walk through a brick wall?



Be sitting down and standing up at the same time?



Turn into a fish?



Have a cup full of milk that’s also empty at the same time?



Have a beard that grows to the ground?



Draw a circle that’s also a square?



Have an invisible dog?



Paint polka dots on a plane?



Eat pickle flavored ice-cream?*



Have a shirt that’s both red all over and green all over?*



Grow money on a tree?*



Experiment 3

In a dream, a story, & real life, could a person...

Ride a magic bicycle?



Suddenly turn into a different person?



Find a room in their house that wasn’t there before?



Meet a talking squirrel?



Jump off the ground and fly through the sky?



Find a castle made of clouds?



Figure 2. Events and pictures from all experiments (starred items were not included in Experiment 2). Events are arranged in one of two trial orders. Also in Experiment 3, children were asked about each world in one of three orders: dream, story, reality; reality, story, dream; story, reality, dream.

¹ Our main interest was in children’s judgments about improbable and impossible events. However, we included illogical events as a precaution to rule out a possible “yes” bias, in case children always affirmed that impossible events could happen in dreams.

The procedure for the reality context was identical, except the inquiry about dreams was excluded, and children were instead asked whether the events could happen in “real life” (e.g., “I’m going to tell you a bunch of things, and I want to know if they could happen in real life... In real life, could a person have a pet peacock?”).

Results and Discussion

In all experiments, the main analyses used Generalized Estimating Equations models (binary logistic) with independent covariance matrices. We first report the effects of world and event-type, and follow with effects of age. For further clarity, we also report single-sample tests against chance; see Table 1. The data for all experiments is available [here](#).

We entered world (dream, reality), event-type (improbable, impossible, illogical), and age (4, 5, 6) as predictors of children’s possibility judgments. We found a main effect of world, Wald $\chi^2(1) = 48.00, p < .001$, as children believed more events could happen in a dream than in reality, $ps < .001$. We also found a main effect of event-type, Wald $\chi^2(2) = 80.56, p < .001$, as children judged that more improbable events could happen than impossible or illogical events, $ps < .005$. However, these effects were qualified by an interaction, Wald $\chi^2(2) = 18.20, p < .001$; see Figure 3. For dreams, children judged that more improbable events could happen than impossible or illogical events, $ps < .001$, but judged that a similar number of impossible and illogical events could happen, $p = .197$. For reality, children again judged that more improbable events could happen than impossible or illogical events, $ps \leq .005$, but also judged that more illogical events could happen than impossible events, $p = .003$.

The main effect of age was only marginally significant, Wald $\chi^2(2) = 4.73, p = .094$, though we found a significant interaction between age and event-type, Wald $\chi^2(4) = 12.78, p = .012$; see Figure 4. At all ages, children judged that more improbable events could happen than

impossible events, $ps < .001$. However, only 5- and 6-year-olds judged that more improbable events could happen than illogical events, $ps \leq .007$. Also, whereas 4-year-olds judged that a similar number of improbable and illogical events could happen, $p = .176$, 5- and 6-year-olds judged that more improbable than illogical events could happen, $ps \leq .007$. The interaction between age and context was only marginally significant, $p = .070$, as was the 3-way interaction between context, event type and age, $p = .097$, so we do not consider them further.

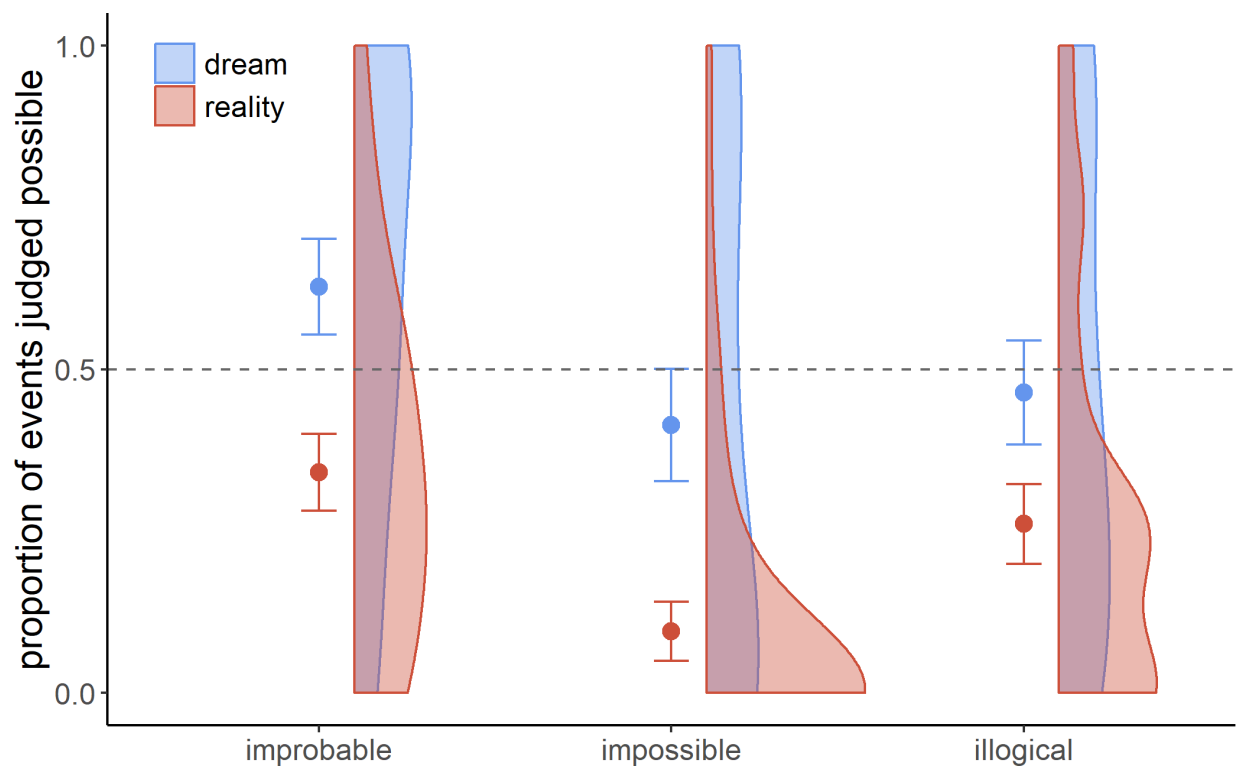


Figure 3. Flat violin plot showing the proportion of improbable, impossible, and illogical events children judged possible in dreams and reality (Experiment 1). Dots and whiskers show means and 95% confidence intervals.

Single sample tests against chance showed that 5- and 6-year-olds mostly agreed that improbable events could happen in dreams, $ps \leq .033$, and that children at all ages mostly disagreed that any event could happen in reality, $ps \leq .049$. No other judgments differed from chance, $ps \geq .096$; see Table 1 for all comparisons.

Table 1. Single-sample tests against chance for children’s judgments in Experiments 1 and 2.

The table shows means with standard deviations in parentheses, followed by *p*-values for each comparison.

Experiment	World	Event	4-year-olds	5-year-olds	6-year-olds	7-year-olds				
1	Dream	Improbable	.60 (.49)	.148	.63 (.49)	.033	.66 (.48)	.036		
		Impossible	.40 (.49)	.216	.39 (.49)	.096	.45 (.50)	.545		
		Illogical	.53 (.50)	.662	.42 (.50)	.176	.44 (.50)	.405		
	Reality	Improbable	.39 (.49)	.049	.30 (.46)	.001	.33 (.47)	.001		
		Impossible	.17 (.38)	<.001	.10 (.30)	<.001	.02 (.13)	<.001		
		Illogical	.36 (.48)	.031	.23 (.42)	<.001	.20 (.40)	<.001		
2	Dream	Improbable	.56 (.50)	.345	.44 (.50)	.425	.71 (.46)	.001	.77 (.43)	.001
		Impossible	.39 (.49)	.088	.33 (.47)	.037	.48 (.50)	.780	.72 (.45)	.008
		Illogical	.46 (.50)	.577	.31 (.47)	.008	.26 (.44)	.004	.42 (.50)	.357
	Story	Improbable	.41 (.49)	.175	.49 (.50)	.934	.43 (.50)	.338	.67 (.47)	.023
		Impossible	.22 (.42)	.001	.21 (.41)	<.001	.19 (.39)	<.001	.41 (.49)	.303
		Illogical	.39 (.49)	.155	.24 (.43)	.001	.24 (.43)	<.001	.30 (.50)	.022

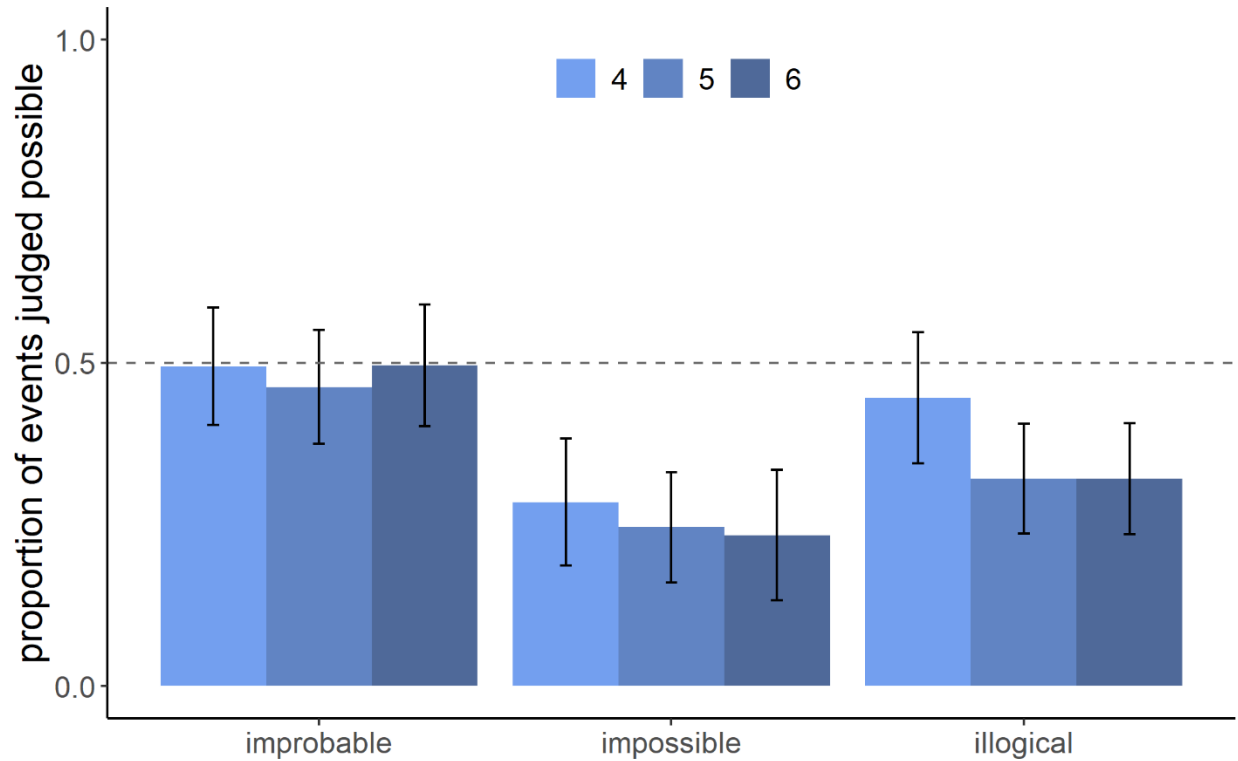


Figure 4. Bar plot showing the proportion of improbable, impossible, and illogical events judged possible by children at each age. The plot shows children’s judgments collapsed across dreams and reality. Whiskers show 95% confidence intervals.

These findings show that children do not reason realistically about what can happen in a dream. Instead, they also consider the world in which the event occurs. However, it is unclear whether children’s judgments in Experiment 1 reflect beliefs specific to dreams, or instead reflect general beliefs about possibility in fantastical or unreal worlds. In Experiment 2, we explore this by comparing children’s judgments about possibility in the fantastical worlds of dreams and stories.

Experiment 2

Method

Participants. We tested 229 children. For the dream condition, we tested 30 4-year-olds ($M = 4;7$, range = 4;1-4;11, 12 girls), 30 5-year-olds ($M = 5;7$, range = 5;1-5;11, 14 girl), 30 6-

year-olds ($M = 6;6$, range = 6;1-6;11, 11 girls), and 26 7-year-olds ($M = 7;3$, range = 7;0-7;11, 13 girls). For the story condition, we tested 30 4-year-olds ($M = 4;8$, range = 4;1-4;11, 17 girls), 30 5-year-olds ($M = 4;7$, range = 5;0-5;11, 18 girls), 30 6-year-olds ($M = 6;6$, range = 6;0-6;11, 13 girls), and 23 7-year-olds ($M = 7;3$, range = 7;0-7;11, 12 girls). Children were randomly assigned to either the dream or story condition. As noted above, we aimed to test 30 children per cell. However, we were unable to do so for 7-year-olds before ending data collection for the season.

Materials and procedure. The procedure was similar to Experiment 1. Children judged whether three kinds of events (improbable, impossible, illogical) could happen in one of two worlds: in a dream, or in a story. Children were first asked if they were familiar with the given world (“Do you know about dreams, like dreams you have when you’re asleep?”; “Do you know about stories, like stories in books?”). They then heard about nine events, each accompanied by a related photo, and judged whether the event could happen in the given world. Events were presented in one of two pseudorandom orders.

Results and Discussion

We entered world (dream, story), event-type (improbable, impossible, illogical), and age (4, 5, 6, 7) as predictors of children’s possibility judgments. We found a main effect of world, Wald $\chi^2(1) = 10.27$, $p = .001$, as children judged that more events could happen in a dream than a story. We also found a main effect of event-type, Wald $\chi^2(2) = 112.88$, $p < .001$, as children judged that more improbable events could happen than impossible or illogical events, $ps \leq .001$. However, these effects were qualified by an interaction, Wald $\chi^2(2) = 12.89$, $p = .002$; see Figure 5. For dreams, children judged that more improbable events could happen than impossible or illogical events, $ps < .001$, and that more impossible events could happen than illogical events, p

= .001. For stories, children judged that more improbable events could happen than impossible and illogical events, $ps < .001$, but judged that a similar number of impossible and illogical events could happen, $p = .174$.

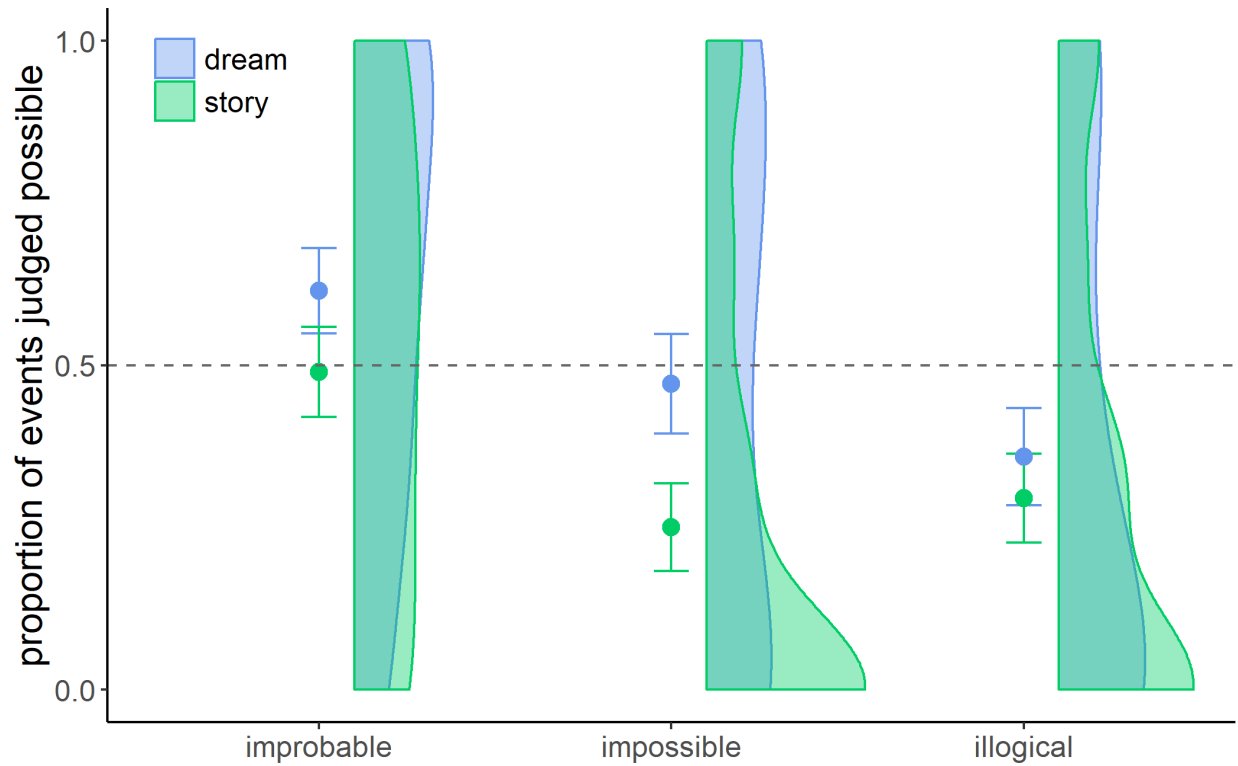


Figure 5. Flat violin plot showing the proportion of improbable, impossible, and illogical events children judged possible in dreams and stories (Experiment 2). Dots and whiskers show means and 95% confidence intervals.

We also found a main effect of age, Wald $\chi^2(3) = 11.47, p = .009$, which was qualified by an interaction with event-type, Wald $\chi^2(6) = 32.49, p < .001$; see Figure 6. These effects had two principle causes. First, in comparison to children at all other ages, 7-year-olds more often judged that improbable and impossible events could happen, $ps \leq .036$. There were no age-related differences for these items between younger ages, $ps \geq .105$. Second, in comparison with 5-6-year-olds, 4-year-olds more often judged that illogical events could happen, $ps \leq .042$. Their

judgments did not differ from those of children aged 7, $p = .447$. All other effects were non-significant, $ps \geq .123$.

Single sample tests against chance showed that for dreams, 6- and 7-year-olds mostly agreed that improbable events could happen, $ps = .001$, and 7-year-olds mostly agreed that impossible events could happen, $p = .008$. Also, 5-year-olds mostly disagreed that impossible and illogical events could happen, $ps \leq .037$, and 6-year-olds mostly disagreed that illogical events could happen, $p = .004$.

For stories, 7-year-olds mostly agreed that improbable events could happen, $ps < .023$. Also, 4- to 6-year-olds mostly disagreed that impossible events could happen, $ps \leq .001$, and 5- to 7-year-olds mostly disagreed that illogical events could happen, $ps \leq .022$. No other judgments differed from chance; see Table 1 for all comparisons.

These findings show that children do not have general beliefs about what is possible in fantastical worlds, and appear to hold more nuanced beliefs about possibility that are specific to different worlds.

Overall, the findings so far suggest that children are most permissible for dreams, and least permissible for reality, with judgments about stories falling in between. This conclusion, though, relies on combining findings from separate experiments (i.e., Experiment 1 compared judgments about reality and dreams, while Experiment 2 compared dreams and stories). We therefore conducted a final experiment to see if this pattern in children's possibility judgments would replicate in a single study using a within-subjects design. We also wanted to know whether this pattern would generalize to other items. Our first two experiments used items based on those from previous investigations of children's possibility judgments (e.g., Lane et al., 2016; Shtulman & Carey, 2007). In our final experiment, we generated new items inspired by common

events in dreams (e.g., Honig & Nealis, 2012; Schredl, Ciric, Götz, & Wittmann, 2004) and fantasy stories (Thompson, 1958). We tested only 5- and 6-year-olds because their judgments about whether impossible events could happen did not differ from those of 4-year-olds in the first two experiments (see Figures 4 and 6), and because we did not previously observe any interactions between age and world that would lead us to predict a different pattern of results across age groups.

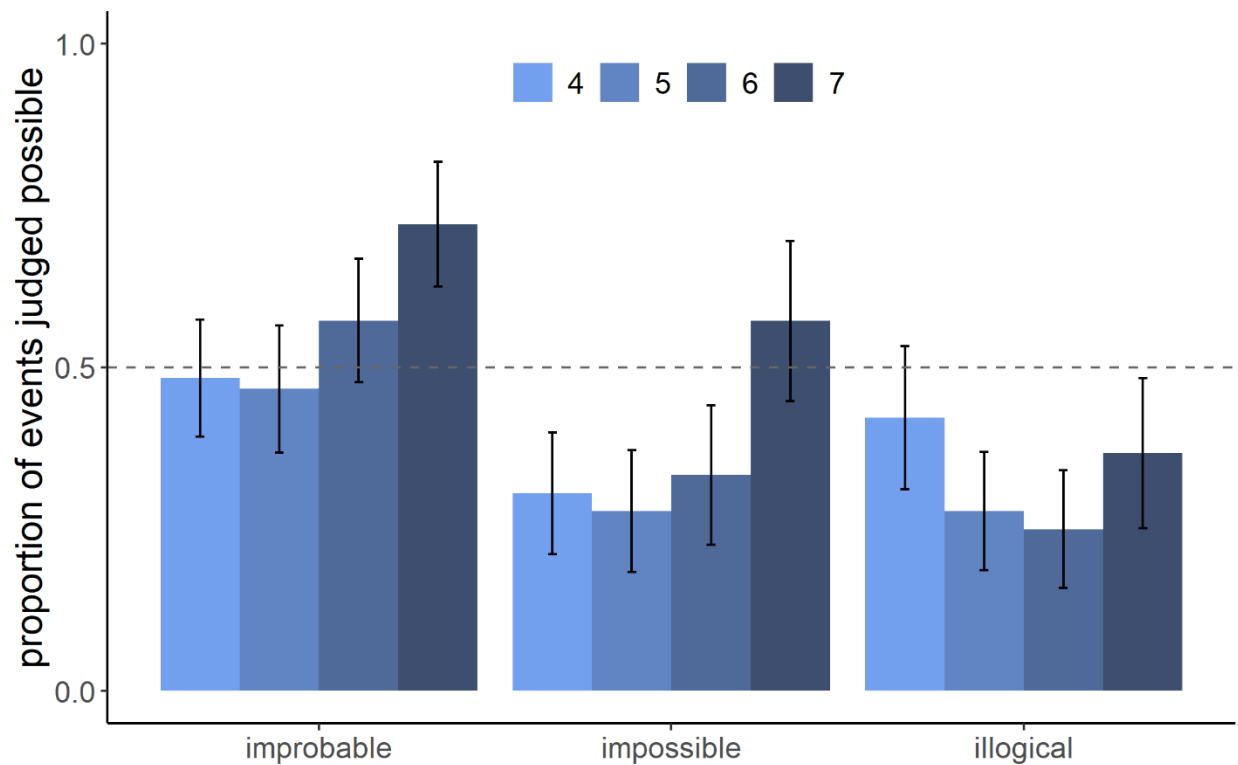


Figure 6. Bar plot showing the proportion of improbable, impossible, and illogical events judged possible by children at each age. The plot shows children’s judgments collapsed across dreams and stories. Whiskers show 95% confidence intervals.

Experiment 3

Method

Participants. We tested 30 5-year-olds ($M = 5;5$, range = 5;0-5-11, 14 girls) and 30 6-year-olds ($M = 6;5$, range = 6;0-6-10, 18 girls).

Materials and procedure. Children were first asked if they were familiar with dreams and stories (“Do you know about dreams, like dreams you have when you’re asleep? And do you know about stories, like stories in books?”). Children then heard about six physically impossible events typical of those encountered in dreams and stories (e.g., meeting a talking squirrel, flying through the sky). Children were asked three separate questions about each event, concerning whether it could happen in a dream, in a story, or in reality (i.e., 18 judgments in total). Children were randomly assigned to hear about events in one of two orders, and answered questions in one of three orders.

We verified that these events are more dream- and story-like than those used in our previous experiments by obtaining judgments from 115 adults via Amazon’s Mechanical Turk, $p < .001$ (see Appendix A).

Results and Discussion

We entered world (dream, story, reality) and age (5, 6) as predictors of children’s possibility judgments. We found main effects of world, Wald $\chi^2(2) = 98.24$, $p < .001$, and age, Wald $\chi^2(1) = 6.13$, $p = .013$, but no interaction, Wald $\chi^2(2) = .46$, $p = .795$; see Figure 7. Children thought more events could happen in dreams than in stories or reality, $ps \leq .034$, and that more events could happen in a story than in reality, $p < .001$. Also, 6-year-olds were more likely than 5-year-olds to judge that events could happen in any world, $p = .012$.

Single sample tests showed that children at both ages mostly agreed that the events could happen in a dream, $ps \leq .019$, but could not happen in reality, $ps \leq .001$. Also, 6-year-olds mostly agreed that the events could happen in a story, $p = .002$, whereas 5-year-olds’ judgments about this did not differ from chance, $p = .180$.

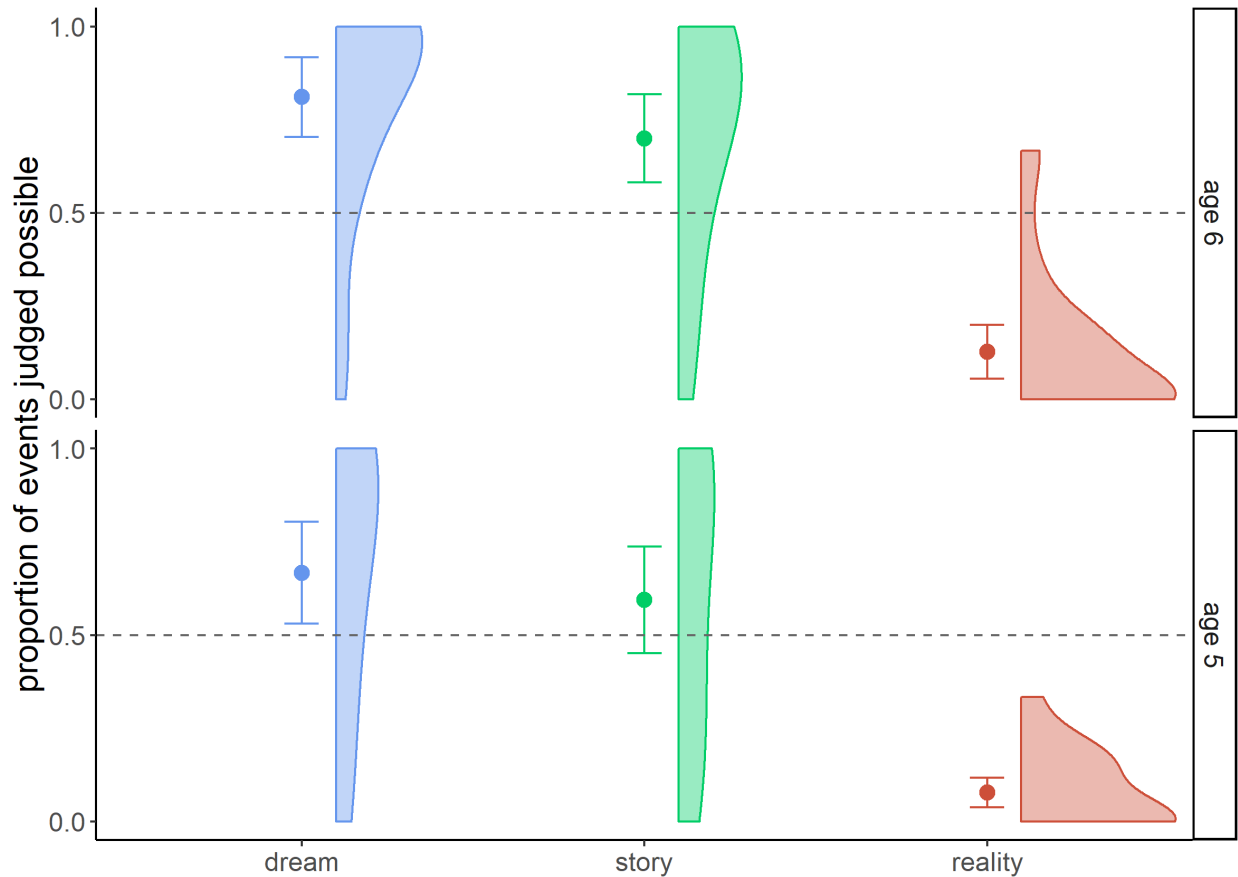


Figure 7. Dual-panel flat violin plot showing the proportion of events judged possible at each age for dreams, stories, and reality (Experiment 3). Dots and whiskers show means and 95% confidence intervals.

The findings show that children judge that even impossible events can occur in dreams and stories when the events are typical of those worlds. We also extend our previous findings by again showing that children believe more events to be possible in dreams than in stories, though more events are possible in either fantasy world than in reality.

General Discussion

We found that children’s judgments about whether an event is possible depend on whether it occurs in a dream, a story, or reality. In Experiment 1, children judged that events were more possible in dreams than in reality, though they endorsed the possibility of improbable events more than impossible events in both worlds. In Experiment 2, children also judged that

events were more possible in dreams than in stories. Finally, in Experiment 3 children often judged impossible events to be possible within dreams and stories when the events were more typical of those worlds.

Our findings extend knowledge of how children conceive of dreams and stories. Earlier work examined children's understanding that dreams and stories are distinct from reality (e.g., Woolley, 1995; Woolley & Cox, 2007; also see Woolley & Boerger, 2002), and children's preferences when constructing their own fictional narratives (Sobel & Weisberg, 2014; Weisberg & Sobel, 2012). However, to our knowledge, only two studies directly examined children's beliefs about what is possible within the worlds of dreams, and these studies focused primarily on anthropomorphic events (Wellman & Estes, 1986; Woolley & Wellman, 1992).

We found that children do not apply realistic principles indiscriminately and universally when deciding whether events are possible in fantastical worlds. If children only relied on real-world principles (e.g., causal knowledge), their judgments should have been similar across worlds. For instance, children should have denied that a person could have a pet peacock in both dreams and stories, as well as in reality. Instead, children were more likely to judge that such events could occur in a fantasy world than in reality.

Further, children distinguished *between* fantastical worlds, as they judged more events to be possible in dreams than in stories. This suggests that children hold nuanced beliefs about each world (Skolnick & Bloom, 2006; Weisberg & Bloom, 2009), and that these beliefs influence their possibility judgments. For instance, children may view dreams as being more distant from reality than stories, leading them to endorse more events as possible in this more distant world (Weisberg & Goodstein, 2009). Note that we did not specify the genre of fiction—we only asked

about “stories in books”. So children might be as permissive in their judgments for some genres of fiction (e.g., fantasy, fairy tales) as they are for dreams (Kibbe, Kreisky, & Weisberg, 2017).

Still, the findings of the first two experiments suggest that children show traces of realistic thinking even when considering dreams and stories. Though children more often judged that any event could occur within dreams and stories, they showed the same graded pattern of possibility judgments (e.g., improbable events are more likely to happen than impossible ones) that they show in judgments about reality (e.g., Shtulman & Carey, 2007). These consistent distinctions between event-types suggest that children carry some of their intuitions about the real world into fantastical worlds, and support the suggestion that children’s reasoning about fantastical worlds is constrained by their real-world knowledge (Lane et al., 2016). For instance, children may use their real-world knowledge as an anchor for whether an event can occur, and then adjust their inferences based on their beliefs about each world (Tversky & Kahneman, 1974; also see Weisberg & Goodstein, 2009).

However, the findings tell a somewhat different story when children considered impossible events more typical of dreams and stories. In the final experiment, we found that children were more willing to endorse the possibility of impossible events in dreams and stories, while also replicating children’s differentiation between the worlds. For instance, children in the first experiment were hesitant to endorse that a person could walk through a wall within a dream, while children in the final experiment mostly agreed that a person could fly through the sky.

Why were children in this final experiment more permissive in their possibility judgments? One possibility is that allowing children to judge whether the events could happen within all worlds more clearly tapped into their intuitions about the differences between dreams, stories, and reality than when they considered only one world. Indeed, the within-subjects design

used in previous studies of children's beliefs about what they can dream and image may have contributed to their high rates of agreement towards impossible events (Wellman & Estes, 1986; Woolley & Wellman, 1992).

A more interesting possibility is that children determined whether an event could occur by recalling whether they had previously encountered it—or a similar event—in *that* particular world. Beards that grow to the ground and invisible dogs may be rare in dreams and stories, but castles made of clouds and talking squirrels are more typical of the events commonly encountered in these worlds (see Appendix A). As such, children may have been more familiar with the kinds of events used in the final experiment than those from the first experiments, leading them to more often endorse the events as possible (also see Woolley, Boerger, & Markman, 2004). On this view, children infer possibility by using an availability heuristic specific to the world under consideration (Tversky & Kahneman, 1973; Bowman-Smith et al., 2019).

This account may seem trivial, as it suggests that children's beliefs about possibility in dreams and stories are largely driven by familiarity. However, this account has important implications for how children infer possibility in the real world. Children's denial that improbable events can happen in the real world is widely believed to stem from limits in their causal understanding (Schult & Wellman, 1997; Sobel, 2004; Cook & Sobel, 2011; Shutlman & Carey, 2007; Shutlman, 2009). For example, children may deny that a person can have a pet peacock because they cannot conceive of how one would be acquired or cared for. The present findings suggest that mere unfamiliarity also contributes to children's denials that events are possible. The final experiment suggests this by showing that children are likely to endorse the possibility of events when the events are typical of a particular world—even if the events are

impossible. (Indeed, children may have judged the atypical events of the first two experiments as more possible within dreams and stories because of their general familiarity with other strange events within these worlds.)

Returning to children's judgments about what is possible in the real world, children may agree that a person can wear a baseball cap because they have seen this, but deny that a person can have a pet lion because they have not. While it remains likely that causal knowledge contributes to the consistent age-related increase in children's judgments that improbable events can happen (e.g., Shtulman & Carey, 2007), we contend that the *typicality* of an event may also contribute to children's beliefs about its possibility in the absence of a richer causal understanding.

Chapter Three: Children judge improbable events possible when they are similar to a known event (Paper Two)

A version of this paper is published:

Goulding, B. W. & Friedman, O. (2021). A similarity heuristic in children's possibility judgments. *Child Development*, 92(2), 662-671. <https://doi.org/10.1111/cdev.13534>

“How many things have been denied one day, only to become realities the next!”
—Jules Verne, *From the Earth to the Moon*

At the turn of the 20th century, a group of French artists produced a series of postcards depicting a vision of what France might look like in the year 2000 (Côté et al., 1910). Their optimistic predictions included flying firemen equipped with wings, a robotic barber, and a long-distance communication device that would allow people to see projections of each other. Almost all of their predictions rested on the advent of technologies that did not yet exist. Yet a cursory glance at the postcards reveals their predictions were fairly limited in scope, and clearly guided by new and familiar technologies like gliders, electricity, and the telephone. The artists likely felt that since these strange and wonderful technologies had recently fallen into the realm of possibility, perhaps similar strange and wonderful things were possible, too.

Here we explore whether a similar intuition drives children's beliefs about what is possible. Specifically, we test whether their knowledge of what *has* happened guides their inferences about what *can* happen, and does so even when the circumstances that would enable events remain mysterious or unclear. This investigation will help us understand the puzzling yet robust finding that children often deny the possibility of improbable events. Drinking onion juice and painting polka dots on a plane are strange and uncommon acts, but they are possible nonetheless. Yet in contrast with adults, 4- to 8-year-olds often judge these events to be almost as impossible as walking through a brick wall or travelling back in time (Shtulman & Carey, 2007). This early skepticism towards the possibility of improbable events has been demonstrated across

a variety of events and study designs (e.g., Lane, Ronfard, Francioli, & Harris, 2016; Nolan-Reyes, Callanan, & Haigh, 2016; Shtulman & Phillips, 2018).

The similarity heuristic in children’s judgements of possibility

Children may judge whether events are possible by using a similarity heuristic. When hearing about an event or outcome, children may search their memory for instances of similar events. If this memory search is successful, children conclude the event can happen. But if the search returns no events similar enough to the target event, children may deny that the event is possible. For ordinary events and circumstances, similar events should be easy to find. For instance, a child who has seen brick houses may also agree that a person could build a house out of stones—even if they have never seen or heard about a stone house—simply because both events are similar enough that the possibility of one suggests the possibility of the other. For improbable events, recalling similar events will be more difficult. After all, improbable events are, by nature, exceedingly rare. So, children may deny the possibility of drinking onion juice and painting polka dots on a plane because they cannot recall sufficiently similar events.

The similarity heuristic can be viewed as a variant of the availability heuristic (Tversky & Kahneman, 1973) for inferring whether events can occur (Bowman-Smith, Shtulman, & Friedman, 2019; Tversky & Kahneman, 1973). It is also consistent with suggestions that familiarity underlies children’s possibility judgments, though this has not been directly investigated (Shtulman & Carey, 2007; Shtulman, 2009; Woolley & Ghossainy, 2013).

An important feature of the similarity heuristic is that it allows children to judge whether an event is possible without ever considering the circumstances that would enable or prevent its occurrence. This contrasts with the assertion that children judge an event to be possible only if they can identify circumstances that would allow it to occur (Shtulman & Carey, 2007). For

instance, children may dismiss the possibility of drinking onion juice simply because they are unable to imagine *how* such a juice could be made. However, when children are asked to generate their own explanations for improbable and impossible events, they often provide realistic explanations while still denying that the events are possible (Nancekivell & Friedman, 2017; Woolley & Cornelius, 2017). So it is unlikely that children rely exclusively on this sort of circumstantial reasoning to determine whether improbable events can happen.

We are not suggesting, though, that children do not use any sort of causal reasoning when inferring possibility. Indeed, children consistently reject the possibility of truly impossible events (Cook & Sobel, 2011; Lane, Ronfard, & El-Sherif, 2018; Shtulman, 2009), likely by referencing their principled knowledge of the world. For instance, children know that solid objects cannot float in the air, and animals of one species cannot give birth to offspring of a different species. They use knowledge of these principles to conclude that specific events are impossible (Schult & Wellman, 1997; Sobel, 2004), and believe that magic would be required to bring about events that violate these principles (Johnson & Harris, 1994; Phelps & Woolley, 1994; Rosengren & Hickling, 1994; Rosengren, Kalish, Hickling, & Gelman, 1994). We should therefore expect children to reject the possibility of impossible events, even if they can recall superficially similar events.

We investigated the similarity heuristic across three experiments. Experiment 1 compares 4-6-year-olds' possibility judgements for improbable events after hearing improbable or ordinary facts that are related to the test events. Experiment 2 compares 5-6-year-olds' possibility judgements for improbable events after hearing improbable facts that are related or unrelated to the test events. Finally, Experiment 3 compares 5-6-year-olds' possibility judgements for both

improbable and impossible events after hearing improbable facts that are related to the test events.

Experiment 1

Method

Participants. We tested 120 4- to 6-year-olds ($M = 5;6$ [years;months], range = 4;0-6;11, 62 girls). In this experiment and the next one, we aimed to test 20 children per age-in-years per between-subjects condition, and randomly assigned equal numbers of children at age-each-in-years to each condition. We determined this sample size as it has sufficed to reveal significant effects in past work in this area of research.

Children were recruited and individually tested at childcare centers and elementary schools. Demographics were not formally collected, but most children were from middle-class families in the region of Waterloo (Ontario, Canada). Approximately 85% of residents in this region are Caucasian, and the largest visible minority groups are of Chinese and South Asian descent. All studies received approval from the Office of Research Ethics at the University of Waterloo.

Materials and procedure. In all experiments, children were shown photos on a laptop, with accompanying narrations from the experimenter; see Figure 8 for an illustration of the full procedure for each experiment. Children completed six trials. In each trial, they heard facts about people and were shown a photo demonstrating that the fact was true. Children completed the trials in one of two between-subjects conditions. In one condition the facts were improbable, and in the other condition they were ordinary. After hearing each fact, children were asked if a related improbable event was also possible. For example, children were either shown and told

facts

events

Exp 1



Here's a person, and they have a pet [elephant/dog]. See?
This [elephant/dog is actually their pet!]

drink [broccoli / orange] juice
wear [pajamas / suit] to work
have [striped / white] plane
eat [pickle- / strawberry-] flavored popsicle
have [shoe- / square-] shaped house



So, could a person also have a pet zebra?

drink cauliflower juice
wear costume to work
have polka dot plane
eat onion-flavored popsicle
have mug-shaped house

Exp 2



Here's a person, and they have a pet elephant. See?
This elephant is actually their pet!

drink broccoli juice
wear pajamas to work
have striped plane
eat pickle-flavored popsicle
have shoe-shaped house



So, could a person also have a [pet zebra/polka dot plane?]

[drink cauliflower juice/eat onion-flavored popsicle]
[wear costume to work/have mug-shaped house]
[have polka dot plane/have pet zebra]
[eat onion-flavored popsicle/drink cauliflower juice]
[have mug-shaped house/wear costume to work]

Exp 3



Here's a person, and they have a pet elephant. See?
This elephant is actually their pet! So now I have
some questions for you.

drink broccoli juice
wear pajamas to work
have striped plane

Could a person also have a pet zebra? Could a person
also have a pet unicorn?

drink cauliflower juice & drink lightning juice
wear costume to work & wear cloud to work
have polka dot plane & have invisible plane

Figure 8. Sample stimuli and scripts for all experiments, as well as a full list of the facts and events used in each. The full set of stimuli can be viewed [here](#). Children in Experiments 1 and 2 saw a photo related to each test question, whereas children in Experiment 3 saw only a blank screen at test. Trials were administered in the order listed, or in the reverse order. For Experiment 3, improbable (i) and impossible (I) events were asked about in two orders: iIiI and IiIi.

that a person could have a pet elephant (improbable) or dog (ordinary) and then asked: “So, could a person also have a pet zebra?”

The similarity account predicts that children who hear improbable facts will judge more improbable events to be possible than children who hear ordinary facts, as the mere possibility of the improbable facts may suggest that similar improbable events are also possible.

Results

In all experiments, the main analyses used generalized estimating equations models (binary logistic) with independent covariance matrices performed using “geepack” for R (Halekoh, Højsgaard, & Yan, 2006); any post-hoc pairwise comparisons were performed using the “emmeans” package for R (Lenth, Singmann, Love, Buerkner, & Herve, 2019). Figure 9 shows the proportion of events judged possible by children in all experiments. The data for all experiments can be found [here](#).

We entered fact-type (improbable, ordinary) and age-in-months (mean-centered) as predictors of children’s judgements about whether improbable events were possible. We found a main effect of fact-type, Wald $\chi^2(1) = 9.59, p = .002$, and a main effect of age, Wald $\chi^2(1) = 13.65, p = .002$, but these effects were qualified by an interaction, Wald $\chi^2(1) = 6.43, p = .011$. We explored this interaction by analyzing the effect of age separately for each fact-type. At all ages, children made similar judgements about whether improbable events were possible after hearing improbable facts, Wald $\chi^2(1) = 0.01, p = .931$, but were less likely with age to agree that improbable events were possible after hearing ordinary facts, Wald $\chi^2(1) = 13.65, p < .001$. We then analyzed the effect of fact-type separately for each age group (4-year-olds, 5-year-olds, 6-year-olds). Both 5- and 6-year-olds more often agreed that improbable events could happen after hearing improbable facts than after hearing ordinary facts, Wald $\chi^2(1) = 4.78, p = .029$ and Wald

$\chi^2(1) = 12.30, p < .001$, but this effect was absent in 4-year-olds' judgments, Wald $\chi^2(1) = 0.00, p > 0.999$.

Consistent with use of the similarity heuristic, 5-6-year-olds were more likely to endorse the possibility of improbable events if they heard about similar improbable facts than if they heard about related ordinary facts. However, 4-year-olds were similarly willing to endorse the possibility of an improbable event after hearing *any* fact. Their results are surprising given that younger children are often especially hesitant to endorse the possibility of improbable events (e.g., Shtulman & Carey, 2007).

Use of the similarity heuristic should lead children to judge whether events are possible by asking themselves if they know about similar events. Hence, they should affirm the possibility of improbable events more often if they learn about related improbable events than unrelated improbable events. Our next experiment tested this prediction in 5-6-year-olds. We did not test 4-year-olds because Experiment 1 suggested their possibility judgments were not influenced by knowledge of similar or dissimilar events.

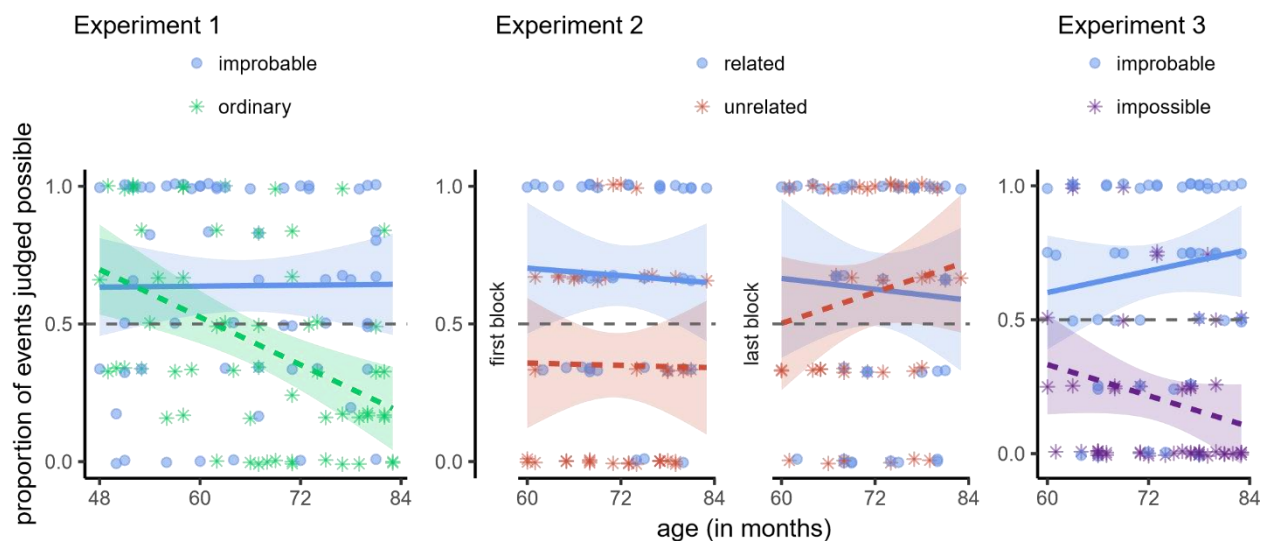


Figure 9. Scatterplots with trendlines showing proportion of events judged possible by each child as a function of their age in months in all experiments. Bands show 95% confidence intervals. Points are jittered slightly to decrease overplotting.

Experiment 2

Method

Participants. We tested 80 5 and 6-year-olds ($M = 6:0$, range = 5;0-6;11, 38 girls). One additional child did not respond to our questions was therefore replaced.

Materials and procedure. Children completed six trials in one of two between-subjects conditions; see Figure 8. In each trial, they heard improbable facts about people and were shown a photo demonstrating that the fact was true. In one condition, they were then asked about the possibility of a related improbable event. For example, children were told and shown that a person could have a pet elephant and then asked: “So, could a person also have a pet zebra?” This condition served as a replication of the improbable-fact condition from Experiment 1. In the other condition, they were instead asked about the possibility of an unrelated improbable event. This condition featured the same facts and events as the related-event condition, but with the pairings shuffled so that the facts were no longer related to the succeeding events. For example, children were told and shown that a person could have a pet elephant and then asked: “So, could a person also have a polka dot plane?”. A consequence of simply rearranging the items from Experiment 1 is that children would inevitably judge the possibility of events related to facts presented in previous trials. We therefore blocked the items such that children’s first three judgments were unrelated to the presented facts, whereas their final three judgments were related to facts presented in the first three trials.

The similarity account predicts that children who hear related facts will judge more improbable events to be possible than children who hear unrelated facts, as only facts that are sufficiently related to the improbable events should be informative about their possibility. Crucially, this difference should be more apparent in children’s first three possibility judgments,

as their last three judgments will be informed by previously presented facts regardless of whether they saw related or unrelated fact-event pairings. Conversely, if children are simply affirming improbable events as possible after hearing any other improbable event, we should find no difference between the influence of related and unrelated facts.

Results

We entered relation (related, unrelated), item-block (first three trials, last three trials), and age-in-months (mean-centered) as predictors of children's judgements about whether improbable events were possible. There was a main effect of relation, Wald $\chi^2(1) = 15.18, p < .001$, as children more often affirmed that improbable events could happen after hearing related rather than unrelated facts. There was also a main effect of item-block, Wald $\chi^2(1) = 28.75, p < .001$, as children more often affirmed that improbable events could happen in the last block than in the first block. However, these main effects were qualified by an interaction, Wald $\chi^2(1) = 17.04, p < .001$. There was no main effect of age, Wald $\chi^2(1) = 0.01, p = .923$, and age did not interact with any other factor, $ps \geq .180$.

We next analyzed the effect of relation separately within each item-block. For the first item-block, there was a main effect of relation, Wald $\chi^2(1) = 14.86, p < .001$, as children who heard about related facts and events were more likely to say that the events were possible than children who heard about unrelated facts and events. This effect was not observed in the last item-block, Wald $\chi^2(1) = 0.04, p = .849$, as children's judgments did not differ across related and unrelated fact-event pairings.

In sum, children were more likely to affirm that improbable events could happen after hearing about related improbable events than after hearing about unrelated ones. This shows that children consider their knowledge of what has happened to be informative about the possibility

of sufficiently similar events, but not other unrelated events. In our final experiment, we test whether children's use of the similarity heuristic is constrained by deeper principles about what is impossible. We do this by asking children about improbable and impossible events that are both related to a given fact.

Experiment 3

Method

Participants. We tested 50 5-6-year-olds ($M = 6;1$, range = 5;0-6;11, 23 girls). We aimed to test 20 children per age, but inadvertently tested an additional 10 6-year-olds. All children are included in our analyses.

Materials and procedure. In four trials, children heard improbable facts and were shown a photo demonstrating that each fact was true. After hearing each fact, all children were asked whether two related events were also possible. One of the events was improbable, and the other was impossible. For example, children were told and shown that a person has a pet elephant and then heard: "OK, now I have some questions for you. Could a person also have a pet zebra? Could a person also have a pet unicorn?".

Results

We entered event-type (improbable, impossible) and age-in-months (mean-centered) as predictors of children's judgements about whether the events were possible. We found a main effect of event-type, Wald $\chi^2(1) = 29.92$, $p < .001$, as children more often affirmed that improbable events could happen than impossible events. There was no main effect of age, Wald $\chi^2(1) = 2.55$, $p = .110$, but there was an interaction between age and event-type, Wald $\chi^2(1) = 5.51$, $p = .019$. We explored this by analyzing the effect of event-type separately for each age group (5-year-olds, 6-year-olds). The effect of event-type remained significant for both age

groups, but the effect was larger in 6-year-olds, $p < .001$, $OR = 0.08$, than in 5-year-olds, $p < .001$, $OR = 0.20$. These findings show that children more often affirmed the possibility of improbable rather than impossible events despite both events being related to a learned fact.

General Discussion

Children judged that improbable events could happen when they were told that similar events had occurred. In Experiment 1, telling children about improbable events made 5-6-year-olds, but not 4-year-olds, likely to judge that similar improbable events could also happen. In Experiment 2, 5-6-year-olds were more likely to affirm that improbable events could happen if told about related improbable events than if told about unrelated ones. Finally, in Experiment 3, children affirmed the possibility of improbable events, but not impossible ones, after hearing about related improbable events. These results are the first to reveal a manipulation leading young children to affirm that improbable events can happen in real life. Recent experiments investigated other manipulations that attenuated children's denials to a degree (Bowman-Smith et al., 2019; Lane et al., 2018), but without shifting children from denying to affirming that improbable events could happen.

These findings suggest that 5- to 6-year-olds use the similarity heuristic to judge whether events are possible. This is consistent with the suggestion that children often reject the possibility of improbable events because the events are too dissimilar from children's own experiences (Shtulman & Carey, 2007; Woolley & Ghossainy, 2013). Our experiments offer the first direct support for this account. Importantly, though, children did not endorse the possibility of impossible events, even after being told about similar improbable events. This shows that besides considering similarity, children's judgments were constrained by awareness of deeper principles making certain outcomes impossible (Schult & Wellman, 1997; Sobel, 2004).

Crucially, we did not provide children with information about the circumstances or causal principles that would have allowed any of the events to occur. For example, we did not tell them how a person could acquire or accommodate a pet elephant. Children therefore had no new causal information to deploy when inferring the possibility of the target impossible events, like having a pet zebra. So our findings are not explained by the suggestion that children infer possibility by identifying circumstances that would allow an event to occur (Shtulman, 2009; Shtulman & Carey, 2007). On this view, knowledge that an improbable event *can* happen should have little influence on children's beliefs about possibility in the absence of further information about *how* the event could have arisen. Our findings contrast with this view, but also do not provide evidence against this account as a strategy for inferring possibility

Nevertheless, the similarity account may help explain findings that are not readily explained by exclusively causal explanations of possibility judgements. For example, it may better explain why children view improbable events as more possible in distant countries than at home, as they may know that their memories are less informative about what might happen in places that are unfamiliar to them (Bowman-Smith et al., 2019). Further, while Shtulman and Carey (2007) found participants of all ages to be equally unfamiliar with their set of improbable events, Shtulman (2009) used a larger and more diverse set of improbable events and found that participants became more likely with age to both encounter the events and to judge them as possible. While these results are mixed, the latter is consistent with our finding that mere exposure to improbable events can lead children to judge that other improbable events can happen.

Two related questions raised by our findings are whether the similarity heuristic is also used by children younger than age 5, and whether its use remains later in development.

Regarding earlier in development, we found that 4-year-olds were similarly willing to endorse the possibility of an improbable event after hearing *any* fact, which is surprising given that younger children are often more hesitant than older children to endorse the possibility of improbable events (e.g., Lane et al., 2016; Shtulman & Carey, 2007). It is therefore possible that the 4-year-olds in our experiments somehow felt pressured to affirm, rather than deny, the possibility of events. However, a different manipulation might show that 4-year-olds, like older children, compare potential events to known events to determine their plausibility. Regarding later development, it might seem that adults should not use the similarity heuristic, perhaps because they have greater knowledge of the causal circumstances that would allow events to occur (Shtulman & Carey, 2007). However, it is likely that adults use it when they have limited knowledge about how or why an event can happen. For instance, adults judge it is possible to stay awake for 5 days, but not for 5 months (Shtulman, 2009). But it is unlikely that most adults know enough about the biological basis of sleep to understand why the less extreme event could happen, while the more extreme one could not. Instead, it could be that they have heard about people staying awake for several days (an outcome similar to 5 days) but have never heard of anyone staying awake for months. The similarity heuristic, then, may not just be for children. It may underlie possibility judgments in adults too.

Chapter Four: Limits in causal knowledge do not explain children's possibility judgments

(Paper Three)

A version of this paper has been invited for revision:

Goulding, B.W. & Friedman, O. (invited revision). Limits in causal knowledge do not explain children's possibility judgments. *Child Development*.

Making an eggplant-onion smoothie would be strange and unusual, but most adults would probably agree it is possible. Adults typically view unusual and improbable events, like having a pet lion or eating pickle-flavored ice-cream, to be almost as possible as everyday events like wearing a hat or washing a car. The same cannot be said for young children, who often deny that improbable events can happen. Indeed, 4-year-olds often view these events as being almost as impossible as truly impossible events, like walking on water or growing money on a tree (Shtulman & Carey, 2007). The finding that 4- to 8-year-old children are skeptical of the possibility of improbable events has proven remarkably robust (Danovich & Lane, 2020; Lane et al., 2018; Shtulman, 2009; Shtulman & Phillips, 2018; Weisberg & Sobel, 2012). So, despite the relative simplicity of making an eggplant-onion smoothie, a young child would probably say that it cannot be done. But the reasons behind children's denial of improbable events remains mysterious.

Limits in children's causal knowledge might explain why they deny that unusual events can happen. People may infer an event's possibility by imagining the causal circumstances that would allow it to occur; if they fail to imagine *how* an event could happen, they reject its possibility (Shtulman & Carey, 2007; also see Cook & Sobel, 2011; Lane et al., 2016; Shtulman, 2009). On this view, children might reject the possibility of having a pet lion or eating pickle-flavored ice-cream because they are unaware of how these events could arise. For instance, children may think all pets come from pet stores. If they know that pet stores do not sell lions,

they might conclude lions are unattainable as pets. Conversely, adults might know that exotic pets can be imported, and therefore decide that a person *could* have a pet lion if they really wanted. This causal-circumstances account has been proposed in numerous studies of children's reasoning about possibility.

Some support for this "causal circumstance" account is provided by the development of children's and adults' explanations of their possibility judgments. When explaining why an event can or cannot happen, such as a person living without a heart, 4- to 9-year-olds usually offer hypothetical explanations (e.g., "You would die in five minutes") or redundant explanations ("It's impossible"; Shtulman, 2009). However, adults usually give factual explanations (e.g., "You need a heart to pump blood"). Further, adults who judge that events are possible often explain their reasoning by referring to circumstances that would enable the events, whereas adults who deny events often refer to causal principles that the events violate (Shtulman & Tong, 2013). Together these findings suggest that people are more likely to see an event as possible if they can identify circumstances that would enable it.

To our knowledge, no study has directly tested this causal-circumstances account, and children's beliefs about possibility can be difficult to reconcile with it. For instance, while 5- to 6-year-olds are usually reluctant to endorse the possibility of improbable events, they will often agree that a person could have a pet zebra if they first learn that a person has a pet elephant, and agree that a person could wear a costume to work if they learn that a person worked in their pajamas (Goulding & Friedman, 2021). This finding suggests that factors other than causal knowledge underlie children's denials that improbable events can happen. For instance, they may be better explained by a memory-based heuristic in which children judge an event's possibility via its similarity to a known event. Children may say that an event is possible if they can recall

an instance of the event happening, or if they can recall the occurrence of an event that is similar to the event at hand (Woolley & Ghossainy, 2013). While the evidence for this memory-based account is also limited, these findings call into question whether gaps in children’s causal knowledge lead them to deny that events can happen.

However, children’s causal knowledge doubtlessly impacts their beliefs about possibility. Despite their frequent denial that improbable events can happen, children are even more likely to deny that impossible events can happen (e.g., Bowman-Smith et al., 2019; Shutlman, 2009; Lane et al., 2018). This is likely because truly impossible events directly violate children’s principled real-world knowledge (Schult & Wellman, 1997; Sobel, 2004). For instance, a person walking through a brick wall is unequivocally impossible if solid objects cannot pass through each other—and even infants seem to understand this (see Baillargeon et al., 2011). Children are also adept at learning causal relations that allow them to see “possibilities” (see Gopnik and Shultz, 2004). For instance, blinket-detection tasks show that even 2-year-olds can determine which objects will and will not cause a novel toy to function (Gopnik et al., 2001). Crucially, though, such uses of causal knowledge cannot explain children’s denials that improbable events can happen, as improbable events *are* possible and therefore unlikely to violate children’s principled knowledge. The claim that gaps in children’s causal knowledge leads them to deny events can happen (i.e., the causal-circumstances account) is distinct from the observation that children can use principled knowledge to determine whether many other events are impossible.

Here, we provide a straightforward test of the causal-circumstances account. We explore whether children will more often agree that an improbable event is possible when they know of circumstances that would allow it to occur. We do this by giving children detailed causal knowledge about how a normal event could arise; for instance, we explain how a juicer works,

and how it can be used to make apple juice. We then probe their beliefs about whether a person could have a related improbable item, such as cauliflower juice. Crucially, the causal information provided is broad and detailed enough that it could be applied to attain a variety of outcomes (i.e., children who learn how to make apple juice also learn how juice, in general, can be made). The key question is whether this new knowledge will lead them to accept outcomes that are strange and improbable. To test this manipulation, Experiment 1 compares 4- to 7-year-old's possibility judgments for ordinary, improbable, and impossible events after hearing causal or noncausal information about a related item.

We also explore whether children's beliefs about improbable events are more impacted by learning causal information about related *improbable* events than related ordinary events. For instance, we tell children how to make either a strawberry- or pickle-flavored popsicle, providing *identical* causal information for both events, before asking whether a person could also have an onion-flavored popsicle. We also include a third condition in which children are merely told that improbable events happened. Comparing across these three conditions allows us to determine whether causal information has any influence on children's beliefs over-and-above the influence of a memory-based similarity heuristic (Goulding & Friedman, 2021). Experiment 2 explores these manipulations in 5- and 6-year-olds.

Experiment 1

Method

Participants. We tested 240 4- to 7-year-olds ($M = 5;11$ [years;months], range = 4;0-7;11, 108 girls). We tested 30 children per age-in-years per between-subjects condition, and randomly assigned equal numbers of children at each age-in-years to each condition. We

determined this sample size as it has sufficed to reveal significant effects in past work in this area of research (e.g., Bowman-Smith et al., 2019; Goulding & Friedman, 2021; Lane et al., 2018).

Children were recruited and individually tested at childcare centers and elementary schools. Demographics were not formally collected, but most children were from middle-class families in the region of Waterloo (Ontario, Canada). Approximately 85% of residents in this region are Caucasian, and the largest visible minority groups are of Chinese and South Asian descent. All studies received approval from the Office of Research Ethics at the University of Waterloo.

Materials and procedure. Children were shown photos on a laptop, with accompanying narrations from the experimenter; see Figure 10 for an illustration of the full procedure and script. In each of three trials, children were told that a person had a normal item (strawberry ice-cream, normal-shaped house, apple juice). Children were randomly assigned to one of two between-subjects conditions: causal-information and noncausal-information. Children in the causal-information condition heard about how each item can be made; for instance: “You can make apple juice with a juicer. To use a juicer, you put stuff in it and it squeezes out all the liquid so you can pour it into a glass and drink it. So, if you put apples in it, you’ll have apple juice.” Children in the noncausal-information condition heard about where the items can be found; for instance: “You can get apple juice in lots of places. You can get apple juice at the grocery store. You can get apple juice at a restaurant. And, you can get apple juice at somebody’s house.” After hearing about each item, children were asked if a person could also have a related normal item, improbable item, and impossible item (e.g., orange juice, cauliflower juice, rock juice). We asked about these items in one of three orders, and question order varied across trials.

Results

In both experiments, the main analyses used generalized estimating equations (GEE) models (binary logistic) with independent covariance matrices performed using the “geeglm” function for “geepack” for R (Halekoh et al., 2006). These analyses were subsequently passed through the “joint_tests” function for the “emmeans” package to produce an omnibus test; any post-hoc pairwise comparisons were also performed using the “emmeans” package (Lenth et al., 2019). Trendlines in each figure show predicted values and 95% confidence intervals, and were produced by passing each GEE model through the “ggemmeans” function for the “ggeffects” package (Lüdtke, 2018). The materials and data for all experiments can be found [here](#).

We entered condition (between-subjects: causal-information, noncausal-information), item-type (within-subjects: ordinary, improbable, impossible) and age-in-months (mean-centered) as predictors of children’s judgments about whether events could happen. This revealed a main effect of item-type, $F(2) = 241.37, p < .001$. Children affirmed ordinary events more often than improbable events, $p < .001, OR = .025$, and impossible events, $p < .001, OR = .005$, and affirmed improbable events more often than impossible events, $p < .001, OR = .183$. The main effect of condition was not significant, $F(1) = 0.07, p = .787$, nor was the main effect of age, $F(1) = 3.79, p = .052$. There was a significant interaction between item-type and age, $F(2) = 19.52, p < .001$. Children were more likely with age to affirm ordinary events, $p < .001$, but less likely with age to endorse improbable or impossible events, $ps \leq .002$. There were no other significant interactions, $ps \geq .067$.

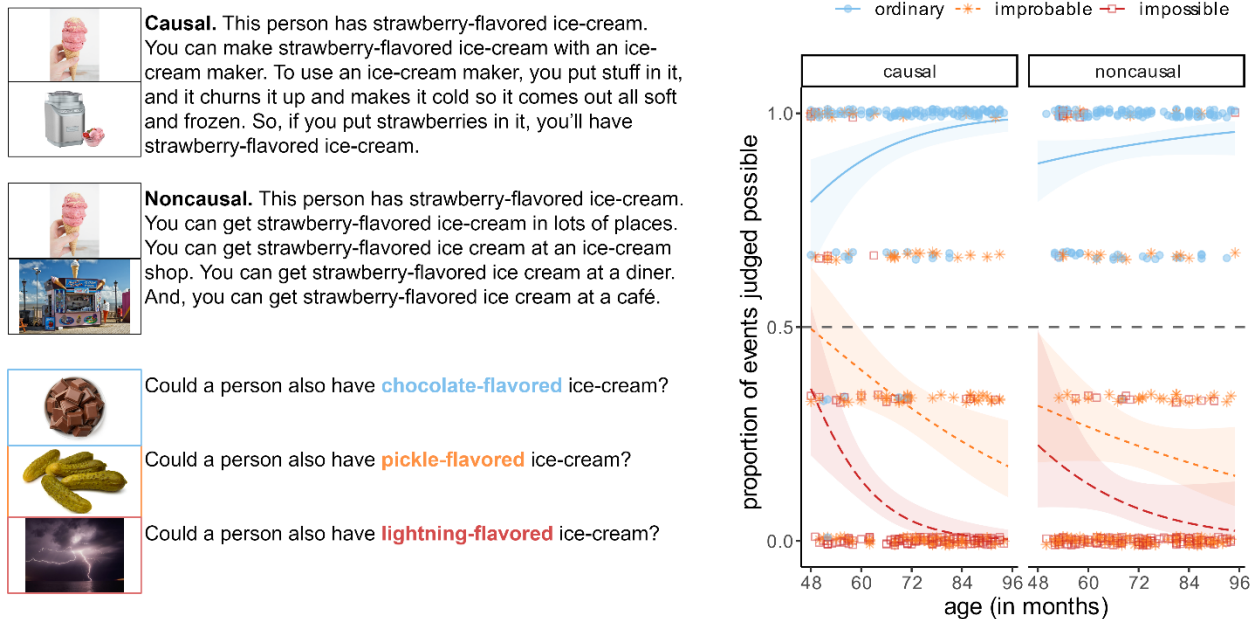


Figure 10. Procedure and results from Experiment 1, with sample images and scripts for one full trial. Trendlines are shown for predicted judgments within each item-type; bands show 95% confidence intervals. Points show the proportion of events judged possible by each participant; the points are jittered slightly to decrease overplotting.

We also performed single-sample tests against chance for responses within each question and age-in-years. All children in both conditions affirmed that ordinary events could happen, $ps < .001$, and denied that improbable and impossible events could happen, $ps < .009$.

The findings suggest that children’s denial of unusual events do not stem from limits in their causal knowledge. We told children about circumstances that could enable ordinary events and asked whether related improbable events were possible, and compared their responses to those of children who instead heard non-causal information about the events. Children’s responses did not differ across the two conditions. Moreover, children were *more* likely to deny the possibility of these events with age. These findings contrast with previously observed age-related increases in affirming improbable events, and with the suggestion that this developmental

trend is driven by a likewise increase in knowledge of causal circumstances (Shutlman & Carey, 2007; Shtulman, 2009).

One concern, though, is that the information provided in this experiment was not detailed or clear enough to influence children's beliefs. For instance, children learned that a juicer could make apple juice, but they did not learn *how* it could do so (i.e., by crushing and grinding food) and they did not see a depiction of this happening. This shallow understanding may have left children unsure about which other events could arise from the same circumstances, whereas a deeper understanding of the causal mechanisms at work may have increased their confidence in the possibility of other outcomes. However, we know that children's beliefs about the possibility of improbable events can be altered after hearing only the minimal information that a related improbable event has happened (Goulding & Friedman, 2021).

We therefore conducted a second experiment with three aims. The first was to provide even more detailed causal information to strengthen the effect of our original manipulation. The second was to contrast the relative influence of causal information with that of knowing that a related event has happened (i.e., a memory-based similarity heuristic). The third was to explore whether children's beliefs about improbable events are more impacted by learning causal information about related improbable events than related ordinary events. We provided children with identical detailed causal information about either ordinary or improbable events, and then asked them if related improbable events were also possible. We also included a third condition in which we merely told children that improbable events happened.

Experiment 2

The design and analysis plans for Experiment 2 were preregistered at aspredicted.org and can be found [here](#). We followed the preregistration in all regards except the number of

observations collected, as our lab abruptly ceased all in-person testing in response to the 2020 COVID-19 pandemic.

Method

Participants. We tested 109 5-6-year-olds ($M = 6;0$, range = 5;0-6;11, 46 girls). As in the first experiment, we aimed to test 30 children per age-in-years per between-subjects condition. However, we were unable to collect our full intended sample before ending data collection.

Materials and procedure. Children were shown a Qualtrics survey administered via an Amazon Fire tablet. The experimenter entered children's responses by touching hidden regions of the screen corresponding to yes/no judgments on each test slide. In all conditions, children responded to the same six test questions and answered two questions per trial. Children were presented with each item-and-question set one-at-a-time, and did not hear about the next set until after responding to both test questions. Assignment to each between-subjects condition, trial order, and question order were fully randomized by Qualtrics. See Figure 11 for an illustration of the full procedure and script.

Children were randomly assigned to one of three between-subjects conditions. In the ordinary causal-information condition, children were introduced to three ordinary items (strawberry-flavored popsicle, normal-shaped house, apple-juice) and saw a photo of each item. They then heard detailed information about how the items could be made. This information was delivered in three steps, and each step was accompanied by a relevant photo. After hearing about each item, children were asked if a person could also have a related improbable item and a related impossible item (e.g., cauliflower juice, rock juice). This condition was similar to the

causal condition from Experiment 1, but was intended to make the causal information more detailed and clear.

In the improbable similarity-information condition, children were instead introduced to three improbable items (pickle-flavored popsicle, shoe-shaped house, broccoli juice) and shown a photo of each item. Children were then immediately asked if a person could also have a related improbable and impossible item; they did not hear any information about the circumstances that enabled the events. This manipulation has been shown to increase children's beliefs about the possibility of improbable events (Goulding & Friedman, 2021), so including it here allows us to see whether children can be led to view these improbable events as possible. It also allows us to compare the effect of causal knowledge with children's use of a memory-based similarity heuristic.

In the improbable causal-information condition, children were introduced to the same three improbable items. The procedure thereafter was otherwise identical to the normal-causal condition; the step-by-step information, accompanying photos, and test questions were the same. Subtle changes in wording were required to match the improbable item under consideration (i.e., the experimenter said "pickle-flavored popsicle" instead of "strawberry-flavored popsicle"). We included this condition because the ordinary causal-information and similarity-information conditions differ in respect to both the item being learned about and the type of information provided, so comparing them directly would not allow us to determine which of these differences is driving any observed effects. By instead comparing children's responses in these two conditions with those of children in the improbable causal-information condition, we will be able to tease apart the role of causal information from the influence of knowing that a similar improbable event happened. At the same time, this condition allows us to explore whether

children's beliefs about improbable events are more impacted by learning causal information about related *improbable* events than related ordinary events.

Results

The abrupt cessation of data collection for this experiment, combined with Qualtrics' fully random assignment of children to each between-subjects condition, resulted in unequal numbers of children in each condition in our final data set. Our analysis includes 37 children in the ordinary causal-information condition, 28 participants in the improbable causal-information condition, and 44 participants in the improbable noncausal-information condition.

We first conducted an analysis with condition (between-subjects: ordinary causal-information, improbable causal-information, improbable similarity-information), item-type (within-subjects: improbable, impossible), and age-in-months (centered) as predictors. This revealed a main effect of condition, $F(2) = 8.07, p < .001$, which we expand on below. It also revealed a main effect of item-type, $F(1) = 70.02, p < .001$, as children more often affirmed improbable events than impossible events. The effect of age was not significant, $F(1) = 2.83, p = .093$, nor were any interactions, $ps \geq .115$.

We next performed pairwise comparisons to follow-up on the main effect of condition. Children more often affirmed improbable and impossible events if they heard causal information about related improbable events than if they heard identical causal information about related ordinary events, $p < .001, OR = 9.04$. Children's responses did not differ depending on whether they heard *how* improbable events happened or merely learned that they occurred, $p = .053, OR = 2.31$. As specified in our pre-registration, we did not compare judgments across the ordinary causal-information and improbable noncausal-information conditions.

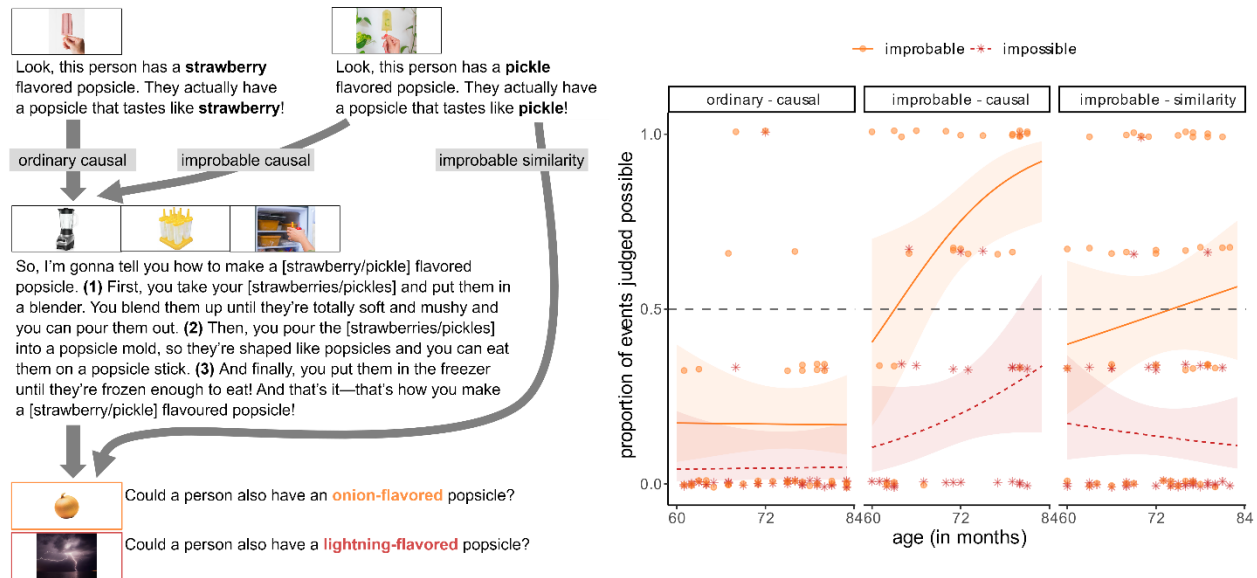


Figure 11. Procedure and results for all three conditions in Experiment 2, with sample images and scripts for one full trial. Trendlines are shown for predicted judgments within each item-type; bands show 95% confidence intervals. Points show the proportion of events judged possible by each participant; the points are jittered slightly to decrease overplotting.

We also ran single-sample tests against chance (i.e., 0.5) to determine children’s overall pattern of endorsement across conditions and item-types. Children in the ordinary causal-information condition denied improbable and impossible events, $ps < .001$, whereas children in the improbable causal-information condition affirmed improbable events but denied impossible ones, $ps < .001$. Children in the improbable similarity-information were ambivalent about improbable events, $p = .794$, but denied impossible ones, $p < .001$.

Given our lack of power to detect significant interactions, we also performed two additional omnibus analyses: one compared responses within the two causal conditions (ordinary causal-information, improbable causal-information), and one compared responses within the two improbable conditions (improbable causal-information, improbable noncausal-information). These analyses confirmed that children’s agreement was higher after hearing causal information about improbable events than ordinary events. In contrast with our primary analysis, they also revealed that children agreed significantly more after hearing causal information about an

improbable event than merely hearing that the improbable event happened, $p = .044$. The results of these analyses are included in Appendix B.

General Discussion

In two experiments we examined why children deny that improbable events can happen. In Experiment 1, we told 4- to 7-year-olds causal and noncausal information about ordinary events and asked whether related ordinary, improbable, and impossible events could also occur. Children's judgments were comparable across both conditions, and they continued to deny that improbable and impossible events could happen. In Experiment 2, we compared the role of detailed causal information with the influence of knowledge that a similar improbable event already happened. Detailed causal information about ordinary events did not lead 5- and 6-year-olds to affirm improbable events as possible, and they more often affirmed events as possible when they simply knew that a similar improbable event occurred. However, children may have been most likely to affirm improbable events if they knew *how* a similar improbable event happened.

The findings suggest that knowledge of causal circumstances alone is not sufficient to alter children's beliefs about possibility. The circumstances that enabled the ordinary events used here were designed to be general enough to apply to many outcomes; for instance, the process for making of pickle-flavored popsicles could enable the creation of almost *any* popsicle. But children still adamantly rejected the possibility of improbable events that could plausibly arise from these circumstances. Their rates of denial did not differ from those of children who heard noncausal information, and were comparable to (or even lower than) children's baseline possibility judgments from previous studies (e.g., Goulding & Friedman, 2020; Lane et al., 2018; Shtulman & Carey, 2007). So, while children and adults often explain whether events are

possible by referencing circumstances that would enable them (e.g., Shtulman, 2009), providing this information to children did not impact their beliefs. In sum, the findings suggest that children's denial of improbable events is not fully due to limitations in their causal knowledge.

One possibility is that the information provided here was not detailed enough to lead children to envision new possibilities. We attempted to address this concern by providing more detailed, stepwise information in the second experiment, with pictures showing exactly *how* each process led to its outcome. But there is a great deal more information that children must know to make educated guesses about the possibility of other outcomes, and we cannot be certain that the children in our experiments had this prerequisite knowledge. For instance, to fully understand how popsicles are made, they must know that most food can be pulverized into a liquid and frozen, and to fully understand how houses are made, they must understand that its shape is not the key feature that makes it structurally sound and inhabitable. These events therefore require comprehension of other knowledge that 4- to 7-year-olds might not yet grasp. However, we think this concern is unlikely to account for most of our findings. Children gain knowledge throughout childhood (see Shtulman, 2017), yet children in our experiments either became *less* likely with age to affirm improbable events or showed no effect of age. If a lack of knowledge is driving these effects, we should have seen the opposite: children should have become *more* likely with age to infer the possibility of improbable events.

Further, we found that we *could* impact children's beliefs about possibility by providing them with minimal information: children more often judged improbable events to be possible when they learned the mere fact that a similar improbable event had already occurred. This is in line with children's use of a memory-based similarity heuristic for inferring possibility, in which children's knowledge of what has happened directly guides their inferences about what can

happen (Goulding & Friedman, 2021; Woolley & Ghossainy, 2013). This similarity heuristic might also underlie children's tendency to view social norms and conventions as laws that cannot be violated or changed (e.g., Browne & Woolley, 2004; Chernyak et al., 2013; Kalish, 1998; Komatsu & Galotti, 1986; Levy et al., 1995; Lockhart et al., 1977; Miller et al., 2000). Crucially, we also found that this effect emerged regardless of whether children also learned *how* the similar event occurred, suggesting that the similar event had a stronger impact on children's beliefs than the detailed causal information that accompanied it. These results show that children's beliefs about the improbable events used here are not immutable. But why does minimalistic knowledge of similar events lead children to make richer inferences about possibility, while more detailed information about causal circumstances does not?

One explanation is that children use similarity in deciding when to extend and apply their causal knowledge. For instance, if children view strawberry and onion-flavored popsicles as fundamentally dissimilar, they may be skeptical that the process that enabled one could also enable the other. But if children know for certain that a pickle-flavored popsicle can be made, and view this event as similar to making a onion-flavored popsicle, they may infer that the circumstances that enabled the first event could likely enable the similar event—even if they do not know what those circumstances are. In this sense, knowledge of similar events may serve as a proxy for knowledge of causal circumstances. Our supplemental analyses of children's responses in the second experiment suggest this, as children were somewhat more likely to infer that improbable events could happen if they also knew *how* a similar event occurred (see Appendix B).² Here, the influence of causal knowledge seemed to stack with children's use of

² This result is compelling but should be interpreted with caution. The supplemental analyses for Experiment 2 revealed a difference between the improbable-causal and improbable-similar conditions, but the main analysis did not. We suspect that our smaller-than-intended sample size reduced our power to detect this interaction, but cannot be certain it would have reached significance in the full sample.

the similarity heuristic, suggesting that children infer that similar events share similar circumstances.

These findings align with the importance of similarity in promoting children's analogical reasoning. Children more often transfer knowledge to novel situations and problems if they perceive similarities between prior events and the situation at hand. Indeed, young children are especially likely to transfer knowledge if situations are similar on the surface, and can struggle with transferring knowledge between situations that only share deeper commonalities (Chen, 1996; Chen & Klahr, 2008). For instance, children are better at reenacting moralistic stories with toys if they can use the toys from the original story rather than novel toys, even if the events and moral lesson remain exactly the same (Gentner & Toupin, 1986). But children's difficulty in transferring knowledge can be lessened if situations are framed as being similar to one another (Holyoak et al., 1984), or if children are asked to detect similarities themselves (Brown, 1988). Here, we found that these same considerations factor into children's judgments about possibility. Children more often view events as possible if they know that superficially similar events have happened. Further, they may only extend causal knowledge to events that share surface similarities with known events.

We close by considering the implications of our findings for the causal-circumstances account of possibility judgment (Shtulman & Carey, 2007). The present experiments suggest that knowledge of causal circumstances either has no effect on children's beliefs about whether improbable events are possible, or only influences their beliefs about events that are similar to known events. The findings also show that the mere knowledge that an event can happen has a robust influence on children's beliefs about the possibility of similar events both with and without further information about how the events could occur. Taken together, this work

suggests that knowledge of causal circumstances may only impact children's beliefs about possibility *after* they are able to draw connections between potential events and known events. It is therefore unlikely that increased knowledge of causal circumstances alone drives the striking developmental difference between children and adults' beliefs about possibility. Instead, adults may be more adept than children at perceiving similarities between events, and may be less distracted by superficial differences between structurally similar events. They can also retrieve more events from memory than young children, and therefore have a larger bank of events to which they can draw connections. These differences may suffice to explain why adults affirm the improbable while young children do not.

Chapter Five: General Discussion

Major Findings

Across eight experiments, I found evidence that children's beliefs about possibility are shaped by knowledge of what *has* happened, and that this might matter more than knowing *how* events could happen.

Chapter Two explored whether children's beliefs about possibility differed between dreams, stories, and reality, and whether their beliefs about fantasy were constrained by their real-world intuitions. In two experiments, I found that 4- to 7-year-olds believed more things to be possible in dreams and stories than in reality, and that children held nuanced beliefs about these different kinds of fantastical worlds. But I also found that children *still* distinguished between the possibility of improbable and impossible events in each fantastical world, suggesting that their beliefs about these worlds are anchored in their real-world intuitions. In a third and final experiment, I found evidence that children use what they *know* to be typical of these worlds when inferring whether events can happen within them. Whereas children in the first two experiments were largely skeptical of both improbable and impossible events, children in the final experiment affirmed truly impossible events that were dream- and story-like. For example, children in Experiment 2 were ambivalent about whether a person in a story could have a pet peacock or grow a beard to the ground, and mostly denied that a person in a story could walk through a wall or grow money on a tree. While there is no *a priori* reason to expect that these events should *not* belong in a story, they were borrowed from previous work on children's possibility judgments and were not necessarily similar to the kinds of events usually included in stories. In contrast, children in Experiment 3 mostly affirmed that a person in a story could meet a talking squirrel, ride a magic bicycle, and fly through the sky. These were items designed to be

significantly more akin to storybook events that children might be familiar with. Together, the findings suggest that children's possibility judgments are driven by both familiarity and real-world constraints.

Chapter Three directly investigated whether children use a memory-based similarity heuristic to infer possibility. In Experiment 1, I found that telling 4.5- to 6-year-olds improbable facts led them to affirm that similar improbable events were possible. Experiment 2 expanded on this by demonstrating that similarity really seems to matter, as children more often affirmed improbable events to be possible after learning related rather than unrelated improbable facts. Finally, Experiment 3 found that children would affirm similar improbable events, but not similar impossible events. This shows that their judgments cannot entirely be explained by the similarity heuristic, and that their beliefs are constrained by knowledge of principles that render certain outcomes impossible.

Chapter Four addressed the alternative account: that children reason about possibility by identifying causal circumstances that would allow an event to occur. In Experiment 1, I provided 4- to 7-year-olds with either causal or noncausal information about how ordinary events could happen. Here, I wanted to determine if this kind of causal knowledge would enable them to entertain the possibility of other, more improbable, outcomes. However, their responses did *not* differ as a function of the information provided, and children persisted in denying the possibility of improbable events. In Experiment 2, I replicated this finding with more detailed, stepwise causal information. I also explored the relative influence of causal and similarity information by telling 5- and 6-year-olds how an *improbable* event could occur, compared to simply telling them that a similar improbable event happened. These findings were less clear. While both kinds of information about improbable events led to greater levels of agreement compared to ordinary

causal information, I also found weak evidence that these kinds of information might stack in influence. That is: children might be *most* likely to affirm that events are possible if they know that a similar event has happened *and* how it could occur.

Together, these findings suggest that our beliefs about possibility are largely driven by our familiarity with, and memory of, past events. They provide the first evidence for a similarity heuristic in children's possibility judgments. They also suggest that knowledge of causal circumstances may play a much weaker role in children's beliefs about possibility than has been suggested (Lane et al., 2016; Shtulman & Carey, 2007), though their beliefs are constrained in other important ways. In the following section, I further contextualize my findings in light of these two accounts. I also explore how information about similar events might work to reshape children's beliefs about possibility, and potential factors that might constrain this process.

The causal-circumstances and similarity accounts, revisited

In the introduction, I outlined two potential accounts for inferring possibility. One account posited that people might reason about possibility by identifying causal circumstances that would enable events to occur. On this view, adults affirm improbable events because they can envision *how* they could happen, and children deny improbable events because they cannot. This has remained a popular account for explaining the development of possibility inferences (e.g., Shtulman, 2009; Shtulman & Carey, 2007; Lane et al., 2016). However, many of my findings are difficult to reconcile with this view.

The most direct evidence against this account comes from Chapter 4. I tested whether providing children with causal information that could potentially enable improbable events would lead them to affirm the events as possible. However, children persisted in denying the events, and making the information more detailed did not change this. This finding alone casts

significant doubt on the causal circumstances account, at least in its simplest form. If children usually deny improbable events because they cannot think of circumstances that could enable them, then the information provided throughout these experiments should have at least partially remedied this issue. Indeed, it was only when causal information was paired with information about a similar event that children's judgments shifted towards affirmation. This suggests that causal information *might* matter for possibility judgments in some circumstances, but in isolation is not sufficient to impact children's beliefs about possibility.

It is also difficult to explain children's beliefs about dreams and stories with a solely causal account of possibility judgments. Previous work has suggested that children are reality-bound when reasoning about fantasy and imagination, and that this might be because their beliefs are largely driven by real-world causal knowledge (see Harris, 2021). But I found that children judged more events possible in dreams and stories than in reality, and that they viewed impossible dream- and story-like events as fully possible in both worlds. If children were using their real-world causal knowledge to reason about possibility in these worlds, then they should have mostly denied both improbable and impossible events, and their beliefs should have closely mirrored reality. Instead, children held nuanced beliefs about possibility for each of these worlds, suggesting that other factors were driving their beliefs.

I also proposed an alternative account for inferring possibility, where people search their memories for similar events that they know to have happened when judging whether an event is possible. Chapters 3 and 4 offer direct support for this similarity account, as I found that children were more likely to judge improbable events possible after being told that a similar event had already occurred. Importantly, none of my manipulations offered children any information about *how* these events might occur. This suggests that merely knowing that a strange and unlikely

event has happened is enough to shift children's beliefs about the possibility of other, yet-unfamiliar events.

This similarity account can also help us explain children's judgments for dreams and stories, which I examined in Chapter 2. When asked to judge the possibility of events that were atypical of dreams and stories, such as a person having a pet peacock or walking through a wall, I found that children were somewhat skeptical about whether these events could happen in either of these worlds. However, when I instead asked about *typical* dream and story events, such as flying through the sky or meeting a talking animal, I found high rates of affirmation. This finding suggests that children may have searched their memories for events they knew had already occurred in dreams and stories, and used these memories to guide their inferences about possibility. When the events were similar, they affirmed them; when they were dissimilar, they were skeptical. This finding further suggests that children's use of the similarity heuristic may be sensitive to the context in which events are embedded, and that their memory searches for events may be guided by the situations and environments they are asked to consider (also see Bowman-Smith et al., 2019).

As a reminder, there is no reason to expect these accounts to be mutually exclusive. In fact, some of my findings suggest that both may be true, at least in part. In Chapter 4, I provided children with information about how improbable events could occur, which led children to mostly affirm that similar improbable events could happen. But children who merely heard that an improbable event occurred, without hearing additional causal information, were ambivalent about these same events. These results should be interpreted with caution, as I was unable to collect my full intended sample before ending data collection. However, they suggest that causal information and knowledge of similar events may stack in influence, such that children are *most*

likely to affirm an event as possible if they have both kinds of knowledge at hand. Children may therefore use similarity to guide their extensions of causal knowledge, and may expect similar events to arise from similar circumstances. On this view, knowledge of causal circumstances *is* important, but children may not know how to apply this knowledge if they do not see a connection between the event in question and what they know. The similarity heuristic may provide this connection.

I also obtained findings that neither account can neatly explain. For instance, in Chapter 3 I found that children judged more events possible in dreams and stories than in reality, but also consistently differentiated between improbable and impossible events in each fantastical world. This finding is especially puzzling. Children's beliefs about these worlds mirror reality more than they really ought to, given that dreams and stories are not obviously constrained in any meaningful way. Yet children still thought more things were possible in these worlds, meaning they saw these worlds as *less* constrained than reality, if not entirely unrestricted. How can we explain their judgments? One possibility is that children employed an entirely different heuristic here: anchoring and adjustment (Tversky & Kahneman, 1974). Children may have taken their baseline beliefs about how possible the events were in reality, and adjusted them according to their intuitions about how much "more possible" events should be in each fantastical world. This would explain their higher affirmations for events in these worlds, as well as their preservation of the distinction between improbable and impossible events. My findings cannot verify whether this account is true, nor can they identify the source of children's differing intuitions for each kind of world (but see Weisberg & Goodstein, 2009, for a discussion of how children might reason about deviant worlds). However, this finding further suggests a potential role of heuristics

in possibility judgment, and highlights that the two accounts offered here cannot offer us a full picture of how people reason about possibility.

How does similarity shape beliefs about possibility?

Across three series of experiments, I found evidence for a similarity heuristic in children's possibility judgments. However, my findings do not address *how* similar events work to alter children's beliefs about possibility. They also cannot speak to how adults and children decide whether two events are similar enough that the possibility of one implies the possibility of the other. The most straightforward account is that children simply decide whether a potential event is similar to something they know and judge it possible without further consideration. But similarity-based judgments may instead reflect richer inferences about implied causal mechanisms and the structure of categories. Below, I outline two accounts for how knowledge of similar events might reshape children's beliefs about possibility. I also discuss how a developmental shift in identifying similarities between events might help explain the development of possibility judgments.

Similarity as a proxy for causality. Knowledge of similar events might serve as a proxy for causal knowledge. In other words, people might infer that two sufficiently similar events should be able to arise from the same circumstances. Further, they may make this assumption despite knowing little about what those circumstances are. For instance, imagine you were told that it was now possible to remotely hijack and drive cars using only a cellphone. You might begin to worry that all manner of vehicles and household appliances are now liable to be compromised, despite knowing nothing about the specifics of this exploit and how it works. You might just assume that the technology that enabled the first event could probably enable similar

ones. On this view, knowledge of similar events serves to *suggest* enabling circumstances without explicitly identifying them.

This is much like the popular “placeholder” account of psychological essentialism, where surface similarities between things are taken to signal more fundamental constraints that bind them together in a deeper, nonobvious sense (Gelman, 2004; Medin & Ortony, 1989; Stevens, 2000). For instance, we might view geese and robins as similar and decide that they share a hidden essence that determines their bird-ness, despite knowing nothing about the physical or biological mechanisms that underly this perceived similarity. Here, the nonobvious “constraints” that bind superficially similar events together are the causal circumstances that may have enabled them. This explanation partially reconciles the causal-circumstances and similarity accounts, as it proposes that knowledge of similar events may enable children and adults to identify enabling causal circumstances.

This account makes two important predictions. First, it predicts that people should be less likely to affirm the possibility of thematically similar events that could *not* arise from the same circumstances. For instance, learning about hacked cars might lead a person to affirm the hackability of boats, but probably not the hackability of bicycles. All these events are thematically similar in that they involve remotely commandeering a vehicle, but bicycles are non-electric and therefore cannot be commandeered under the same circumstances. Further, bicycles may usually be seen as *more* similar to cars than boats, since cars and bicycles enable urban transport whereas boats do not, but *less* similar in this hacking situation given the electrical requirements. This suggests that inferences about shared causality may shift people’s perceptions about the similarity between two events when inferring whether they are both possible. These points may seem trivial, but a non-causal explanation for the similarity-based possibility

judgments would not necessarily predict these distinctions, and none of my data so far indicate whether they are clearly present in children's judgments.

Second, this account predicts that providing people with more detailed causal knowledge should augment the influence that similarity has over their judgments of possibility. For instance, learning that the hack works via radio signal should *decrease* the number of similar events seen as possible since not all vehicles have radios. Conversely, learning that the hack operates via *any* electrical signal should make more events seem possible. In this sense, this account is functionally a hybrid between the causal-circumstances and similarity accounts, as it proposes that both knowledge of causal circumstances and similar events should factor into judgments of possibility. My findings from Chapter 4 offers some support for this view, as a combination of enabling causal knowledge and information about a similar event had the greatest positive impact on children's possibility judgments for improbable events. However, more work is needed to directly test these assumptions.

Similar events may restructure categories. Alternatively, knowledge of similar events might serve to influence people's categorical knowledge. This category-knowledge account rests on the suggestion that improbable events are often denied because they are viewed as category errors, rather than being seen as strictly impossible. For instance, consider whether a pet lion could be viewed as a pet. You might reasonably deny this suggestion because lions do not meet some essential criteria of "pets", despite also knowing that a person could acquire one. For instance, you might see lions as extremely dangerous, wholly untameable, and pragmatically difficult to house without building an entirely separate outdoor enclosure, which disqualifies them from being a true "pet" in your eyes. Children's possibility judgments may also operate in this way: children may deny that an event is "possible" because they perceive it to violate some

core categorical assumption, or because the event lacks superficial features that would usually indicate category membership. For instance, they may believe that a zebra cannot be considered a pet, that pajamas cannot be considered work attire, and that a liquid made from onions cannot be considered a juice. Previous work suggests that children often reject category members that lack characteristic features of a category, despite also having a defining feature that should allow for its membership. For example, they might deny that a castle with swimming pools and delicious food could be a “prison”, despite also knowing that the residents can never leave (Keil & Batterman, 1984). However, no work has addressed whether this pattern of reasoning intersects with children’s possibility judgments.

On this view, informing children about similar events may serve to challenge, and therefore broaden, their beliefs about the kinds of things that are considered acceptable category members. This category-knowledge account predicts that *any* atypical category member may become a “possible” candidate, irrespective of whether the events themselves might arise from similar circumstances. For instance, learning that a person could have a pet elephant may lead children to question their knowledge of what a “pet” can be, and may lead them to accept new members that they would have previously dismissed, such as a pet zebra. But it may *also* lead them to affirm less-related candidates as well, such as a pet jellyfish or a pet penguin, despite these events requiring vastly different enabling circumstances. Elephants and zebras are large and difficult to house, jelly-fish can simply be placed in an aquarium, and penguins require a frozen environment to live in—and even *more* differences become apparent if you also consider where you would find these animals, how you might reasonably bring them to your home. This is in contrast to the previously discussed hybrid account, which proposes that beliefs about similarity and possibility are constrained by inferences about shared causality. On this view, any

consideration of whether the events could be enabled in the same way might disqualify jellyfish and penguins as possible pets, since it is unlikely that they can be accommodated in the same way as elephants and zebras.

Previous work on children's category learning has found that a single exposure to a new category member (e.g., caterpillars) leads them to extend membership to perceptually similar items (e.g., ropes), whereas exposure to multiple category members leads them to infer that membership should only be given to items sharing deeper, less obvious similarities (e.g., snakes, turtles; Gentner & Namy, 1999). If children's possibility judgments proceed in a similar manner, we might also expect them to be most accepting of new events after learning a single improbable fact, and more restrictive in their inferences if confronted with multiple improbable facts with deeper commonalities—for instance, shared causality. For example, learning about a pet elephant may lead children to broadly accept improbable pets (e.g., zebra, jellyfish, penguins), whereas learning about a pet elephant *and* pet rhinoceros might cause them to narrow their inferences to a smaller, more similar set of candidates (e.g., zebra, giraffe, hippopotamus). Exploring the breadth and kind of events that children are willing to consider after learning improbable facts should allow us to tease apart these two accounts for inferring possibility.

Seeing similarity. Regardless of *how* the similarity heuristic works, we might expect that adults affirm more events as possible than children because they have a larger knowledge base and can therefore retrieve more similar events from memory. However, the developmental shift in possibility judgments may also be driven by a greater ability among adults to construe events as similar in a meaningful way. As discussed in Chapter 4, children primarily attend to superficial features when determining whether two things are similar or dissimilar, and often

struggle to perceive deeper similarities (Chen, 1996; Chen & Klahr, 2008; Gentner & Toupin, 1986).

But affirming improbable events as possible may often require noticing deeper similarities between two superficially dissimilar events. For instance, apples and onions might seem dissimilar on the surface, and children might be tempted to dismiss the possibility of onion juice on these grounds alone. But apples and onions are both fleshy foods with a high moisture content, they are both often peeled before they are cooked or eaten, they both caramelize when heated, and they both rot when left in the sun. A person who notices these similarities might conclude that apples and onions are indeed similar, and might infer that onion juice is a possibility given that apple juice exists. Adults might spontaneously make these connections more often than children, which may help explain why they see so many more events as possible. One way to test this would be to point out these kinds of similarities to children before asking them to make possibility judgments. Indeed, previous work has shown that children's analogical reasoning is improved when deeper similarities are highlighted (Holyoak et al., 1984), so this seems like a promising manipulation for exploring possibility judgments as well.

Possibility, atypicality, and inductive reasoning

One final point to consider is whether children's possibility judgments stem from a more general pattern in their reasoning: children often dismiss *any* notion that appears atypical or counterintuitive. This bias against the atypical appears in judgments of category membership (Keil & Batterman, 1984), beliefs about moral violations (Shtulman & Phillips, 2018) and social norms (Cimpian & Salomon, 2014; Komatsu & Galotti, 1986), beliefs about fantasy worlds (Weisberg et al., 2013), and their predictions about their future selves (Bélanger et al., 2014). To illustrate: children judge that a garbage bag cannot be a dress (Keil & Batterman, 1984), that a

person could not clean their room by shovelling clothes under their bed (Shtulman & Phillips, 2018), that school buses could not be any colour other than yellow (Cimpian & Salomon, 2014), that fantastic stories should contain ordinary events (Weisberg et al., 2013), and that they will prefer sippy cups to coffee mugs when they grow older (Bélanger et al., 2014). What these findings have in common is that they show children rejecting possibilities that are dissimilar from what they know. This is the same general finding we observe in children’s possibility judgments.

Rather than representing converging yet distinct findings, it seems likely that children’s reasoning in each of these areas—possibility included—stem from common cognitive mechanisms or processes. One possibility is that all of these judgments are largely driven by features of inductive reasoning. Indeed, many of the explanations for children’s possibility judgments raised here are echoed by Hayes and Heit (2018) in a discussion of how children and adults may reach conclusions from given premises:

“In many cases, domain experts prefer to make inductive inferences based on their deeper knowledge of causal and ecological relations between premise and conclusion categories rather than on general heuristics such as typicality and diversity. Notably, violations of the standard induction phenomena among experts are only found for stimuli that lie within the domain of expertise. Fish experts, for example, used causal knowledge to generalize a novel disease property (“has a disease called sarca”) but used taxonomic similarity to generalize a novel blank property (“has a property called sarca”) (Shafto & Coley, 2003).”

Here, the authors are suggesting that naïve inductive inferences may be driven by similarity, whereas inferences about well-known and familiar categories may be driven by deeper knowledge of the non-obvious properties and principles that bind members together. The same could certainly be true for possibility judgments. My findings show that children affirm events as possible if they simply know that something similar has happened, though they consistently reject truly impossible events that violate their real-world causal knowledge. Also,

adults often affirm events that seem superficially possible, such as travelling the Milky Way or performing a brain transplant (Shtulman & Tong, 2013), but they might be considerably more skeptical about these events if they knew more about the circumstances that would be required to enable them. It therefore seems plausible that the mechanisms that allow us to perform inductive inference are similar to those that allow us to distinguish between the possible and impossible. Further, we may find that these mechanisms are involved whenever we are asked to consider events and outcomes that deviate from premises that are familiar to us. Future work should aim to establish how judgments across these varying domains diverge and develop, as we may discover that many of our beliefs about our social, moral, and physical reality are often explained by how familiar we are with things that seem strange and improbable.

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Appendices

Appendix A: Adult Ratings of Impossible Events from Chapter 2

In Experiment 3 we sought to ask children about impossible events that are more dream and story-like than those used in our first two experiments (whose items were closely based on those from previous studies of children's possibility judgments). To test whether our items were more dream and story-like, we sought adults' impressions of both kinds of items.

Participants. We recruited 115 American adults via Amazon Mechanical Turk (mean age = 33.7, SD = 9.73). We excluded 37 additional participants because they failed to respond appropriately to two catch questions.

Materials and Procedure. Participants read instructions informing them that they would read about different impossible events, and were asked to rate "the extent to which each is typical of the impossible events that happen in stories and dreams". Below these instructions were 12 test sentences, and participants rated each on a 5 point scale ranging from "Extremely" to "Not at all"; the intermediate options on the scale were not labelled.

Six of the test sentences were the impossible items from Experiment 3 intended to be dream/story-like. The other six test sentences were those from Experiments 1 and 2 (four items), or from Shtulman & Carey (2007; two items: car vanishing into thin air, drinking lightening juice). We added these items so that there would be six items in each set.

The list also included two "catch" items, which instructed participants to give particular responses, e.g., "Having a helicopter made of jello (regardless of how you feel, please score this NOT AT ALL)." Participants who did not follow the instructions for these catch items were excluded.

Results and Discussion

The complete data are available [here](#). Participants rated the six impossible items from Experiment 3 ($M = 3.49$) as more dream/story-like than the other six items ($M = 2.95$), paired-samples t-test, $t(114) = 8.93$, $p < .001$, and as more dream/story-like than just the 4 items from Experiments 1 and 2 ($M = 3.06$), $t(114) = 7.78$, $p < .001$.

These findings suggest that the items from Experiment 3 were more typical of dreams and stories than the items used in the first two experiments.

Appendix B: Supplemental Analyses from Chapter 4

Comparison between causal conditions

The analysis included condition (between-subjects: ordinary causal-information, improbable causal-information), item-type (within-subjects: improbable, impossible), and age-in-months (centered). This revealed a main effect of condition, $F(1) = 14.59, p < .001$, as children more often agreed that a person could have improbable and impossible items if they heard causal information about how to make related improbable items than if they heard identical causal information about making ordinary items. There was also a main effect of item-type, $F(1) = 38.29, p < .001$, as children more often agreed that a person could have improbable items than impossible items.

There was a marginal effect of age, $F(1) = 3.74, p = .053$, but this effect was further qualified by a marginal interaction with information-type, $F(1) = 3.45, p = .063$. We explored this by analyzing the effect of age separately for each condition. Children's responses in the ordinary causal-information condition did not change as a function of age, $F(1) = 0.00, p = .999$. However, agreement among children in the improbable causal-information condition increased significantly with age, $F(1) = 5.90, p = .015$. No other interactions were significant, $ps \geq .139$.

Comparison between improbable conditions

The analysis included condition (between-subjects: improbable causal-information, improbable similarity-information), item-type (within-subjects: improbable, impossible), and age-in-months (centered). There was a main effect of condition, $F(1) = 4.06, p = .044$, as children were more likely to agree that a person could have both kinds of items when provided with causal information. There was a main effect of item-type, $F(1) = 87.33, p < .001$, as children

more often agreed that a person could have improbable items than impossible items. Children's agreement also increased with age, $F(1) = 3.88, p = .049$.

There was a marginal interaction between condition and age, $F(1) = 3.42, p = .064$, which was explored by analyzing the effect of age separate for each condition. Children's responses in the improbable similarity-information condition did not change as a function of age, $F(1) = 0.15, p = .694$. However, agreement among children in the improbable causal-information condition increased significantly with age, $F(1) = 5.90, p = .015$.

There was also a marginal interaction between item-type and age, which was explored by analyzing the effect of item-type separate for each age-group. Agreement towards improbable items was higher than agreement towards impossible items in each age group, though this effect was larger among 6-year-olds, $p < .001, OR = .0169$, than among 5-year-olds, $p < .001, OR = .199$.

No other interactions were significant, $ps \geq .106$.