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The Early Emergence and Puzzling Decline of Relational Reasoning in Childhood:

Insights from Bayesian Inference

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**Abstract**

We explore the developmental trajectory and underlying mechanisms of higher-order relational reasoning. In several studies, we describe a surprising developmental pattern: Younger learners are better than older ones at inferring abstract relations from evidence. Walker and Gopnik (2014) demonstrated that toddlers are able to infer that an effect was caused by a higher-order relation between two objects (whether they are the same or different), rather than by features of each individual object. However, these findings appear to contrast with a large literature suggesting that older children have difficulty inferring these same relational concepts. Across three experiments, we manipulated both the data and children’s search procedure in a causal relational match-to-sample task to assess the influence of these factors on relational reasoning in preschool-aged children. In Experiment 1, we demonstrate that while younger children (18-30-month-olds) have no difficulty learning these relational concepts, older children fail to draw this abstract inference (36-48-month-olds). In Experiment 2, we adapted this procedure to test the hypothesis that older children have the capacity to reason about higher-order relations, but are unable to access these abilities as a result of a learned a bias to attend to the individual properties of objects. In Experiment 3, demonstrated that including an explanation prompt during learning serves to allow children to access this same relational insight. These findings are discussed in light of recent computational theories of learning .

*Keywords:* Cognitive development, causal learning, relational reasoning, Bayesian inference

**Significant Statement**

(120 words in broadly accessible language)

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A growing literature indicates that children as young as 16 months of age are able to learn specific causal properties from contingency information in statistical data and can act on this information to bring about novel effects in the world (e.g., Gopnik & Schulz, 2007; Gweon & Schulz, 2011; Gopnik & Wellman, 2012). In addition, recent computational theories suggest that children are not only learning particular causal relationships, but also abstract principles *about* causal structure. These higher-order generalizations, or “overhypotheses” (Goodman, 1955) provide the learner with information about the types of hypotheses that are likely to be true. According to Bayesian accounts, these generalizations help children learn new specific relationships from perceptual data more quickly and accurately (e.g., Goodman, Ullman, & Tenenbaum, 2011; Kemp, Perfors, & Tenenbaum, 2007). The ability to reason about these higher-order abstract relations therefore plays an essential role in rapid learning, and may explain how children acquire the impressive amount of causal knowledge evident in early “intuitive theories.” Here we present empirical work exploring the mechanisms underlying the human ability to infer the most basic of these higher-order relations – that of sameness and difference between two objects.

Intuitively, it might seem plausible that these more abstract, relational hypotheses would be acquired later than lower-level, concrete ones based on perceptual features of objects. However, theoretical advances drawing on Hierarchical Bayesian Models (HBM) and the “blessing of abstraction” (Goodman et al., 2011) combined with empirical research on early learning (Dewar & Xu, 2010; Schulz, Goodman, Tenenbaum, & Gopnik, 2008) suggests that children’s ability to learn abstract principles does not necessarilydepend on extensive prior experience. Instead, these higher-order concepts often occur quite rapidly, on-line, and in tandem with inferences about specific causal relations. This literature supports a picture of development in which cognitive immaturity carries unique capacities for learning. In fact, some recent research suggests that in some cases, younger children may actually be better at learning new abstract relations than older ones (Gopnik, Griffiths, & Lucas, in press; Finn, Lee, Kraus, & Hudson Kam, 2014; Kuhl, 2008; Werker, 2012; Lucas, Bridgers, Gopnik, & Griffiths, 2014; Seiver, Gopnik, & Goodman, 2013; Defeyeter & German, 2003; Walker & Gopnik, 2014).

According to probabilistic models of cognitive development, learners use Bayes rule to combine the prior probability of a particular hypothesis before observing any data with the likelihood that the hypothesis would be true, given the data that is observed. Having an some general principle, or overhypothesis, leads the learner to assign a higher prior probability for a particular set of hypotheses. As a result, the learner will need much more evidence for a competing hypothesis than if they had no prior expectations, and assigned all possible hypotheses an equal prior probability (i.e., a “flat” prior). Therefore, as knowledge increases, learners develop a set of expectations that constrains the hypotheses they consider, making it more difficult to learn new information that is inconsistent with the general principles they have already inferred (see Lucas et al., 2014).

In the current paper, we consider the hypothesis that a combination of knowledge acquisition and the development of strategies for constraining hypothesis search may result in narrowing the range of possibilities that learners consider. In particular, we examine children’s developing ability to infer an abstract causal principle – a higher-order relation between objects (i.e., “same” and “different”) – from a limited set of observations. In previous research, Walker & Gopnik (2014) demonstrated that toddlers (18-30-month-olds) are surprisingly adept at learning and using the relational concepts “same” and “different” in a causal relational match-to-sample (RMTS) task. In this task, children were randomly assigned to *same* or *different* conditions, and observed as four pairs of objects (two “same” pairs and two “different” pairs) were placed on a toy that played music when activated. In the *same* condition, pairs of identical objects activated the toy while the pairs of different objects did not. This pattern of activation was reversed for children in the *different* condition. Then, during test, children were given a choice between two novel pairs: one pair of “same” objects and one pair of “different” objects, and asked to select the pair that would activate the toy. Children in both conditions overwhelmingly selected the pair that was consistent with their training. Results suggest that the ability to reason about abstract relations is in place surprisingly early – emerging spontaneously only a few months after the first evidence of children’s ability to learn about specific causal properties.

However, Walker and Gopnik’s (2014) results challenge a large body of research and a long-standing theory that relational reasoning is a late developing ability (e.g., Gentner, 2010; Christie & Gentner, 2014). It well known that preschool-aged children have difficulty inferring abstract relational principles, and instead consistently demonstrate a bias to attend to individual objects (e.g., Gentner, 1998; Christie & Gentner, 2007, 2010). This bias has also been observed in a variety of causal learning tasks, in which preschool children assume that causal powers are inherent to individual objects (e.g. Sobel & Gopnik, 2000). These robust findings have led some to conclude that reasoning about higher-order relations likely depends upon direct instruction, language, and cultural input (e.g., Gentner, Anggoro, & Klibanoff, 2011). This type of experience has even been proposed to explain the differences reported in relational reasoning abilities found between human and non-human primates (e.g., Genter, 2010).

How might this tension be resolved? It is possible that older children’s failure to engage in relational reasoning in previous studies was due to the fact that the materials used to assess their abilities were simply too difficult. If this is the case, then the toddlers’ success reported by Walker & Gopnik (2014) may be the result of the novel procedure. In Experiment 1, we therefore used the same relational reasoning task reported in Walker & Gopnik (2014) (see Figure 1). In addition to replicating this procedure with 18-30-month-olds, we also assessed relational reasoning performance in older children (36-48-month-olds) on the same task. In addition, we included a group of 30-36 months, to detect the presence of a linear developmental trajectory. If the results reported in Walker & Gopnik (2014) were due to the introduction of a simplified relational reasoning procedure, then we would expect that all three groups of children would succeed on the task. If, however, younger children are more likely to infer the relational properties and older children continue to fail (as has been reported in previous research), then there must be some other reason to explain this puzzling developmental decline.

In particular, we propose that the apparent “loss” of relational reasoning abilities between 18 months and 3 years may be the result of a learned bias to attend to individual objects, leading children to fail to represent the information they observe in terms of abstract relations. If older children have learnedthe general principle that individual objects are more likely to be causal, this may serve to constrain their interpretation of the data, leading them to privilege individual properties over relational ones. In Experiment 2, we adapted this causal RMTS procedure (Walker & Gopnik, 2014) to test the hypothesis that older children have the capacity to reason about higher-order relations, but are unable to *access* those abilities as a result of a learned a bias to attend to the individual properties of objects. To do so, Experiment 2 provided older children with explicit negative evidence that would serve to disconfirm an individual object hypothesis. In this experiment, 36-48-month-olds observed the same procedure described in Experiment 1, with one critical change to the training trials: Prior to placing the pairs of blocks simultaneously on the toy and observing presence or absence of the effect, blocks in each pair were first placed on the toy one at a time, and children observed as the toy failed to activate for these individual objects (see Figure 2). By providing evidence *against* the more common individual cause, these negative observations may prompt older children to override the hypothesis that is more consistent with their prior knowledge and instead consider the abstract relational principle.

Previous work has demonstrated that simply asking children to explain patterns of events imposes top-down constraints on their search procedure, leading them to privilege more general and inductively rich hypotheses (e.g., Walker, Lombrozo, Legare, & Gopnik, 2014; Walker, Williams, Lombrozo, & Gopnik, 2012; Walker Lombrozo, Williams, & Gopnik, under review). If preschool-aged children are indeed already able to reason about relational properties, but tend to attend to individual objects, then introducing a prompt to explain may impose the opposite constraint, leading children to privilege abstract properties instead. Accordingly, Experiment 3 contrasted two conditions in which we asked 3- and 4-year-olds to either report *whether* the toy activated in each training trial or to explain *why* the toy did or did not activate in in each case. We hypothesized that changing the way that children were thinking about the RMTS evidence may motivate a different search procedure, therefore allowing them to access the relational hypothesis.

Across studies, we therefore examine the proposal that relational reasoning is not a late-developing ability. Instead, we hypothesize that the ability to learn abstract relations is a fundamental part of the mechanism underlying human learning and that older children’s “failure” on traditional relational reasoning tasks is due their increasing prior knowledge about the importance of individual objects.

**Results**

Replicating the results reported by Walker & Gopnik (2014), 18-30-month-olds selected the test pair that was consistent with their training, in both *same* (78%), *p* = .01 (two-tailed binomial) and *different* (77%), *p* = .02 (two-tailed binomial) conditions. However, 3-year-olds, as in previous studies, failed to select the correct test pair in either *same* (46%), *p* = .85 or *different* conditions (43%), *p* = .57 (see Figure 3), with 18-30-month-olds outperforming 3-year-olds in both cases (*same*: χ2(1) = 5.37, *p* = .02; *different*: χ2(1) = 5.99, *p* = .02). As predicted, the performance of 30-36-month-olds fell between these younger and older groups, selecting the correct test pair marginally above chance (70%) in the *same* condition, *p* = .06 (one-tailed binomial) and at chance (50%) in the *different* condition, *p* = 1.0. These results demonstrate a surprising decline with age on the same RMTS task. To provide additional support for this developmental trajectory, we combined children across age groups and conducted a logistic regression, treating age as a continuous factor and correct selection (collapsing across *same* and *different*) as the dependent variable. Results of logistic regression show a significant decline between 18- and 48-months, χ2(*N* = 141, *df* = 1) = 3.88 (Wald), *p* < .05.

The results of Experiment 1 replicate Walker & Gopnik’s (2014) findings that very young children are already equipped with the capacity to infer higher-order relational properties.

However, over time, children fail to demonstrate this knowledge in behavioral tasks. As discussed above, this change may result from children’s increasing prior knowledge, in which experience has strengthened the hypothesis that individual causes have independent probabilities of bringing about effects. Because the evidence presented in this task could rationally, if somewhat unparsimoniously, be interpreted in terms of the individual blocks, rather than the relation between them, a learned bias to attend to individual properties may result in older children attending to objects and ignoring the higher-order relation between them. In an effort to assess this claim in Experiment 2, we manipulated the data that children observed in order to provide evidence against this individual principle (see Figure 2).

The results of Experiment 2 are consistent with this proposal (see Figure 3). Once 3-year-olds were provided with negative evidence for the individual object hypothesis, they selected the correct relation significantly more often than chance (64%), *p* = .045 (exact binomial). This overall effect was entirely due to the improved performance of children in the *same* condition, in which 79% of children selected the correct pair, *p* = .005 (exact binomial). This performance was significantly better than children of the same age in the *same* condition in Experiment 1, χ2(1) = 6.17, *p* = .01, and no different than the 18-30-month-olds (78%). However, children in the *different* condition did not differ from chance performance (50%), *p* = 1.0 (exact binomial), leading to a significant difference between *same* and *different* conditions, χ2(1) = 4.98, *p* = .03. Therefore, the inclusion of negative evidence allowed 3-year-olds to learn the relational property “same,” but was not effective for learning the “different” relation.

How might we explain this condition effect? In the *different* condition, every pair that the child observes contains unique individual objects. Therefore, if the child currently believes that individual objects are likely to be causal, then all of the data that she observes remains consistent with that hypothesis. The child may therefore interpret the negative evidence to mean that two objects are required to activate the machine. However it does not necessarily prompt children to attend to the relation between them. Given that both test pairs contain two objects together, this assumption leads to chance performance. In the *same* condition, however, every pair that the child observes contains two identical objects, introducing a “suspicious coincidence” to the sampling procedure. In other words, given the expectation that the experimenter is sampling objects from a random distribution, this pattern of observations is more likely to prompt consideration of the higher-order relation.

Results of Experiment 2 demonstrated that manipulating the evidence that children observed facilitated their ability to infer the higher-order relation “same.” In Experiment 3, we examined whether we could induce relational reasoning by manipulating children’s hypothesis search. Results indicate that 3- and 4-year-olds who were prompted to explain during the training trials selected the correct relation significantly more often than chance (79%), *p* = .007 (exact binomial) (see Figure 3). Children in the *report* condition did not differ from chance (42%), *p* = .54, and there was a significant difference between *explain* and *report* conditions, *p* = .017. Unlike in Experiment 2, there was no significant overall difference between *same* (58%) and *different* (63%) relations, *p* = .76. There were also no differences found between *same* and *different* within each condition (*explain*: *same* = 75%, *different* = 83%; *report*: *same* = 42%, *different* = 42%). Comparing the overall pattern of responses of 3- and 4-year-olds who explained to the 18-30-month-olds in Experiment 1, results in no significant difference, χ2(1) = 0.02, *p* = .88, while 3- and 4-year-olds in the *report* condition performed significantly worse than the 18-30-month-olds, χ2(1) = 9.0, *p* = .003, and no differently from the 3-year-olds in Experiment 1, χ2(1) = 0.06, *p* = .81, thus replicating the results found in older children in Experiment 1.

Finally, in order to analyze whether the content of children’s explanations mattered for this pattern of responses, we identified the type of explanation (i.e., object-focused, relation-focused, uninformative) that each child produced most often, and analyzed their performance on the relational task as a function of this designation. Sample sizes for each modal explanation were too small to conduct statistical analyses. However, children who provided *relation-focused* explanations as their modal response (N=6) – the most relevant explanation for the task – always selected the correct relational pair (100%). Children who provided *object-focused* explanations (N=9) were also highly likely to select the relational pair (89%). However, children who provided *uninformative* explanations or failed to provide an explanation at all (N=9) selected the fewest number of relational pairs (56%). These data indicate that providing a meaningful explanation (regardless of its content) is sufficient to improve relational reasoning, but that simply being prompted for an explanation might not be enough to impact subsequent reasoning.

**Discussion**

Across three experiments, we manipulated the data that children observed (Experiments 1 and 2), as well as their search procedure (Experiment 3) to assess the influence of these factors on relational reasoning ability. In Experiment 1, we replicated the findings reported by Walker & Gopnik (2014) that 18-30-month-olds are able to infer the relations “same” and “different” from very little data in a causal RMTS task, and use this inference to guide their subsequent judgments. We also contrasted toddlers’ performance with a group of 30-36-month-olds and a group of 3-year-olds. As in previous work, older children failed to learn the relation, indicating that younger children’s success could not be attributed to the methodological aspects of Walker & Gopnik’s novel task. Instead, we found evidence for a genuine decline in relational reasoning between 18 and 48 months of age. Findings of Experiment 2 help to further explain this decline, suggesting that children may develop prior knowledge that strengthens a bias to attend to individual object properties: When provided with evidence against this bias, 3-year-olds were able to infer the relation. Finally, in Experiment 3, we demonstrated that prompting children to explain during learning leads 3- and 4-year-olds to re-represent the RMTS task to privilege the abstract relational hypothesis. These results are consistent with previous developmental work indicating that generating explanations prompts generalization and abstraction in causal reasoning (e.g., Walker et al., 2014; Legare & Lombrozo, 2014).

Discovering when and how children learn relational concepts is important for understanding the processes underlying early causal learning, but it is also important for understanding the development of abstract reasoning, both in ontogeny and phylogeny. First, these results indicate that relational reasoning is *not* a late developing ability, as has been previously proposed. Instead, toddlers are able to infer the relational causal principles “same” and “different” from just a few pieces of evidence, and use this inference to bring about a novel outcome. These abilities are in place surprisingly early – emerging spontaneously only a few months after the ability to learn specific causal properties. Although older children often fail to demonstrate these abilities (e.g., Christie & Gentner, 2007, 2010, 2014; Gentner, 2010), this failure can be explained by appeal to the role of prior knoweldge in constraining their judgments (see also Gopnik, Griffiths, & Lucas, in press).

These results also shed light on the inconsistency that has been reported between infants and older children. In particular, research using habituation measures suggests that human infants may be able to recognize data that involve “same” and “different” relations in visual displays (Dewar & Xu, 2010; Ferry Hespos, & Gentner, 2012; Tyrrell, Stauffer, & Snowman, 1991). However, this early competence seems to “disappear” when older children are provided with behavioral tasks assessing explicit relational reasoning ability. Then, later in development, researchers report a “relational shift” (Gener & Rattermann, 1991; Gentner & Toupin, 1986), in which children transition from focusing on individual objects to consider abstract relations. This shift has been attributed to several factors, including an increase in relational knowledge (Gentner & Rattermann, 1991), exposure to relational language (Christie & Gentner, 2014), and various maturational variables (Halford, 1992; Richland, Morrison, & Holyoak, 2006; Rhibaut, French, & Vezneva, 2010). Indeed, there is a large literature indicating the dissociation between children’s knowledge and the ability to act on this knowledge across a variety of developmental domains (e.g., Hood, Cole-Davies & Dias, 2003; Kirkham, Cruess & Diamond, 2003; Munakata, 201; Zelazo, Frye, & Rapus, 1996). However the current results may indicate a different explanation for this developmental trajectory. This new picture highlights the difference between *ability* and *access*. Here we claim that relational reasoning is an early ability – a product of the basic inferential capacities that form the foundation for human learning. The developmental trajectory of relational reasoning may therefore be better characterized as a “u-shaped curve,” in which early reasoning abilities are overshadowed by children’s failure to access this knowledge in the face of conflicting hypotheses. This access issue is gradually overcome, which has been traditionally described as achieving relational insight.

This novel proposal also provides an alternative explanation for the influence of scaffolding on relational abilities. In Experiment 3, for example, we demonstrate that a bias to attend to objects may be overcome with relatively minimal intervention. In fact, children in *explain* and *control* conditions observed identical sets of data. The only variable differentiating these groups was the inclusion of a prompt to explain, which changed children’s representation of (or approach to) the task. Similarly, previous research has demonstrated that the use of labels (Christie & Gentner, 2007; Loewenstein & Gentner, 2005; Namy & Gentner, 2002; Son, Doumas & Goldston, 2010; Ratternmann & Gentner, 1998; Gentner & Rattermann, 1991, see also Premack, 1983; Thompson & Oden, 2000; Thompson et al., 1997 for similar findings in chimpanzees) and prompts to compare across multiple exemplars (e.g., Christie & Gentner, 2014; Gick & Holyoak, 1983; Kotovsky & Gentner, 1996; Gentner, Anggoro, & Klibanoff, 2011) supports relational competence. Historically, this work has been interpreted as evidence for a *structural alignment* process that serves to highlight the relations between compared objects or events (e.g., Gentner, Holyoak, & Kokinov, 2001). While our data are not inconsistent with this model, it is also possible that these scaffolds simply allow children to overcome a bias to attend to individual object properties by influencing the hypotheses that are generated during search. This latter idea is also consistent with the fact that preschoolers perform much worse on relational reasoning when there are highly salient competing object matches available (Gentner & Toupin, 1986; Richland et al., 2006, DeLoache, 1995; Paik & Mix, 2006; Genter & Rattermann, 1991). In other words, relational insight may not be due to “discovery” of the relation, but rather to a shift in the probabilities assigned to the individual object and relational hypotheses.

Finally, these findings also reflect issues regarding the broader evolution of relational reasoning (Penn et al., 2008) or causal cognition in general (Buchsbaum et al., 2012; Heyes & Frith, 2012), suggesting that the ability to quickly learn abstract relational concepts might be a dimension on which humans differ from other primates. There is an ongoing debate in the comparative literature regarding whether differences reported in relational reasoning indicates a qualitative difference, or merely a quantitative gap (see Penn et al., 2008). For example, Gentner and colleagues (Gentner, 2003, 2010; Gentner & Christie, 2008; Christie & Gentner, 2014) have proposed that the difference in relational abilities between humans and chimpanzees is initially rather modest, but expands significantly due to the influence of language and culture. In particular, Genter (2010) has argued that symbolic language abilities support a process of structure mapping, in which close, object-based comparisons potentiate more distant, purely relational ones, through a process of progressive alignment. While we agree that relations are learned through experience, we propose that this learning occurs much earlier, and need not proceed from local properties to more abstract ones.

In sum, these results suggest that the abstract constraints that guide relational inferences are themselves learned (see also Dewar & Xu, 2010). Therefore, the very fact that children know less to begin with may, paradoxically, make them better (or at least more flexible) learners. In Bayesian terms, this flexibility results from a “flatter” initial prior. As we acquire abstract knowledge about causal structure, this experience provides a set of inductive biases that are typically quite helpful, allowing the learner to draw quick conclusions when a new situation is consistent with their past experiences. However, experience can also be a double-edged sword – occasionally leading learners away from the correct hypothesis. As a result, apparent limitations in children’s knowledge may be the very feature that allows for the plasticity of early beliefs, and may help to explain the extraordinary innovation that characterizes learning in childhood.

**Materials and Methods**

**Experiment 1.*****Participants*.** A total of 141 children participated in Experiment 1, including 56 36-48-month-olds (*M* = 41.6 months; range= 36.0 - 48.2 months), 40 30-36-month-olds (*M* = 33.6 months; range= 30.1 – 35.8 months), and 45 18-30-month-olds (*M* = 25.1 months; range= 18.9 – 29.9 months). Half of the children in each age group were randomly assigned to one of two between subject conditions: *same* and *different*. An additional 10 participants were tested, but excluded. Six children were excluded due to experimenter error or toy failure, and 4 were excluded due to participants’ failure to complete the experiment. Children were recruited from local preschools and museums, and a range of ethnicities resembling the diversity of the population was represented.

***Materials and Procedure*.** The procedure for Experiment 1 was an exact replication of the procedure used in Experiment 2 of Walker and Gopnik (2014) (see Figure 1). Children were tested individually in a small testing room, seated at a table across from the experimenter. During the training phase, children saw 4 pairs of painted wooden blocks (2 same and 2 different) placed on top of the toy. The toy consisted of a 10- x 6- x 4-in. opaque white cardboard box that appeared to play music when certain blocks were placed on top. In fact, the box contained a wireless doorbell that the experimenter activated by surreptitiously depressing a button.

In the *same* condition, the pairs that activated the toy consisted of two identical blocks, while in the *different* condition the pairs that activated the toy consisted of two blocks that differed in both shape and color. The experimenter started the training phase by introducing the toy to the child, saying, “This is my toy! Sometimes when I put blocks on top of my toy, it plays music, and other times it does not. Should we try some and see how it works?” The experimenter then took out two blocks, saying, “Let’s try these!” and placed both blocks simultaneously on the toy, and the toy played music. The experimenter responded to the effect by saying, “Music! My toy played music!” The experimenter then placed the two blocks on the toy one more time and said, “Music! These ones make my toy play music!” Next, the experimenter took out a second pair of blocks in the opposite relation as the first pair. The experimenter placed these two blocks simultaneously on the machine, and the toy did not activate. In response, the experimenter said, “No music! Do you hear anything? I don’t hear anything.” The experimenter placed this pair on the machine again and said, “No music. These ones did not make my toy play music.” The experimenter then repeated this with two more pairs of blocks, one pair that activated the toy and one pair that did not.

The test phase began after all 4 pairs of blocks had been demonstrated on the toy. In both conditions, the child was given a choice between a novel same pair and a novel different pair to activate the toy herself. Thus, the pairs of blocks children observed on the machine and the pairs they were asked to choose in the test phase were the same across conditions; the only difference between the two conditions was which relation activated the toy. The experimenter said, “Now that you’ve seen how my toy works, I need your helping finding the things that will make it play music. I have two choices for you.” The experimenter took out two trays, one supporting a novel same pair and one supporting a novel different pair, saying, “I have these” (holding up one tray) “and I have these” (holding up the other tray). Once the child had looked at both trays, the experimenter continued, saying, “Only one of these trays has things that will make my toy play music. Can you point to the tray that has the things that will make it play?” The experimenter then placed both trays on opposite sides of the table just out of reach of the child, and prompted the child to point. After the child pointed to a tray, the experimenter pushed the trays closer and asked the child to make the toy play music. The side of the correct pair was counterbalanced between children.

Children’s first point or reach was recorded. Children received 1 point for selecting the pair of novel test blocks in the relation that matched their training (same or different) and 0 points for selecting the pair of test blocks in the opposite relation. A second researcher who was naïve to the purpose of the experiment recorded all responses. Interrater reliability was very high; the two coders agreed on 94% of the children’s responses.

**Experiment 2. *Participants.*** A total of 56 3-year-olds (*M* = 41.9 months; range= 35.9 - 49.9 months) were randomly assigned to one of two conditions (28 *same,* 28 *different*)*.* An additional 4 participants were excluded for failure to complete the study.

***Materials and procedure.*** The materials were identical to Experiment 1 and the procedure included the following critical changes. For each pair of blocks, the experimenter first placed each block on the machine *sequentially*, before placing them both on simultaneously (see Figure 2). Therefore, in addition to observing positive evidence that pairs of same or different blocks (depending upon the child’s condition) activated the toy together, children also observed negative evidence for the causal efficacy of individual blocks (i.e., each block failed to activate the toy on its own). This training phase was immediately followed by a test phase, which was identical to the test phase in Experiment 1. Interrater reliability was very high; the two coders agreed on 93% of children’s responses to the test questions.

**Experiment 3. *Participants.*** Forty-eight 3- and 4-year-olds (*M* = 45.1 months; range= 36.5 -58.9 months) were randomly assigned to one of two conditions (*explain:* n = 24, *M* = 45.9 months, range= 37.0 – 58.9 months; *report:* n = 24, *M* = 44.2 months, range= 37.2 – 58.5 months). Half of the children in each condition (12 per condition) observed evidence that was consistent with the *same* relation and the other half observed evidence that was consistent with the *different* relation. An additional 3 participants were excluded for failing to complete the study.

***Materials and procedure.*** The procedure for Experiment 3 was nearly identical to Experiment 1 (see Figure 1), except for the following changes. Children in the *explain* condition were prompted for an explanation after the second placement of each training pair on the toy, asking, “Why do you think these ones made/did not make my toy play music?” In the *report* condition, the experimenter asked, “What happened to my toy when I put these ones on it? Did it play music?” (prompting a yes/no response).

In addition to coding children’s selections, all explanations were categorized into 3 mutually exclusive types: (1) object-focused (e.g., *“because it’s red”*, *“because it has batteries”*), (2) relation-focused *(“because they are the same,” “because they are not the same”*), and (3) uninformative *(“I don’t know,” “because it played music”*). Interrater reliability was again very high; the two coders agreed on 96% of children’s responses to the test questions, and 89% of the explanation categories.

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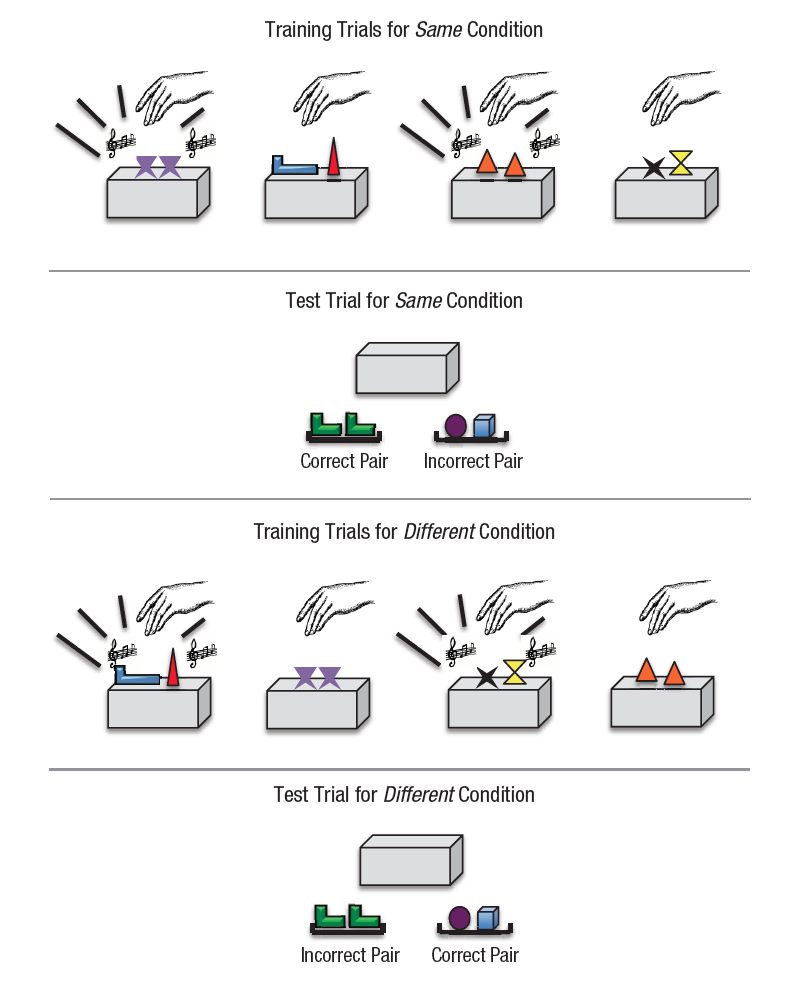
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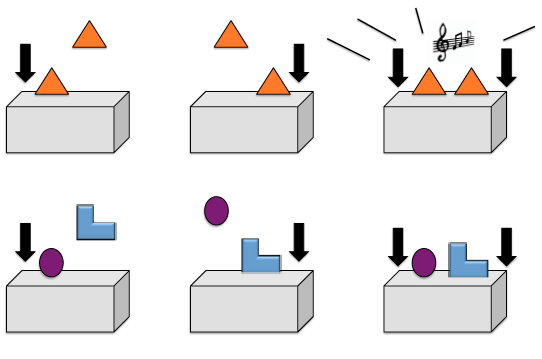
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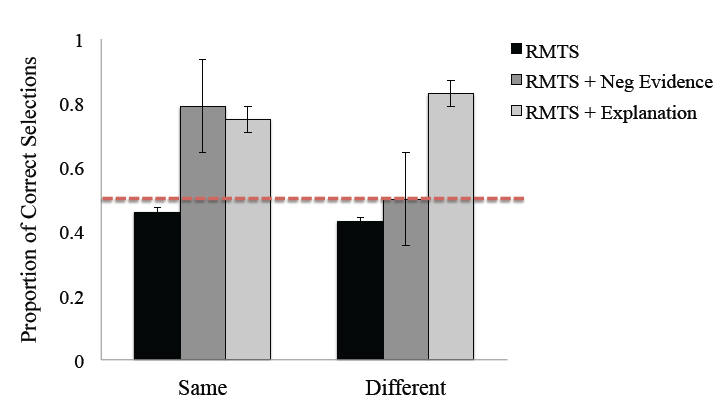
**Figures**



**Figure 1.** Schematic representation of training and test trials in the *same* and *different* conditions. Participants observed four training trials (two causal and two inert). On each testtrial, a novel pair of “same” blocks and a novel pair of “different” blocks were presented. Thechild was asked to select the pair that would activate the toy.



**Figure 2.** Schematic representation of two (of four) training trials in the *same* condition. The pattern of activation was reversed for the *different* condition. All test trials were identical to those used in Experiment 1.

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**Figure 3.** Proportion of correct relations selected for 3-year-olds following the manipulations in Experiments 1-3.