Don’t throw the (associative-learning) baby out with the bathwater just yet: Backwards-blocking reasoning with *multiple* potential causes in human children

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Data availability statement: The code and network-modeling scripts are available upon reasonable request.

Conflicts of interests: none

Abstract

Causal reasoning is a fundamental cognitive ability that enables humans to learn about the complex interactions in the world around them. However, the available evidence suggests that the mechanism or set of mechanisms that underpin causal reasoning are not well understood. It is unclear, for example, whether causal reasoning is underpinned by a Bayesian mechanism, an associative mechanism, or both. Some theorists have argued that a Bayesian mechanism underpins causal reasoning because it can better account for backward-blocking (BB) and indirect screening-off (IS) findings in children and adults (e.g., Sobel, Tenenbaum, & Gopnik, 2004). However, the evidence is mixed about the extent to which learners engage in both kinds of reasoning. Here, we report three experiments that examine to what extent adults engage in BB and IS reasoning using the blicket-detector design (e.g., Gopnik et al., 2001), what mechanism best explains their behavior in this task, and under what conditions are adults’ causal ratings consistent with the predictions of the three competing computational and analytical models. The results of Experiment 1 revealed that adults’ causal ratings in the backwards-blocking condition (as well as in the indirect screening-off condition) were consistent with the predictions of the traditional and modified Rescorla-Wagner models when asked to reason about two objects. The results of the present study suggest that adults use associative processes to reason about two objects but a Bayesian-inference-like process to reason about three or more objects.

Keywords: causal reasoning; causal mechanisms; computational models; analytical models; associative learning; Bayesian inference

Few capacities are more important than the ability to reason and make inferences about cause-and-effect relations. This is a key cognitive ability that enables human learners to encode causal relations to inform prediction and inference (e.g., Leslie & Keeble, 1987; Oakes & Cohen, 1990), to intervene on those relations to generate new effects (e.g., Gopnik et al., 2001), and counterfactually to reason about causal events to determine what would have happened if alternative actions were chosen (e.g., Harris, German, & Mills, 1996; Sobel, 2004).

To date, most studies on causal reasoning in human children have used the blicket-detector design. In these studies, children are introduced to a machine called the "blicket detector" and told that the machine lights up and plays music when certain objects—namely, "blickets"—are placed on it. Children are then asked to determine which objects are blickets and to “make the machine go” by placing the blicket on the machine.

Research with this paradigm has yielded a number of important insights about causal reasoning in human children such as the fact that causal reasoning generally emerges by 19 months of age (e.g., Benton, Rakison, & Sobel, 2021; Gopnik & Sobel, 2000; Gopnik et al., 2001; Kimura & Gopnik, 2019; Meltzoff, Waismeyer, & Gopnik, 2012; Sobel & Kirkham, 2006; Sobel & Munro, 2006; Walker & Gopnik, 2014), but the finding that has generated that the most discussion was that by Sobel, Tenenbaum, and Gopnik (2004). They showed that by 4 years of age children can engage in two forms of causal reasoning called “backwards-blocking” (henceforth, BB) reasoning and “indirect screening-off” (henceforth, ISO) reasoning. BB reasoning is the process by which learners discount or “block” causal cues that are revealed to be redundant in producing some effect. ISO reasoning is the process by which learners discount or “screen off” a causal cue that is shown not to produce some effect and whose causal status is known unambiguously.

In their study, children were first shown that two novel objects, A and B, together caused the detector to activate when they were placed on the machine. Children were then shown that object A alone either failed to activate the detector (i.e., AB+ A-; ISO condition) or activated the detector when placed on it (i.e., AB+, A+; BB condition). Children in both conditions were then asked which of the two objects were blickets and to make the machine go by placing the blicket on the detector. Sobel et al. (2004) found that the 4-year-olds responded by placing object B on the machine in the ISO condition; these same children responded by placing object A on the machine in the BB condition. Subsequent research by Sobel and Munro (2009) found that 3-year-olds could also engage in BB and ISO reasoning if the machine possessed animate-like qualities.

These findings were interpreted to mean that human children can engage in BB reasoning based on Bayesian-inference. Proponents of the Bayesian-inference perspective maintain that human learners use a simple form of Bayes’ rule to reason about causal events and to choose the causal hypothesis—within a psychological hypothesis space that can contain infinitely many hypotheses—that is most consistent with the observed data (e.g., Sobel et al., 2004; Gopnik & Wellman, 2012). These findings were also argued to rule out as veritable models of human causal reasoning certain classes of associative learning models such as the traditional Rescorla-Wagner (RW) model mean that associative-learning processes cannot explain how human children reason about causal events (e.g., Rescorla & Wagner, 1972; Griffiths et al., 2011; Sobel et al., 2004). This model has been criticized because it predicts that object B should be treated equivalently across the BB and ISO conditions—this prediction is at odds with participants’ actual treatment of object B across conditions.

Some caution should be exercised either before accepting the conclusion that Bayesian inference rather than associative learning underpins how children process BB events. One reason concerns the fact that there are significant problems with how BB reasoning itself has been measured in previous research. For example, Sobel et al. (2004; see also Beckers et al., 2009; McCormack et al. 2009, Exp. 1; Sobel & Kirkham, 2006) operationally defined BB reasoning as greater B choices in the ISO condition than in the BB condition (although for alternative operationalizations, see De Houwer, Beckers, & Glautier, 2002; Larkin, Aitken, & Dickinson, 1998; Griffiths et al., 2011; Kruschke & Blair, 2000; Lovibond et al., 2003; Shanks, 1985; Van Hamme and Wasserman, 1994). This operationalization suffers from two key limitations. First, as Beckers et al. (2005) and McCormack et al. (2009) pointed out, it cannot be determined *why* participants treated object B differently between the BB and ISO condition. For example, participants could have treated B differently between the BB and ISO conditions because of a BB effect, an ISO effect, or both. Participants could have also treated B differently between these conditions because they observed a positive effect during the elemental (i.e., A+) phase in the BB condition but a negative effect during the elemental (i.e., A-) phase in the ISO condition. Crucially, neither of these alternative explanations would be evidence of a true retrospective reevaluation of object B by participants based on A’s *relation to and effect* *on* object B across both conditions (which is the intended inference).

The operationalization that we adopt here—which was independently discovered by McCormack et al. (2009, Exp. 2)—eschews this limitation. Specifically, we operationalize BB reasoning by comparing how participants treat object B following an AB+ A+ sequence of events (i.e., the BB experimental condition) to how participants treat object B following an AB+ C+ sequences of events (i.e., the BB control condition). These two conditions differ in terms of the object that is shown during the elemental phase (i.e., A or C) and that object’s *relation* to B (and thereby the potential impact that this object has on how B is treated). For example, in the BB experimental condition, a dependency is presumably established between objects A and B because both objects appear together during the compound phase of the condition. This means that the observed causal efficacy of object A during the subsequent elemental phase *should* affect participants’ (retrospective) treatment of object B. In contrast, in the BB control condition, object C never appeared with object B, which necessarily means that C’s causal status should not affect how participants evaluate object B. Crucially, the blicket effect itself is held constant such that, across both conditions and the compound and elemental phases the machine activates.

Still another reason to exercise caution before accepting the claim that human beings use Bayesian inference to engage in BB reasoning is that it remains unknown whether human children engage in BB reasoning for three (or more) objects. Consider a modified version of the standard BB event in which children first see an ABC+ sequence followed by an A+ sequence. If BB reasoning is an ability that is unaffected by the number of objects with which children are presented, then they should be less likely to label objects B and C as blickets compared to the same objects in a control event in which ABC+ is followed by D+. Relatedly, it remains unanswered whether the BB reasoning performance of children depends on the number of objects that are presented during the typically single-object elemental phase (the A+ of the BB event). For instance, how will children treat object C if they are shown the same ABC+ event as before but this time followed by an AB+ event (compared to a control event in which children are shown an ABC+ event followed by a DE+ event)? These questions are worth addressing because if the goal is to elucidate and better understand the cognitive mechanisms that subserve causal reasoning *in the real world*, then it is crucial that we understand how causal reasoning unfolds in situations that mirror children’s natural environments.

One may question whether asking children to reason about three to five objects can really tell us more about the cognitive mechanisms that underpin causal reasoning than asking children to reason about two objects. This is because the two situations differ trivially by at most three potential causes. However, if Bayesian inference is the cognitive mechanism that underpins BB reasoning, then the difference between these two settings is far from trivial. This is because in the two-potential-cause setting, participants need only to determine which of *four* candidate causal hypotheses generated the observed data. In contrast, in the three-, four-, and five-potential-cause setting, participants need to determine which of *eight* (in the case of 3 candidate causes), *sixteen* (in the case of 4 potential causes), or even *thirty-two* hypotheses (in the case of 5 potential causes) is the one that generated the observed data. This means that participants must consider eight times as many causal hypotheses in the five-potential-cause setting as participants in the two-candidate-cause setting.

Crucially, this difference may have important implications for the nature of the underlying cognitive mechanisms; that is, this difference may have important implications about whether an associative-learning mechanism or a Bayesian-inference mechanism underlies causal reasoning in children. For instance, it is possible that when children’s information-processing abilities are taxed—such as when they are asked to reason about three (or more) objects (see the General Discussion for a fuller discussion)—they may resort to simpler modes of causal inference that are better explained by associative processes. Crucially, this may be independent of whether participants engage in BB reasoning. Thus, if participants’ performance in a BB task adheres to the predictions of an associative-learning mechanism (see below) in a setting that includes many potential causes, this would suggest associative learning is sufficient to account for causal learning in human children.

There is one final reason to exercise caution before accepting the claim that Bayesian inference rather than associative learning based on the RW model subserves how human children reason. This concerns the fact that associative-learning processes may well explain how children process causal events that involve more than the number of objects that are typically used in causal studies with children. For example, one class of models that could account for how children processed the BB events in the present series of experiments is connectionist artificial neural networks. These models consist of “neuron-like” processing units, which are organized into layers. These layers typically include an input layer, a hidden layer, and an output layer. Layers within a connectionist model are connected to each other via modifiable weights. The input layer of a connectionist model is typically connected to the hidden layer immediately “above” it via adjustable connections. The hidden layer, in turn, is typically connected to the output layer via a different set of adjustable connections weights. Training in these models typically proceeds by presenting them with some pattern of activation along the input layer, comparing the model’s “observed” pattern of activation along the output layer to some “desired” pattern of activation along the same layer, and then using one or more algorithms or procedures to adjust the weights. The purpose of these weight adjustments is to reduce the difference between the observed and desired output.

A fundamental feature of these models is that they are fundamentally associative-learning devices—the weights encode associations among units in the model, and the learning procedures that are used to modify the weights in the models operate either to strengthen or to weaken those associations. This means that these models can serve as a proof of concept that associative learning, perhaps in conjunction with richly structured input and maybe a small number of learning biases (e.g., Rakison & Lupyan, 2008), is often sufficient to account for various aspects of cognitive development (e.g., Benton & Lapan, 2022; Benton et al., 2021; Cohen et al., 2002; Mareschal et al., 2000; Munakata et al., 1997; Rakison & Lupyan, 2008; Westermann & Mareschal, 2004; for an extensive review see Yermolayeva & Rakison, 2013). We show that this modeling formalism is not only sufficient to explain how children processes the present BB events, but that it provides a better account of the present data than a simple Bayesian model.

**Possible cognitive mechanisms underlying BB reasoning for multiple potential causes**

Given that one of the goals of the current series of experiments was to elucidate whether Bayesian inference or associative learning subserved children’s causal inferences, a critical first step was to derive the predictions of a simple Bayesian model and to build a simple connectionist model of the present series of experiments. We restrict our discussion below to each model’s predictions but interested readers should consult the Appendix for the formal details of the Bayesian model.

**Bayesian inference.** Proponents of the Bayesian-inference account maintain that human learners use a simple form of Bayes’ rule to determine which hypothesis is responsible for the observed data. Learners achieve this by combining their prior beliefs about each hypothesis (in the absence of data; this is sometimes called the “prior”) with the likelihood that the observed data was produced by a particular hypothesis (this is sometimes called the “likelihood”). Given that learners were asked to reason about three potential causes (i.e., objects A-C) during the experimental trials in both the BB and ISO conditions and four potential causes during the control trials in both the BB and ISO conditions (i.e., objects A-D), the corresponding psychological hypothesis spaces consist, respectively, of 8 and 16 hypotheses. Figure 1 below shows the hypothetical hypothesis space for three objects.

**Timeline

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Figure 1. The eight different causal hypotheses indicating the possible causal relations for a causal event that involves three objects and one blicket detector. *A*, *B*, and *C* correspond to the three objects that were used on the machine and *E* indicates the activation of the machine.

By application of Bayes’ rule, the prediction that this model makes for how participants should treat the objects after the BB main trial is shown below in Table 1.

|  |  |
| --- | --- |
| BB Experimental Condition – 3 objects | |
| Object A | 1 |
| Object B | p |
| Object C | *p* |
| BB Control Condition – 4 objects | |
| Object A | *p* |
| Object B | *p* |
| Object C | *p* |
| Object D | 1 |

Table 1. This table displays the predictions of the Bayesian model for the BB experimental and control trials.

As can be seen in Table 1, this model predicts that following the AB+ A+ BB experimental event participants should be maximally confident that object A is a blicket but should categorize as blickets objects B and C at the same rate. In contrast, the model predicts that following the ABC+ D+ BB control trials participants should be maximally confident that object D is a blicket after the BB control trials but should treat objects A-C equivalently. The model’s predictions for the ISO experimental and control trials is shown below in Table 2.

|  |  |
| --- | --- |
| ISO Experimental Condition – 3 objects | |
| Object A | 0 |
| Object B | p |
| Object C | *p* |
| ISO Control Condition – 4 objects | |
| Object A | *p* |
| Object B | *p* |
| Object C | *p* |
| Object D | 0 |

Table 2. This table displays the predictions of the Bayesian model for the ISO experimental and control trials.

As is shown in Table 2, this model predicts that*,* following the AB+ A- ISO experimental event participants should be maximally confident that object A is not a blicket but should treat objects B and C equivalently. In contrast, the model predicts that following the ABC+ D- ISO control trials participants should be maximally confident that object D is not a blicket after the ISO control trials but should treat objects A-C equivalently. In sum, a simple Bayesian model predicts that learners should be maximally confident about the status of a candidate cause when it is shown in isolation but should treat objects that are shown in combination (and never alone) equivalently.

**Associative learning: a simple “counting” cognitive mechanism.** In contrast, to explore whether associative learning could account for children’s inferences in the present context, we built a simple, two-layer connectionist computational model (Figure 2). The model used to simulate Experiments 1 and 2 consisted of an input layer and an output layer. The input layer for the model that simulated Experiment 1 consisted of four units, and the output layer consisted of a single unit. Each input unit corresponded to each of the four possible objects used in Experiment 1. The input layer for the model that simulated Experiment 2 consisted of five units, which corresponded to each of the five possible objects used in Experiment 2. The input units for objects that were presented to the model was set to a value of “1”; these units were set to a value of “0” if the corresponding objects were not presented to the model. The single output unit was set to a value of “1” whenever a predetermined blicket was presented to the model. This simulated “activation” of the blicket detector. In contrast, this output unit was set to a value of “0” whenever a non-blicket was presented to the model. This simulated “non-activation” of the blicket detector. If a predetermined blicket was presented at the input layer, then the model was trained to turn on the single output unit (i.e., to produce an activation of 1). All simulations (unless noted) used a learning rate of .05 but no momentum.

The models were trained on the same events as children in Experiments 1 and 2. For example, for Experiment 1 models, networks were randomly assigned to the ISO condition or to the BB condition. To match the behavioral experiment, within conditions networks experienced two of each kind of event. For example, during the two “experimental trials” for networks in the BB condition, the first three input units were turned on (i.e., the activation of each input node was set to a value of 1), and the network’s task was to learn to activate the single output unit (i.e., set the activation of the single output unit to 1). Turning on the first three input units corresponded to presenting the model with objects A, B, and C, and training the model to turn on the single output unit corresponded to the activation of the blicket machine. This segment of training corresponded to the ABC+ events. During the A+ “elemental” trials, only the first input unit was turned on, but again the network had to learn to activate the single output unit. The BB control trials were identical to the BB experimental trials except that the fourth input unit (corresponding to object D) rather than first input unit was turned on. The ISO experimental and control trials were identical to the BB experimental and control trials except that the network was trained not to turn on the single output unit during the elemental phase of the ISO experimental and control trials were identical to the BB experiment Both segments lasted 50 epochs (for a total of 100 epochs of training). An alternative cognitive mechanism that children may rely on is a simple associative based “counting” strategy. We argue that this kind of mechanism is sensitive to the frequency with which (i.e., the number of times that) a given object—shown either individually or in combination with other objects—appeared with the blicket effect. To understand how this process might work mechanistically, consider the ABC+ D+ BB control trial. In contrast to the simple Bayesian model, this mechanism predicts that learners should treat objects A-D equivalently following the BB control event. This is because all four objects would have been paired with the machine’s activation an equal number of times: object A-D would have been seen with the machine’s activation exactly once. Below in Table 4 are the predictions that this account makes for all four conditions.

|  |  |  |  |
| --- | --- | --- | --- |
| The predictions of a simple associative-based counting mechanism | | | |
| BB main – ABC+ A+ | | | |
| Is A a blicket? | Is B a blicket? | Is C a blicket? | Is D a blicket? |
| +2 | +1 | +1 | N/A |
| BB control – ABC+ D+ | | | |
| Is A a blicket? | Is B a blicket? | Is C a blicket? | Is D a blicket? |
| +1 | +1 | +1 | +1 |
| ISO main – ABC+ A- | | | |
| Is A a blicket? | Is B a blicket? | Is C a blicket? | Is D a blicket? |
| 0 | +1 | +1 | N/A |
| ISO control – ABC+ D- | | | |
| Is A a blicket? | Is B a blicket? | Is C a blicket? | Is D a blicket? |
| +1 | +1 | +1 | 0 |

Table 4. This table shows the predictions a simple counting mechanism makes for the BB experimental and control trials and the ISO experimental and control trials. A 0 indicates that the number of times that a particular object was paired with the machine’s activation was exactly cancelled out by the number of times that it was paired with the machine’s inactivation. A +1 indicates that a particular object was paired with the machine’s activation once. A +2 indicates that a particular object was paired with the machine’s activation twice. Learners are said preferentially tos choose objects with larger values.

As shown in the table above, this account predicts that for the BB main trials children should say that object A is a blicket significantly more often than either B or C but that their treatment of B and C should not differ. This is because objects B and C would have been paired with the machine exactly once. In contrast, object A would have been paired with the machine twice. Similarly, this account predicts that during the BB control trials participants’ treatment of all four objects should not differ. This prediction results from the fact that all four objects would have been paired with the machine’s activation exactly once. In contrast, this account predicts that for the ISO experimental trials participants should not consider object A to be a blicket but should be split in their treatment of objects B and C because B and C would have been paired with the machine’s activation an equal number of times. Likewise, during the ISO control trials, this account predicts that participants should not consider object D to be a blicket but should be split in their treatment of objects A, B, and C.

**The present investigation**

The present investigation had two goals. First, it was designed to determine whether 5- and 6-year-olds could engage in BB reasoning for three and four objects and when a more appropriate measure of such reasoning was used. Second, it was designed to gain greater insight into how—that is, by what underlying cognitive mechanism—children reasoned about the present causal events. We aimed specifically to determine which of two cognitive mechanisms—that is, a Bayesian-inference mechanism or an associative based counting mechanism—best explained children’s causal inferences in the present context.

**Current study**

Five- and 6-year-old children were introduced to a computer-animated machine called the “blicket detector” and were told that their task was to determine which objects activated the machine. They were told that objects that made the machine “go” were “blickets”; objects that did not make the machine go were not blickets. Participants then received either two BB main trials and two BB control trials or two ISO main trials and two ISO control trials. Participants in both conditions were then asked to indicate whether the objects in each trial were blickets. Participants were randomly assigned to the BB or ISO conditions.

**Method**

**Participants.** Participants were 32 5-year-olds (16 boys and 16 girls) and 31 6-year-olds (17 boys and 15 girls). Sample size was determined based on previous studies on BB reasoning in human children (e.g., Gopnik & Sobel, 2000; Griffiths et al., 2011; Sobel et al., 2004). Two children were excluded from analysis for failing to participate (*N* = 1) or missing video (which made coding their responses impossible) (*N* = 1). Although most children were from white, middle-class backgrounds, a range of ethnicities that resembled the diversity in the population were represented. All children were tested in a quiet room at a local children’s museum.

**Materials.** The “device” used in the current study was a computer-animated version of the blicket detector. The device was a white rectangle with a black border that measured 5.99 cm × 23.47 cm. If the device was “on”, the white region of the rectangle turned blue. If the device was “off”, the white region remained white. A maximum of 4 differently colored circles were used, and each circle measured 2.67 cm × 2.67 cm (see Figure 2 below). The machine was designed such that it activated immediately when a circle that was predetermined to be a blicket contacted it. At the start of any given trial, three (for the BB or ISO experimental trials) or four equally spaced (for the BB or ISO control trials) circles appeared above the blicket machine. Finally, the videos contained a built-in script, which experimenters were instructed to read. All video events were created in Microsoft PowerPoint.

**Procedure.** Participants were either tested in a quiet room in local children’s science museum. At the beginning of the experiment, all participants were shown a pretraining video. The video consisted of a rectangular base (i.e., the previously mentioned blicket detector) and two shapes (i.e., a gray triangle and a gray pentagon). Crucially, these shapes were unrelated to the circles used during the main portion of the experiment. The pretraining phase began with the triangle (object A) and pentagon (object B) above the machine and next to one another. Object A then descended until it contacted and immediately activated the machine (i.e., the white region changed from white to blue). Object A then returned to its starting position above the machine. Object B then descended until it contacted and failed to activate the machine. Object B then returned to its starting position. Finally, both objects descended until they contacted and activated the machine. Participants were then asked whether each object was a blicket. This event was identical to the “one-cause” event in Gopnik et al. (2001) and was included to ensure that participants understood the task.

Diagram

Description automatically generated

Figure 2. Schematic of one of the two BB experimental events. The upper-right portion of the figure shows the BB event as it unfolded across time. The lower-left portion of the figure shows the three objects and the text, “Is this one a blicket?” above each object across time.

Following the pretraining phase, participants were given four test trials—either the two BB experimental trials and 2 BB control trials or two ISO experimental trials and 2 ISO control trials—in counterbalanced order using a Latin square. Differently colored objects were used across all trials to prevent carryover effects.

The two BB main trials began with three differently colored objects, which were located above the machine. The text, “Look, I have these three toys. Let’s find the blickets. Watch what happens” appeared above the objects. All three objects (i.e., objects A, B, and C) then descended until they contacted and activated the machine. At this point, the text, “Look, these also make the machine go!” appeared above the objects. The objects then returned to their starting positions. The left- or right-most (counterbalanced) object (i.e., object A) then descended until it contacted and immediately activated the machine. The text, “Look, this one makes the machine go!” then appeared above the objects. This object then returned to its starting position. Children were then asked whether each object was a blicket. Specifically, the text, “Is this one a blicket?” with a downward-facing arrow then appeared above each object, and participants were asked to indicate whether each object was a blicket. The first and second BB experimental trials were identical except for the object colors.

The two BB control trials began with four differently colored objects (i.e., objects A, B, C, and D), which were located above the machine. Objects A, B, and C then descended until they contacted and activated the machine; object D remained in place while objects A-C descended onto the machine. Object D then descended by itself until it contacted and activated the machine. The left-right position of object D was counterbalanced. Children were then asked whether each object was a blicket. The experimental and control trials used the same text.

Finally, the ISO experimental and control conditions were identical to the BB experimental and control conditions except that objects A (during the ISO main trials) and D (during the ISO control trials) failed to activate the machine (see Table 5 for a schematic).

|  |  |  |  |
| --- | --- | --- | --- |
| Schematic of Experiment 1 | | | |
|  | Compound | Elemental | Test |
| BB experimental trial | ABC+ | A+ | Is A/B/C a blicket? |
| BB control trial | ABC+ | D+ | Is A/B/C/D a blicket? |
| ISO experimental trial | ABC+ | A- | Is A/B/C a blicket? |
| ISO control trial | ABC+ | D- | Is A/B/C/D a blicket? |

Table 5. The +/- signs corresponds to whether the machine activates (+) or not (-)

**ResultsChart, bar chart

Description automatically generated**Figure 3. Participants’ mean responses to whether each object was a blicket across the conditions and trial types (i.e., “eventType”). Bars show standard error.

Figure 3 shows the results for this experiment. The dependent measure was the number of times that participants responded “Yes” to the “Is this a blicket” question. Thus, across two trials, the maximum number of times that a participant could respond “Yes” was 2; the minimum number of times that a participant could respond “Yes” was 1.

**Assessing BB under the new operationalization of BB reasoning**

To examine whether there was evidence of BB reasoning according to the new operationalization of BB reasoning, data for the redundant causes within the BB experimental and control conditions were entered into a three-way linear model with Age (5-year-olds vs. 6-year-olds) as the between-subjects factor and Objects (A, B, and C) and Trial Type (main vs. control) as the within-subjects factors. Evidence of BB reasoning based on this operationalization would be a main effect of Trial Type. This is what we found, *F*(1, 139) = 5.28, *p* = .02. This result reflected the fact that participants were more likely to respond that a redundant object was a blicket during the control trials (*M* = 1.60, *SD* = 0.71) than during the main trials (*M* = 1.27, *SD* = 0.82). Follow-up planned comparisons revealed that participants were less likely to respond that object B was a blicket during the BB main trials (*M* = 1.21, *SD* = 0.83) compared to object A during the BB control trials (*M* = 1.61, *SD* = 0.72), *t*(27) = 3.06, *p* = .005. Moreover, participants were less likely to respond that object B was a blicket during the BB main trials compared to object B during the BB control trials (*M* = 1.58, *SD* = 0.72), *t*(27) = 2.17, *p* = .04. Finally, participants were less likely to consider object B to be a blicket during the BB main trials compared to object C during the BB control trials (*M* = 1.61, *SD* = 0.72), *t*(27) = 3.29, *p* = .003. No other differences reached statistical significance. Given that participants did not treat object C during the main trials differently than objects A, B, and C during the control trials, these data only provide *some* evidence of BB reasoning based on the new operationalization.

**Assessing BB under the old operationalization of BB reasoning**

To examine whether there was evidence of BB reasoning according to the old operationalization of BB reasoning, data for the redundant causes between the BB and ISO conditions were entered into a three-way linear model with Condition (BB vs. ISO) as the sole between-subjects factor, and Objects (A, B, and C) and Trial Type (main vs. control) as the within-subjects factors. Evidence for BB reasoning based on this operationalization would be a main effect of Condition (averaging over Objects and Trial Type). This is what we found. Specifically, participants were more likely to call a redundant object a blicket in the ISO condition (*M* = 1.73, *SD* = 0.58) compared to the BB condition (*M* = 1.48, *SD* = 0.77), *F*(1, 277) = 7.60, *p* < .01. Thus, there was stronger evidence for BB reasoning based on an old operationalization of it than based on the new operationalization of it.

General Discussion

This study had two aims. The first was to examine whether 5- and 6-year-olds would engage in BB reasoning for 3 and 4 objects. This departs from the typical convention of using two objects to study causal reasoning in human children. We evaluated BB reasoning under both an old and new operationalization. The second aim was to clarify the debate on *how* children reason about the present causal events. Specifically, we were interested inn whether participants used a Bayesian-inference mechanism or an associative-based counting mechanism to process the current causal events.

With respect to the first aim, there was no evidence that children engaged in BB reasoning. This was true regardless of how we measured BB reasoning. This finding extends previous research to show that when children are asked to reason about three objects, they do not engage in BB reasoning. With respect to the second aim, the data were most consistent with an associative-based counting mechanism. This is because children’s willingness to say that an object was a blicket depended on the frequency with which that object was paired with the machine’s activation; the more frequently that the object was paired with the machine’s activation, the more likely children were to say that the object was a blicket. This finding is significant because it has been suggested that causal reasoning in human children is best explained by Bayesian inference and rational processes rather than by associative processes. The present data suggest that whether children engage in Bayesian inference depends on how causal reasoning is measured and the number of objects about which they are asked to reason.

One potential criticism of this study is that the results are inconsistent with the findings from previous studies on BB reasoning in human children. Such previous research showed that children do engage in BB reasoning when asked to reason about two objects; the current study showed that children do not engage in BB reasoning when asked to reason about three objects. However, we believe that the present results extend (rather than are at odds with) such previous research. Specifically, the present study demonstrates that when children’s information-processing capacities are stretched such as when they are asked to reason about multiple potential causes, they may deploy and rely on simpler associative processes. Although at the level of individual objects the difference between three and four objects is miniscule, by contrast the corresponding increase in the size of the underlying psychological hypothesis space is substantial. Such an increase in the size of the underlying psychological hypothesis space may have important ramifications on the cognitive mechanism that gets deployed by children, especially if children are sensitive to and affected by this increase. For example, children who are asked to reason about two candidate causes need only to represent and choose among *four* candidate causal hypotheses (i.e., 2n, where *n* is the number of potential causes). Four candidate causal hypotheses may be within the information-processing capacities of 5- and 6-year-olds. In contrast, children who are asked to reason about three candidate causes must now consider *eight* candidate causal hypotheses, which may well be outside the limits of their restricted information-processing capacities for the developing child.

It turns out that there is a wealth of data that is consistent with this general proposal (Doebel & Zelazo, 2015; Frye, Zelazo, & Palfai, 1995; Zelazo, Frye, & Rapus, 1996; Zelazo et al., 2003). One such recent study by Kenderla and Kibbe (2023) showed that when 8- and 10-year-old children’s information-processing abilities were stretched in a virtual memory game—such as when children were asked to find three cards that shared one feature and differed on another feature—they relied less on working memory and more on manual exploration. Given that children are not required actively to maintain information in memory when manually exploring, manual exploration is an ostensibly simpler, less cognitively effortful strategy than one that requires working memory. In a similar vein, Richland, Morrison, and Holyoak (2006) found that 3- and 4-year-old children made more featural and relational errors when asked to reason about multiple relations or when a salient distractor was made to compete with the critical relation than when asked to reason about a single relation without a distractor. Finally, there is evidence that preschool-age children's performance on theory-of-mind and social-problem-solving tasks is adversely affected when they are first made to complete tasks that taxed their information-processing abilities compared to when such capacities were not taxed (Caporaso & Marcovitch, 2021; Powell & Carey, 2017; Steinbeis, 2018).

Together, this research demonstrates that although children can process information at higher levels, if the task that they are given requires information-processing abilities that extend beyond what they possess, then there will be a tendency for them to process information at lower levels and to rely on less sophisticated strategies and cognitive mechanisms. This may provide a developmental explanation for why children in the present study did not engage in BB reasoning or show evidence that they relied on Bayesian inference. A testable prediction of this account is that there should be a point at which children go from using a simple associative-based counting mechanisms in contexts like the present one to more rationale processes like Bayesian inference. This issue should be explored more fully in future research.

A second potential criticism is that we cannot be sure that a simple Bayesian-inference mechanism underpinned participants’ performance in the present study. For example, if participants assumed that blickets were common in the present context—which is plausible given how frequently the detector activated in the present study—then participants should be *less* likely to block redundant causes; in other words, participants should be *more* likely to treat all potential blickets (expect for the ones that are explicitly shown not to be causal) equally. This could explain participants’ performance in the BB control condition—in that condition, participants treated all objects equally. However, this explanation cannot explain *all* the present data. This is because this explanation predicts that participants should have also treated objects A-C equivalently in the BB experimental condition as well, but this was not the case: Participants treated object A differently than either objects B or C in the BB experimental condition.

Nonetheless, because we did not systematically manipulate base-rate information, this alternative explanation cannot yet be ruled out entirely. However, if we are correct that participants do not rely on Bayesian inference when asked to reason about multiple causes, we predict that their performance in this proposed future study would not differ from participants’ performance in the current study. However, if children’s causal judgements are shown to be affected by base-rate information, such that their BB reasoning performance changes with changes to base-rate information, then this would suggest that participants may use Bayesian inference to reason about multiple candidate cause after all, at least when a Bayesian-inference mechanism is primed by explicitly and systematically manipulating base-rate information.

**Conclusion**

These potential criticisms notwithstanding, these experiments constitute one of the first systematic attempts to examine BB and ISO reasoning in human children in the context of three objects. A longstanding view has been that the cognitive mechanism by which human beings reason about causal events is Bayesian inference (e.g., Gopnik et al., 2004) rather than associative processes. The experiments reported here support a different conclusion: an associative-learning counting mechanism supports 5- to 6-year-old children’s reasoning about multiple potential causes.

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