Revising Core Beliefs in Young Children

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Abstract

A set of fundamental beliefs governs our reasoning about objects and agents since infancy. Studies have shown that infants and children show enhanced exploration and learning when they observe apparent violations of these beliefs. However, little is known about whether these beliefs can be revised given counterevidence. In the present experiments, we demonstrate that 4- to 6-year-old children can revise their most fundamental beliefs in the physical domain (Experiment 1) and the psychological domain (Experiment 2) when they observe multiple pieces of belief-violating evidence.

Keywords: belief revision; core knowledge; intuitive theories

Introduction

Developmental psychologists (e.g., Spelke & Kinzler, 2007) have argued that infants are endowed with core knowledge systems – a small number of systems of domain-specific knowledge. Later in development, infants and young children construct intuitive theories based on these systems, such as intuitive physics and intuitive psychology (e.g., Carey, 1985; Gopnik & Meltzoff, 1997; Wellman & Gelman, 1992).

Research has found that by 2.5 to 6 months of age, a set of principles guides how infants represent and reason about inanimate objects. These principles include solidity (Spelke, Breinlinger, Macomber, & Jacobson, 1992), continuity (Anguiar & Baillargeon, 1999), cohesion (Anguiar & Baillargeon, 1999), and contact (Leslie & Keeble, 1987). Infants reason about agents in ways that are distinct from their reasoning of inanimate objects. Between the ages of 6 to 12 months, infants understand that agents' intentional actions are directed to goals (Woodward, 1998), agents choose efficient means to achieve their goals (Gergely & Csibra, 2003), and agents' preferences can be inferred based on violations of random sampling[1] (Wellman, Kushnir, Xu, & Brink, 2016).

These principles are either early developing or some have argued that they might be innate. That is, these are foundational beliefs that guide later learning and development about the physical and psychological world. Yet one of the hallmarks of human learning is that beliefs can be revised given evidence (Chater & Oaksford, 2008; Tenenbaum, Kemp, Griffiths, & Goodman, 2011). Are these earliest-emerging principles and beliefs also subject to revision once we acquire them? If children are given enough evidence that violates these principles, will they rationally update their beliefs?

Studies with infants and young children have shown that counterevidence against these principles leads to enhanced attention, exploration and learning. The abovementioned studies that established these principles in infancy used the violation of expectation paradigm (VOE) and demonstrated that infants look longer at events that violates these principles. More recent studies have also shown that apparent violations of these principles led to exploration and learning. After infants observed that an object violated a physical principle, they explored that object more and showed enhanced learning of an auditory property of that object, compared to infants who observed an event that did not violate any physical principles (Stahl & Feigenson, 2015). Similarly, 3-6-year-olds robustly learned novel nouns and verbs following events that violated physical principles, but not following expected events (Stahl & Feigenson, 2017).

The literature on children's belief revision has mostly focused on beliefs about more complex domains that go beyond the basic physical and psychological principles. That literature has demonstrated children's ability to learn from counterevidence and update their beliefs. Legare and colleagues have shown that outcomes inconsistent with children's prior beliefs trigger their explanatory reasoning in both the physical domain (Legare, Gelman, & Wellman, 2010) and the psychological domain (Legare, Schult, Impola, & Souza, 2016). Those explanations lead to exploratory, hypothesis-testing behaviors that are conducive to learning (Legare, 2012). When children observed evidence that violated their initial theories about balance (Bonawitz, van Schijndel, Friel, & Schulz, 2012) and shadow (van Schijndel, Visser, van Bers, & Raijmakers, 2015), they engaged in exploratory behaviors and informative experiments. In the domain of agents, 2-year-olds can revise their initial beliefs and infer that another person has preference different from their own based on non-random sampling behaviors (Ma & Xu, 2011). Three-year-olds can update their understanding of theory of mind after observing belief-violating evidence in microgenetic sessions (Amsterlaw & Wellman, 2006). Furthermore, children's belief revision appears to be rational; their learning can be captured by Bayesian probabilistic models (e.g., Kushnir & Gopnik, 2007; Kimura & Gopnik, 2019; Lucas, Griffiths, Xu,

[1] For ease of exposition, we will refer to these as the Goal principle, the Efficiency principle, and the Sampling principle from now on.

Fawcett, Gopnik, Kushnir, Markson, & Hu, 2014; Schulz, Bonawitz, & Griffiths, 2007).

However, one question still remains. Are our most fundamental beliefs about objects and agents, already present in infancy, revisable given counterevidence? The only study we are aware of is Kushnir & Gopnik (2007), who showed that the contact principle can be revised if preschoolers were shown contrasting evidence that violated their beliefs (i.e., placing an object above the toy made it go but placing an object on the toy did not).

In the present studies, we systematically tested if children's most fundamental beliefs in the physical and the psychological domain can be revised. In the physical domain, we tested the Contact principle (i.e., objects do not interact at a distance), the Continuity principle (i.e., objects exist and move continuously in time and space), the Solidity principle (i.e., objects cannot occupy the same space as other objects). In the psychological domain, we tested the Efficiency principle (i.e., agents choose efficient means to achieve their goals), the Goal principle (i.e., agents' intentional actions are directed to goals), and the Sampling principle (i.e., agents' preferences can be inferred based on violations of random sampling). Children observed events that either supported or violated these principles. Then, they made predictions about the outcomes of new events. We hypothesized that compared to those who saw the belief-consistent evidence, children who saw the belief-violating evidence would be more likely to predict outcomes that are inconsistent with the principles. We further hypothesized that children would be more likely to revise their beliefs for the psychological principles than for the physical principles, since the physical principles emerge earlier in development and there are more violations of the psychological principles in the real world.

Experiment 1: Physical Principles

Method

Participants Twenty-four children between the ages of 4 and 6 years (mean age = 5.04; range = 4.08 to 6.92; *SD* = 0.82; 11 females) participated in the experiment. Participants were tested via Zoom, a video conferencing software. Parents of the participants provided written informed consent prior to the experimental session.

Stimuli and Procedure Families joined the Zoom session on their personal devices. The experimenter displayed the stimuli by screen-sharing the PowerPoint slides on Zoom. We instructed parents to set up their screens such that the Zoom software was in full-screen mode, and the videos of the participant and the experimenter were either beside the stimuli (i.e., side-by-side mode), or in a corner of the screen not blocking the stimuli. When the study began, children sat in front of the device and their faces were fully captured by the camera. The stimuli, the child's video, and the experimenter's video were recorded throughout the experimental sessions.

Children were randomly assigned to one of the two conditions, the Belief Consistent (BC) condition and the Belief Violation (BV) condition. They were tested on the 3 principles in counterbalanced orders. For each principle, there were 4 familiarization trials and 4 test trials (2 easy test trials and 2 hard test trials; order counterbalanced). The familiarization trials in the BC condition displayed events that were consistent with the principle and those in the BV condition displayed events that violated the principle. In test trials, children chose between the *Belief Consistent (BC) response* and the *Belief Violation* (*BV*) *response*. After each test trial, the experimenter said, "Good job!" and moved on to the next trial. The experimenter never provided feedback about whether children's choices were correct or not.

Contact principle. In the familiarization trials, a blue box appeared on the slide. The experimenter said, "This is my toy! I am going to make it go!" An object was placed either on the toy (BC condition) or above the toy (BV condition), and immediately the toy lit up and played music for 5 seconds (Figure 1). A different object was used to activate the toy in each trial.

In the easy test trials, a new object was placed next to the blue box. The experimenter said, "This plane can make my toy go!" A red star and a yellow star indicated the location on the toy (the *BC response*) and the location above the toy (the *BV response*) (Figure 1). The experimenter asked children, "Where would you put the plane to make my toy go? At the red star, or at the yellow star?"

In the hard test trials, a brown box and a new object appeared (Figure 1). The experimenter said, "The brown box is my other toy! The panda can make this toy go!" Again, children chose the location that they would place the object to activate the toy.

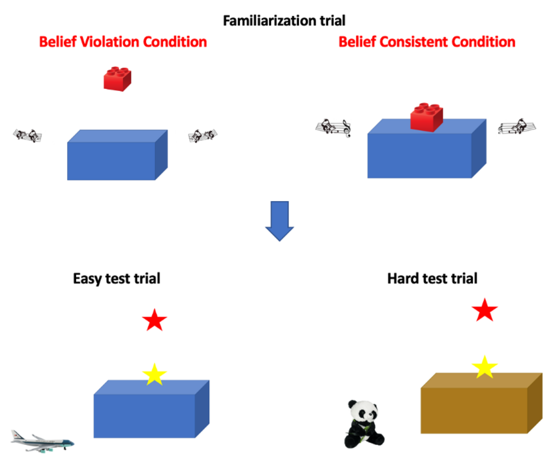

Figure 1: Events shown in the familiarization trials and test trials for the Contact principle.

Continuity principle. In the familiarization trials, two orange screens appeared side by side, with a gap in between. An object disappeared behind one of the screens. Then, the screens were removed. The object was either at the location of the screen that the object disappeared behind (BC condition) or at the location of the other screen (BV condition) (Figure 2). The object was different in each trial.

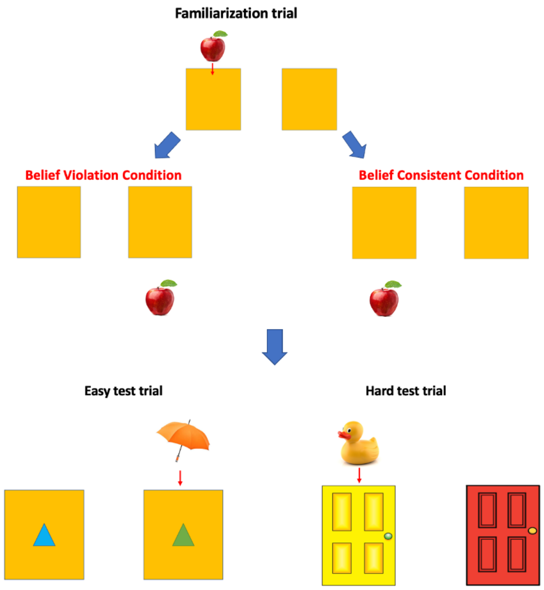

Figure 2: Events shown in the familiarization trials and test trials for the Continuity principle.

In the easy test trials, a new object disappeared behind one of the orange screens. A blue triangle and a green triangle indicated the screen that the object disappeared behind (the *BC response*) and the other screen (the *BV response*) (Figure 2). The experimenter asked, "Where do you think you will find my backpack? Behind the blue triangle, or behind the green triangle?"

In the hard test trials, a red door and a yellow door appeared. A new object disappeared behind one of the doors (Figure 2). The experimenter asked, "Which door would you open to find the duck? The yellow door, or the red door?"

Solidity principle. In the familiarization trials, a dark grey wall appeared and rotated 180 degrees to show that there was no hole on the wall. A green screen was placed in front of the wall and occluded the lower half of the wall. An object moved behind the screen. Then, the screen was removed. The object was either at the side of the wall that it went behind (BC condition) or at the other side of the wall (BV condition) (Figure 3). A different object was used in each trial.

In the easy test trials, a new object moved behind the green screen. A purple heart and an orange heart indicated the side of the wall that the object went behind (the *BC response*) and the other side of the wall (the *BV response*) (Figure 3). The experimenter asked, "Where do you think you will find my cat? Behind the purple heart, or behind the orange heart?"

In the hard test trials, two doors (side by side, with no gap in between) were placed in front of the wall and occluded the lower half of the wall. A new object moved behind the doors (Figure 3). The experimenter asked, "Which door would you open to find my notebook? The yellow door, or the red door?"

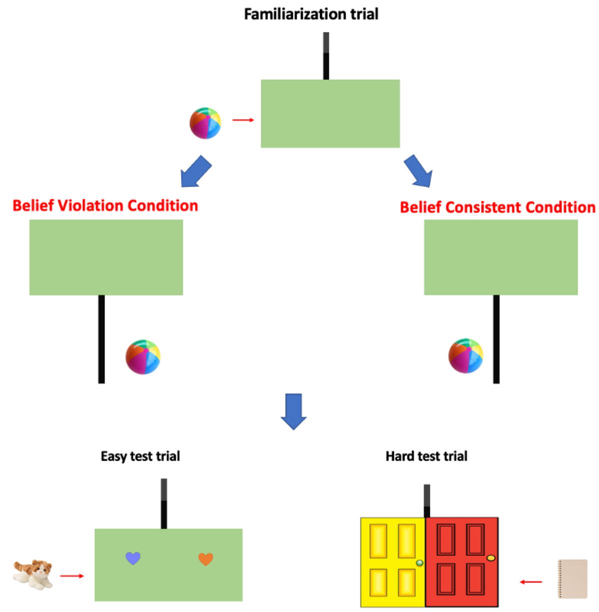

Figure 3: Events shown in the familiarization trials and test trials for the Solidity principle.

Results

The proportion of *BV response* by condition and principle are shown in Figure 4.

An n-way repeated measure ANOVA was conducted to determine the effects of condition, principle, test trial type and their interactions on *BV response*. We found a significant main effect of condition, $F(1, 124)= 50.74$, $p < .001$, as well as a significant interaction between condition and principle, $F(2, 124)= 5.56$, $p = .005$. Test trial type did not have an effect on *BV response*, $F(1, 124) = 0.453$, $p = .502$. The interactions between test trial type, condition, and principle were not significant.

For the main effect, children in the BV condition selected the *BV response* more than children in the BC condition ($M_{BV} = .67$, $SD_{BV} = .4$, $M_{BC} = .23$, $SD_{BC} = .35$, $t(20.8) = -5.64$, $p < .001$, Cohen's $d = 1.17$). Post-hoc pairwise comparison showed that the effect of condition was significant for the Continuity principle ($M_{BV} = .81$, $SD_{BV} = .34$, $M_{BC} = .10$, $SD_{BC} = .20$, $t(17.73) = -6.25$, $p < .001$, Cohen's $d = 2.55$), the Solidity principle ($M_{BV} = .69$, $SD_{BV} = .36$, $M_{BC} = .30$, $SD_{BC} = .33$, $t(21) = -2.73$, $p = .013$, Cohen's $d = 1.13$), and marginally significantly for the Contact principle ($M_{BV} = .5$, $SD_{BV} = .3$, $M_{BC} = .27$, $SD_{BC} = .27$, $t(21.75) = -1.96$, $p = .063$, Cohen's $d = 0.81$).

For the interaction between condition and principle, the *BV response* in the BV condition was higher for the Continuity principle ($M = .81$, $SD = .34$) than for the Contact principle ($M = .5$, $SD = .30$), $t(21.7) = -2.39$, $p = .026$, Cohen's $d = 0.67$.

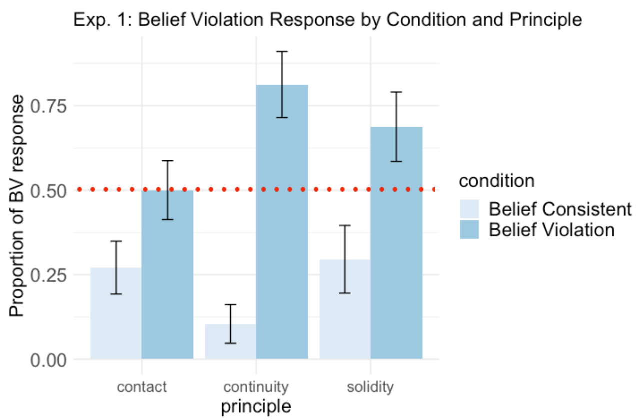

Figure 4: The proportion of trials that children selected the *BV response* by condition and principle, in Experiment 1. Error bars represent one standard error of the mean.

Discussion

Taken together, these results suggest that 4- to 6-year-olds can revise their beliefs about the most fundamental principles that govern object representation. When given evidence that supported their prior beliefs, children mostly selected the outcomes that were consistent with the principles. But when given evidence that violated their prior beliefs, they were more likely to select the outcomes that were inconsistent with the principles. Children revised their beliefs about both the events that are similar to the counterevidence (easy test trials) and events that are different from the counterevidence (hard test trials), suggesting that they generalized the revised beliefs to new situations.

Children's responses were largely consistent across the 3 physical principles. They reliably revised their beliefs for the Continuity and the Solidity principle when given belief-violating evidence. For the Contact principle, children were also more likely to select the *BV response* after observing belief-violating evidence (this result is not statistically significant, but the effect size is large).

Experiment 2: Psychological Principles

Method

Participants The same 24 children who participated in Experiment 1 also participated in Experiment 2 in the same session. The order that they completed the two experiments were counterbalanced. Children were assigned to different conditions in Experiment 1 and 2 (e.g., if a child was in the BV condition in Experiment 1, then she would be in the BC condition in Experiment 2).

Stimuli and Procedure The procedure of Experiment 2 was similar to that of Experiment 1, except that the principles tested were the Efficiency principle, the Goal principle, and the Sampling principle. Because each familiarization trial was longer in Experiment 2 than in Experiment 1, there were 3 familiarization trials, instead of 4, to control for the time that children spent in the familiarization phase.

Efficiency principle. In the familiarization trials, a dark grey wall appeared and rotated 180 degrees to show that there was no hole on the wall. Two agents (i.e., shapes of different colors with eyes) appeared. The experimenter said, "The red kid wants to play with the yellow kid." The red agent went toward the yellow agent by jumping over the wall. Then, the wall was moved to the side. The red agent went toward the yellow agent by taking a straight path (BC condition) or a jumping path (BV condition) (Figure 5). The goal was a different agent in each trial.

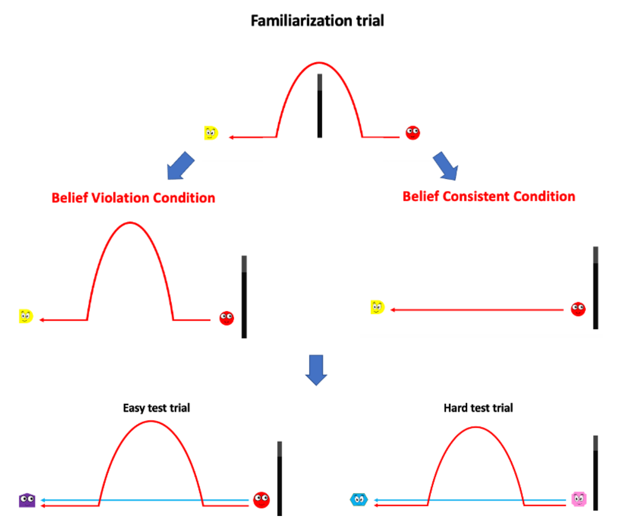

Figure 5: Events shown in the familiarization trials and test trials for the Efficiency principle.

In the easy test trials, the red agent went toward a new agent by jumping over a wall. Then, the wall was moved to the side. A red path and a blue path indicated the jumping path (the *BV response*) and the straight path (the *BC response*) (Figure 5). The experimenter said, "The red kid wants to play with the purple kid. Which path will the red kid take? The red path or the blue path?"

In the hard test trials, two new agents appeared. The pink agent went toward the green agent by jumping over the wall. Then, the wall was moved to the side. Again, children chose the path that they thought the pink agent would take.

Goal principle. In the familiarization trials, an agent and 2 objects appeared. The agent repeatedly went toward one of the objects and took the object (e.g., the bear) for a total of 3 times. Then, the two objects switched locations. The agent either took the new object at the old location (e.g., the soccer ball) (BV condition) or the old object at the new location (e.g., the bear) (BC condition) (Figure 6). A different pair of objects was used in each trial.

In the easy test trials, a new pair of objects appeared. The same agent repeatedly took one of the objects 3 times. Then the two objects switched locations. Children were asked, "Which toy will the pink kid take, the fox or the drum?" The new object at the old location is the *BV response* and the old object at the new location is the *BC response*.

In the hard test trials, a new agent and a different pair of objects appeared. The agent repeatedly took the same objects for 3 times. Then, the two objects switched locations. Again, children chose the object they thought the agent would take.

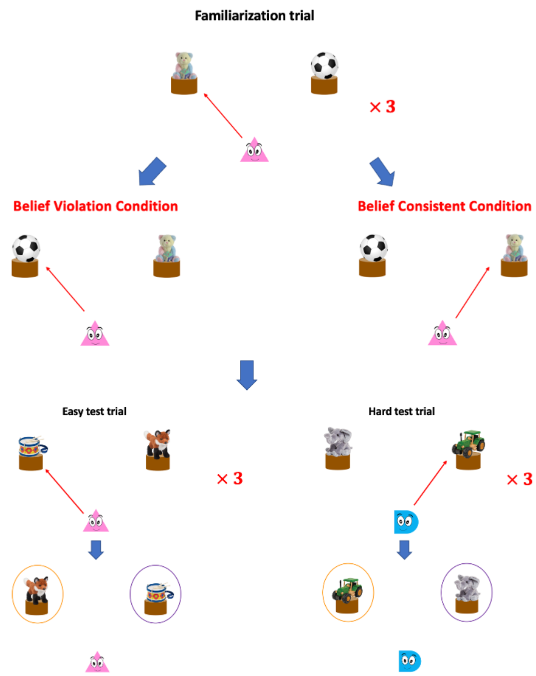

Figure 6: Events shown in the familiarization trials and test trials for the Goal principle.

Sampling principle. In the familiarization trials, an agent and a box of objects appeared. The box contained 7 objects of one type and 31 objects of the other type. The agent picked out 4 objects of the minority type from the box and put them into a small box in front of the agent. Then, one object of each type appeared, equidistant from the agent. The agent went toward the majority type (BV condition) or the minority type (BC condition) (Figure 7).

In the easy test trials, the same agent sampled 4 objects of the minority type from a new toy box. Then, one object of each type appeared, equidistant from the agent. Children were asked, “Which toy does the green kid like better, the green one or the brown one?” The majority type object is the *BV response,* and the minority type object is the *BC response.*

In the hard test trials, a new agent sampled 4 objects of the minority type from a new toy box. Then, one object of each type appeared, equidistant from the agent. Children chose the object that they thought the agent liked better.

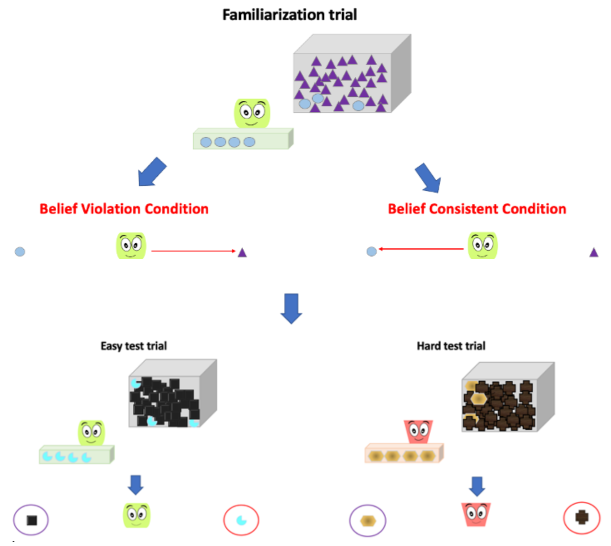

Figure 7: Events shown in the familiarization trials and test trials for the Sampling principle.

Results

The proportion of *BV response* by condition and principle are shown in Figure 8.

An n-way repeated measure ANOVA was conducted to determine the effects of condition, principle, test trial type and their interactions on *BV response*. There was a significant main effect of condition, $F(1, 120)= 28.43$, $p < .001$, as well as a significant interaction between condition and principle, $F(2, 120)= 7.46$, $p < .001$. Test trial type did not have an effect on *BV response*, $F\ (1, 124) = 0.582$, $p = .447$. The interactions between test trial type, condition, and principle were not significant.

For the main effect, children in the BV condition were more likely to select the *BV response* than children in the BC condition ($M_{BV} = .72$, $SD_{BV} = .33$, $M_{BC} = .4$, $SD_{BC} = .4$, $t(19.9) = 4.10$, $p < .001$, Cohen’s $d = 0.87$). Post-hoc pairwise comparison showed that the effect of condition was significant for the Goal principle ($M_{BV} = .79$, $SD_{BV} = .32$, $M_{BC} = .35$, $SD_{BC} = .42$, $t(20.5) = -2.88$, $p = .009$, Cohen’s $d = 1.18$), and Sampling principle ($M_{BV} = .69$, $SD_{BV} = .37$, $M_{BC} = .19$, $SD_{BC} = .24$, $t(12.95) = -3.58$, $p = .003$, Cohen’s $d = 1.60$), but not significant for the Efficiency principle ($M_{BV} = .65$, $SD_{BV} = .25$, $M_{BC} = .65$, $SD_{BC} = .25$, $t(22) = 0$, $p = 1$).

For the interaction between condition and principle, *BV response* in the BC condition was higher for the Efficiency principle ($M = .65$, $SD = .25$) than the Sampling principle ($M = .19$, $SD = .24$), $t(21.98) = 4.58$, $p < .001$, Cohen’s $d = 1.26$, and marginally significantly higher than the Goal principle ($M = .35$, $SD = .42$), $t(17.91) = 2.07$, $p = .052$, Cohen’s $d = 0.59$.

Lastly, we analyzed the results of Experiment 1 and Experiment 2 to test for any domain differences.

A two-way ANOVA was conducted to determine the effects of condition, domain, and their interaction on *BV response*. There was a significant effect of condition, $F(1, 44)=$

47.50, p < .001, and a marginally significant effect of domain, $F(1, 44)= 3.93$, $p = .054$. For the condition effect, *BV response* was higher in the BV condition than in the BC condition ($M_{BV} = .69$, $SD_{BV} = .18$, $M_{BC} = .31$, $SD_{BC} = .21$, $t(45.28) = 6.67$, $p < .001$, Cohen's $d = 1.47$). For the domain effect, *BV response* across both conditions was slightly higher in the psychological domain ($M = .56$, $SD = .25$) than in the physical domain ($M = .45$, $SD = .29$).

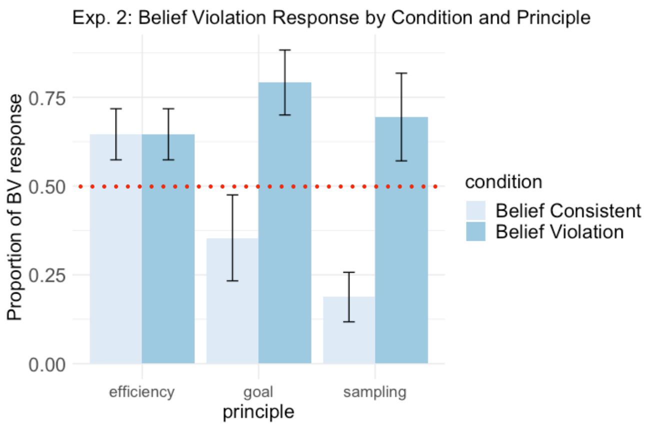

Figure 8: The proportion of trials that children selected the *BV response* by condition and principle, in Experiment 2. Error bars represent one standard error of the mean.

Discussion

The results from Experiment 2 suggest that 4- to 6-year-olds can also revise their beliefs about agents when they are shown counterevidence. Children revised their beliefs about both the agents shown in the counterevidence (easy test trials) and different agents (hard test trials), suggesting that they were generalizing the revised beliefs to new agents.

For the Goal and the Sampling principle, children reliably revised their beliefs when given belief-violating evidence. For the Efficiency principle, children were already selecting the *BV response* in more than half of the trials in the BC condition. As a result, their *BV response* did not increase in the BV condition compared to the BC condition. This finding suggests that children may have a weaker prior belief for the Efficiency principle (i.e., agents choose the most efficient means to achieve their goals).

General Discussion

In the first few months of our lives, we have already formed the most fundamental beliefs about objects and agents that are important for our later learning in these domains. In two experiments, we showed children evidence that either supported or violated these beliefs. We found that children revised their beliefs for most of the principles tested when they observe multiple pieces of belief-violating evidence, and generalized the revised beliefs to new situations and new agents.

For the Continuity principle, the Solidity principle, the Goal principle and the Sampling principle, children reliably revised their beliefs after observing the counterevidence. The effect of the counterevidence was weaker for the Contact principle, but the results were in the predicted direction. Interestingly, children might have a weaker prior belief for the Efficiency principle, and therefore the counterevidence did not have any effect on their beliefs.

Since the counterevidence was presented through a slide show on Zoom, and since some of our stimuli resemble cartoon characters, it is possible that children believed that the events in this slide show did not have to conform to the real-world principles, or that they were interpreting the events as pretense or fantasy scenarios. In a follow-up study, we are asking children to explain the belief-violating events at the end of the study, to assess their interpretation of the evidence.

We also found that children were more likely to choose the outcomes that violated the principles in the psychological domain than in the physical domain. This might also suggest that they have weaker prior beliefs for the psychological principles, perhaps because there are more violations of these principles in the real world. Future research is needed to test this possibility. In the current experiments, however, to equate the total time that children spent in the familiarization phase, we did not control for the number of familiarization trials that children received in the two experiments. Thus, children in Experiment 1 received one more piece of evidence supporting or violating each of the principles, which might explain the observed domain difference. In the follow-up study, we are controlling for the number of familiarization trials instead, in order to test the reliability of this domain difference. In order to more accurately measure the strength of children's prior beliefs, we also include a baseline condition (without the familiarization phase) in the follow-up study.

The present study reports the first systematic investigation of whether children can revise their earliest and most fundamental beliefs in the physical and psychological domains. We found that with just a few pieces of counterevidence, children were able to revise most of these principles. Our study also revealed intriguing differences across domains and principles, and raise many questions for future studies. For example, we may manipulate the strength of the counterevidence to see if it increases the proportion of belief-violation responses; we may probe whether there are indeed more violations of some of the principles – contact, efficiency – in the real world than others, which may make these principles more probabilistic than others.

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