24-Month-Olds Engage in Relational Causal Reasoning

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Abstract

Children make inductive inferences about the causal properties of individual objects from a very young age. When can they infer higher-order relational properties - a task that has proven difficult for non-human primates? In two experiments, we examined 18-24-month-old infants' relational inferences using a causal version of a relational match-to-sample task. Results suggest that by 21-24 months of age, infants are able to infer a relational causal principle from just a few observations and use this inference to guide their own subsequent actions and bring about a novel causal outcome. Findings are considered in light of recent discussion about the nature of relational and causal reasoning, and their evolutionary origins.

Keywords: Cognitive development; infancy; relational reasoning; causal learning; inference

Introduction

Learning about causal relationships is one of the most important and challenging problems young humans face. Causal knowledge allows you to act on the world – if you know A causes B, you can act on A to bring about B. Recent research shows that children as young as 19 to 24 months of age can quickly learn causal properties of objects from patterns of statistical contingency and can act on that knowledge to bring about effects (Gopnik, 2012; Gopnik & Wellman, 2012; Sobel & Kirkham, 2006; Meltzoff, Waismeyer & Gopnik, 2012). At 20 months, children can infer the desires of others from sampling patterns (Kushnir, Xu & Wellman, 2010) and at 16 months, they can use contingency information to determine whether an effect was caused by their own actions (Gweon & Schulz, 2011). Other lines of research suggest that infants can infer abstract linguistic structure from statistical data (e.g. Saffran, Newport & Aslin, 1996; Lany & Gomez, 2008).

However, little is known about the development of children's ability to infer higher-order relational causal principles from data. In particular, an effect might be caused by an object property (e.g., red blocks activate a toy) or by a higher-order relationship between properties (e.g. two blocks that are the same, regardless of their color, activate a toy). Inferring higher-order relations is essential for building abstract knowledge (Kemp, Perfors & Tenenbaum, 2007; Dewar & Xu, 2010) and reasoning about concepts that are not tied to perceptual properties. The ability to form generalizations about higher-order relations from limited data allows children to make principled abstractions that go beyond the particular properties they have observed.

To investigate this, we used a causal version of Premack's (1983) match-to-sample task. In this task, animals observe an abstract relational pattern – AA', BB', and CC' all lead to a reward. Then they are given a choice between AB (object match) and DD' (relational match). Although A and B have each individually been associated with the reward, an animal who has inferred the more abstract relational pattern ("same") should choose DD'. Premack found that chimpanzees could not solve this relational task without hundreds of trials (Premack, 1988) or explicit training to use linguistic symbols for "same" (Premack, 1983; Premack & Premack, 1983; 2002). Additional comparative studies have confirmed this pattern for non-human primates and other animals (Penn, Holyoak, & Povinelli, 2008). These observations have led some researchers to conclude that abstract relational reasoning may be uniquely human.

Research examining the origins of relational reasoning using looking-time measures suggests that human infants, like primates, may be able to recognize relational patterns of data (Dewar & Xu, 2010; Tyrell, Stauffer & Snowman, 1991; Ferry, Hespos & Gentner, 2012). However, there is no evidence that infants can use those patterns to make causal inferences or guide actions. In fact, earlier studies have concluded that even preschoolers have difficulty with relational tasks (Christie & Gentner, 2010; Gentner, 2010). Not unlike chimpanzees, children succeeded only when given linguistic coaching to point out the pattern of similarity between two simultaneously presented cases. Even when explicitly instructed to compare objects, 3-year-olds' performance on these relational tasks was rather tenuous, dropping significantly below chance when the test items were presented sequentially, rather than simultaneously (Christie & Gentner, 2010). This might lead to the conclusion that, even in humans, learning higher-order relations and using them to guide actions is a relatively late-developing ability, which depends on direct instruction, language, and cultural scaffolding.

However, the striking success of young children on causal tasks suggests that placing these problems in a causal context might enhance performance. For example, recent evidence suggests that by 24 months, toddlers readily learn novel causal relations by observing others acting causally on the world, and use this information to fashion their own actions to achieve the same causal outcomes (Meltzoff, Waismeyer, & Gopnik, 2012). In the current study, we used a similar observational learning paradigm to examine whether infants as young as 18- to 24-months could abstract a relational property from their observations in a manual causal task. If infants succeed, this would suggest that the human ability to learn abstract relations is in place earlier than previously thought. It would also suggest that these abilities might be responsible for the impressive learning of very young children. Could infants solve these relational problems spontaneously, and without linguistic cues or explicit directives to compare, if evidence for the existence of a relational property were provided in a causal context?

Experiment 1

In Experiment 1, the experimenter introduced 18- to 24-month-old infants to a novel toy that played music when "activated," and 3 unique pairs of identical blocks AA', BB', and CC'. Infants observed as the experimenter placed blocks on the toy, one at the time. In 3 demonstrations, infants observed that while individual blocks failed to activate the toy alone, pairs of identical blocks did produce the effect. Immediately after this brief training, we examined whether these infants learned the novel relational property (i.e., pairs of identical objects make the toy play music) by placing a novel block on the machine, asking the infants to generate the effect on their own and observing their first selection.

Methods

Participants A total of 46 18- to 24-month-old infants participated in Experiment 1 (M = 20.9 months; SD = 2.0 months; range = 18.0-24.4 months; 22 girls). Five additional children were tested but excluded for fussiness during the training phase or for failing to respond to the experimenter during test trials. Children were recruited from daycare centers and museums, and a range of ethnicities resembling the diversity of the population was represented.

Materials The toy was designed to be similar to the "blicket detectors" used in past research (see Gopnik & Sobel, 2000). The toy consisted of a 10" x 6" x 4" opaque box constructed from cardboard and painted white with blue borders. The box contained a wireless doorbell that was not visible to the participant. When a block "activated" the toy, the doorbell played a novel melody. The toy was in fact surrepticiously activated by a remote control that was held out of view by the experimenter. Six painted wooden blocks in assorted colors and shapes (3 unique pairs of 2 identical blocks) were placed on the toy during the training phase in Experiment 1. Six additional blocks were used during the test phase in Experiments 1 and 2, including 2 novel pairs of identical blocks and 2 unique individual blocks.

Procedure The procedure for Experiment 1 is illustrated in Figure 1. Following a warm-up period in which the child was familiarized with the experimenter, the toy was placed on the table. The experimenter said, "This is my toy. Some things make my toy play music and some things do not make my toy play music." Children then observed while the experimenter placed 6 blocks (3 unique pairs: AA', BB', CC') on the table in front of the toy. The experimenter said, "Let's try!", selected a block (A), and placed it on top of the toy. No effect was produced. After a brief pause, the experimenter again said, "Let's try!" and selected the paired block (A') and placed it next to the first block (A) on top of the toy. This pair of objects (AA') activated the toy, which played a novel melody. The experimenter smiled and said, "Music!" Both blocks were removed from the toy and returned to the pile of 6 blocks. This procedure was repeated with the two remaining pairs (BB' and CC'). The order of the pairs was randomized. Following all three demonstrations, the 6 training blocks were removed from view. Blocks were placed on the toy one at a time due to the causal nature of the task: In order to provide evidence for the conjunctive causal relation (that both blocks were necessary to activate the toy), infants must observe a single block fail to activate the toy on its own.

Immediately following the training phase, the experimenter produced 3 test blocks (1 *novel paired block* (D), 1 *familiar block* (A), and 1 *novel distractor block* (E) and placed them in a row on the table. The order of presentation was randomized. The experimenter said, "Let's try!", produced the *target block* (D'), and placed it on top of the toy. No effect was produced. The experimenter then pushed the toy and a tray with all 3 test blocks towards the child, and asked, "Can you pick one of these (pointing to the row of test blocks) to make my toy play music?" The first test block that the child placed on the toy was recorded. The toy activated if the child correctly selected the *novel paired block* (D). If the child selected the *familiar block* (A) or the *novel distractor block* (E), the toy failed to activate. After this feedback was provided, this procedure was repeated a second test trial with a new set of test blocks.

If infants were acting based upon the previous association between the block and the effect, they should choose the *familiar block* (A). If they simply preferred to try novel blocks they should pick the *novel distractor block* (E) as often as the *novel paired block* (D). However, if infants were able to learn the relational causal property, then they should select the *novel paired block* (D) to produce the effect.

Coding Children received 1 point for selecting the *novel paired block* and 0 points for selecting either of the other two blocks. Therefore, children in the Experiment 1 could receive up to 2 points for their performance across the two test trials. Children's responses were recorded by a second researcher during the testing session, and all sessions were video recorded for independent coding by a third researcher who was naïve to the the hypotheses of the experiment.

Interrater reliability was very high; the two coders agreed on 99% of the children's responses to the test questions. Two minor discrepancies were resolved by a third party.

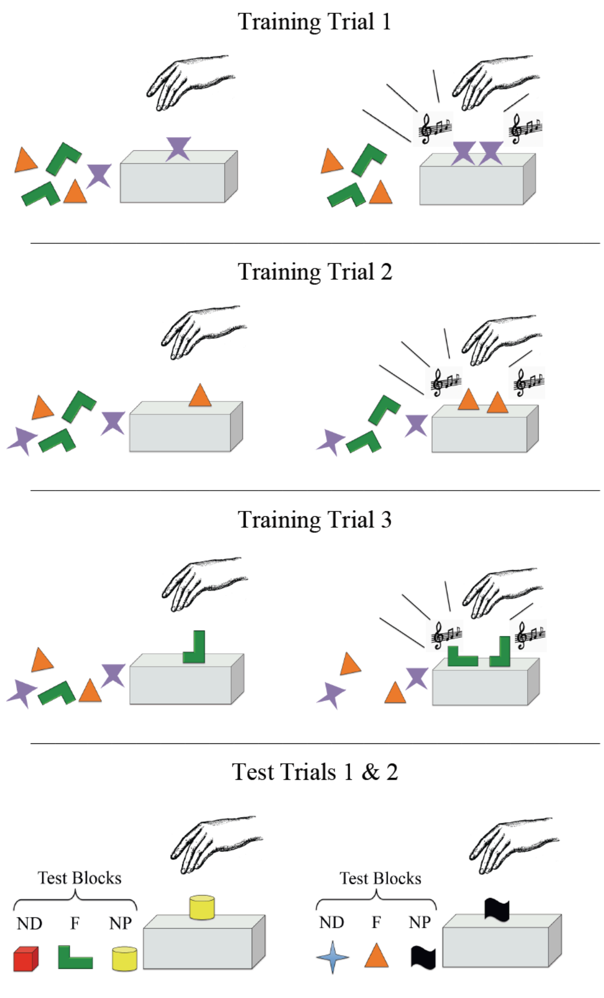

Figure 1: Schematic representation of training and test trials in Experiment 1. On each training trial, the experimenter first placed a single block on the toy (no activation) and then added an identical block, activating the toy. The procedure was repeated for all 3 training pairs. On each test trial, 3 test blocks (*novel distractor block* [ND], *familiar block* [F], *novel paired block* [NP]) were presented. The experimenter then placed the target block on the toy, yielding no effect. The child was asked to select one test block to activate the toy.

Results & Discussion

Across the two test trials, infants inferred the relational property and selected the *novel paired block* (D) more often than expected by chance (M = .91, SD = .69; chance = .66), $t(45) = 2.47$, $p<.02$ (Fischer exact test revealed no order effects for test trials, $p = .39$).

Linear regression revealed a significant developmental change in performance on test trials between 18 and 24 months of age, $F(1, 44) = 8.23$, $p < .01$. The regression model predicts that while the youngest children in our sample (18-month-olds) perform just above chance values (chance = .66), by 21 months, children select the *novel paired block* on at least half of the test trials.

To further investigate this change, we divided infants into two age bins: 18-21 months and 21-24 months. Older infants performed significantly better than chance, (M = 1.13, SD = .82), $t(22) = 2.77$, $p < .02$, and significantly better than younger infants, $F(1, 44) = 4.91$, $p < .05$ who performed at chance, (M = .70, SD = .47), $t(22) = .36$, p = .72. Older infants chose the *novel paired block* significantly more often than the *novel distractor block* (binomial, $p < .05$ for both trials 1 and 2) and the *familiar block* (binomial, $p < .01$ for both trials 1 and 2) .

Previous proposals have suggested that children are unable to reason relationally because they tend to focus on the individual objects which have been previously associated with the outcome, thus interfering with their ability to detect the relation (e.g., Gentner, 2010). We show no evidence of this. In fact, only 33% of infants who answered incorrectly on a given trial selected the *familiar block* over the *novel distractor block*. This is particularly surprising, given that this block had been associated with the effect during the training trials. Instead, significantly more incorrect selections were due to infants' choice of the *novel distractor block* (60%) over the *familiar block*, $p < .05$. This suggests that the younger infants' failure may have been due to a preference for exploring the novel block.

Results indicate that by 21-24 months of age, infants are able to infer a relational causal principle from a few pieces of evidence, and use this inference to bring about a novel causal outcome. However, these data do not rule out some alternative interpretations: Infants may have succeeded on this task by "matching" the experimenter's selection or because they preferred to create pairs on the toy, regardless of training. Experiment 2 was designed to address these alternatives.

Experiment 2

The procedure for Experiment 2 was identical to Experiment 1, except that infants did not observe the training trials. Infants were therefore given no evidence for the relational property. Instead, after being introduced to the toy, infants were immediately presented with a test trial. If infants were simply matching the experimenter or had a preexisting preference for pairs of blocks, then performance should not differ significantly from the infants in Experiment 1. However, if these alternatives are insufficient to explain the infants' success, then infants should perform at chance.

Method

Participants Twenty-two 21-24-month-olds participated (M = 22.8 months; SD = 1.3 months; range = 21.5-24.8 months; 10 girls). Two additional children were tested but excluded for failing to respond. Recruitment procedures and demographics were identical to Experiment 1.

Materials & Procedures Materials and procedures were identical to Experiment 1. However, infants did not observe the training trials. Instead, after infants were introduced to the toy, they were given a single test trial. Only one test trial was administered, in order to avoid providing feedback. Therefore, infants could receive 0 or 1 point. Interrater reliability for Experiment 2 was 100%.

Results & Discussion

In the absense of evidence for the relational principle, only 36% (8 out of 22) of infants selected the paired block, [binomial test, $p = .72$, ns], which was significantly different from the infants of the same age on their first trial in Experiment 1, $p < .05$ by Fischer's exact test. These results demonstrate that the findings from Experiment 1 could not have been the result of imitation or a preexisting bias to prefer pairs.

General Discussion

These findings suggest that the differences in relational reasoning between humans and non-human primates may be in place very early, and that human infants can succeed on match-to-sample tasks in a causal context without explicit linguistic cues or instruction. On the other hand, the failure of younger infants may suggest that the ability to *use* language may play a role. Alternatively, failure may be due to other factors that make it difficult for younger infants to display competence in manual tasks, such as a general impulse to explore novel objects. Additional research is needed to examine whether relational abilities are supported by the development of linguistic capacities – and language production in particular. To this end, we are currently examining the relationship between infants' performance on the causal match-to-sample task and their general language skills. In particular, we are examining infants' comprehension and production of relational words (e.g., "more").

The method outlined in this paper provides a novel and powerful paradigm for assessing relational reasoning in a causal context. Importantly, this method minimizes the need for verbal guidance, and is thus suitable for very young children. Earlier "blicket detector" studies using very similar methods have confirmed that children's inferences in these tasks go beyond simple associative learning and have the distinctive profile of causal inferences. For example, children will use inferences about the causal relation of the block and machine to design novel interventions – patterns of action they have never actually observed – to construct counterfactual inferences and to make explicit causal judgments, including judgments about unobserved hidden features of the objects (e.g. Gopnik & Sobel, 2000; Schulz, Gopnik, & Glymour, 2007; Sobel, Yoachim, Gopnik, Meltzoff, & Blumenthal, 2007).

However, due to the constraints of the particular causal context (i.e., the need to provide evidence for the conjunctive relation over the disjunctive relation, noisy OR), we opted to present evidence one block at a time, rather than in simultaneously presented pairs. In the earlier primate studies, the canonical relational tasks presented the pairs simultaneously, so that the animals had to choose between pairs of AA and BB. This difference in procedure may have led to the divergent results between infants and primates.

We have recently completed an additional follow-up experiment exploring this possibility (Walker & Gopnik, under review). In this study, 18- to 30-month-old infants (M = 25.7 months) were divided into one of two conditions: *same* or *different.* In the *same* condition, infants were given two pieces of evidence that pairs of "same" objects (AA', BB', CC') simultaneously placed on the toy produce the effect. In order to provide evidence for a conjunctive causal relationship, we also provide two pieces of evidence that pairs of "different" objects (DE, FG, HI) *fail* to produce the effect. In the *different* condition, infants were given the same four pieces of evidence, with the causal pattern reversed: "different" pairs (i.e., DE) produced the effect, while "same" pairs (i.e., AA') *failed* to do so. By combining positive and negative evidence, we were able to use a similar causal method to demonstrate that infants are able to learn the relational properties "same" and "different." Results of this study provide strong evidence that 2-year-olds are able to quickly learn relational causal principles, with 81% of children selecting the relational match in both the *same* and *different* conditions.

Clearly, toddlers are able to rapidly learn abstract relational causal principles from minimal evidence and use them to guide their subsequent actions in the world. This ability appears to be in place surprisingly early in human development. It emerges only a few months after the first evidence of the ability to learn about specific causal properties from contingency. This may help explain how children acquire the impressively general and abstract causal knowledge evident in early "intutive theories" (Gopnik & Wellman, 2012; Carey, 2010).

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