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More than meets the eye: Early relational reasoning cannot be reduced to perceptual heuristics

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Abstract

The ability to represent *same-different* relations is a condition for abstract thought. However, there is mixed evidence for when this ability develops, both ontogenetically and phylogenetically. Apparent success in relational reasoning may be evidence for conceptual understanding or may be due to low-level, perceptual strategies. We introduce a method to discriminate these possibilities by pitting two conditions that are perceptually matched but conceptually different: in a "fused" condition, same and different objects are joined, creating single objects that have the same perceptual features as the pairs in the "relational" condition. However, the "fused" objects do not provide evidence for the relation. Using this method in a causal task provides evidence for genuine conceptual understanding. This novel technique offers a simple manipulation that may be applied to a variety of existing match-to-sample procedures used to assess *same-different* reasoning to include in future research with non-human animals, as well as human infants.

Keywords: cognitive development; causal inference; relational reasoning; perceptual processes

The ability to represent relations between objects and events is an essential condition for abstract thought; some have suggested that relational abilities may be the key to the cognitive differences between humans and other animals (Penn, Holyoak, & Povinelli, 2008). However, there is mixed evidence about when this ability develops, both ontogenetically and phylogenetically. Traditionally, there was little evidence for relational reasoning in either young children or non-human animals. More recent results, particularly involving the foundational relations "same" and "different" challenge that conclusion. Ducklings can generalize these relations in an imprinting paradigm (Martinho & Kacelnik, 2016). Human infants are able to generalize these relations in looking-time experiments. In particular, pre-verbal infants can be habituated to pairs of *same* and *different* objects (Addyman & Mareschal, 2010; Ferry, Hespos, & Gentner, 2015; Hochman, Mody, & Carey, 2016; Tyrell et al., 1991), discriminate and generalize patterns of repeated visual or auditory elements (ABA/AAB/ABB) (Dawson & Gerken, 2009; Johnson et al., 2009; Marcus et al., 1999; Saffran et al., 2007), and provide a conditioned response to pairs of identical stimuli (Kovács, 2014; Hochmann, 2010). Moreover, very young toddlers can apparently use *same-different* relations in an active causal learning paradigm (Walker & Gopnik, 2014), although this ability declines in the preschool period (Walker, Bridgers, & Gopnik, 2016). In these studies, toddlers, aged 18-30-months, were able to infer *same-different* relations in a causal version of a match to sample task (i.e., matching AA' with BB', not CD, and matching EF with CD, not BB').

On the other hand, it is possible that these successes may be mediated by perceptual factors that are quite separate from the abstract *same-different* concepts that these tasks are intended to assess (see Addyman & Mareschal, 2010 for a review). It is clear that both human and non-human animals are able to *perceive* the similarity of objects, agents, and events in their environment; these abilities are necessary for basic cognitive functions (Martinho & Kacelnik, 2016; Hochman, Mody, & Carey, 2016). However, noticing similarity does not necessarily imply the existence of the conceptual representation, *same*. This distinction is difficult to make, and this point has been widely debated in the comparative literature (Penn, Holyoak, & Povinelli, 2008; Thompson & Oden, 1996).

For example, non-human primates (Wasserman, Fagot, & Young, 2001) and several species of birds (Smirnova et al., 2015; Pepperberg, 1987) have succeeded in solving similar relational problems, in the context of multiple trials in reinforcement learning paradigms (Wasserman, Fagot, & Young, 2001; Smirnova et al., 2015; Pepperberg, 1987), suggesting that these species, like humans, may possess the ability to learn abstract relational properties (Cook & Wasserman, 2007). However, there is also growing evidence indicating that these trained abilities may be grounded in perceptual expertise, reflecting learned sensitivity to surface cues, rather than higher-order reasoning, per se (Thompson & Oden, 2000).

This suggests that the match to sample tasks that have historically served as the standard for assessing *same-different* understanding across species may be passed in the absence of genuine conceptual representations. In particular, lower-level, perceptual strategies, like attention to the symmetry, contrast, and the variance of the stimuli could contribute to success (Young & Wasserman, 2001; Smith et al. 2008; Blaisdell & Cook, 2005). Might infants, toddlers, and non-human animals in an imprinting paradigm, like non-human animals in reinforcement training, be responding to a perceptual analysis of the stimuli pairs rather than a *same-different* strategy?

One candidate for such a strategy is a low-level heuristic, called "perceptual entropy," that has been proposed to facilitate relational recognition in non-human animals (Penn, Holyoak, & Povinelli, 2008; Wasserman, Fagot, & Young, 2001; Fagot, Wasserman, & Young, 2001; Young & Wasserman, 1997; Wasserman, Young, & Cook, 2004; Wasserman & Young, 2010; Zentall et al., 2008). In particular, any visual display can be reduced to "a continuous analog estimate of the degree of perceptual variability between the elements" (Penn, Holyoak, & Povinelli, 2008, pg. 112), a strategy similar to a process of conceptual chunking (Halford, Wilson, & Phillips, 1998). In other words, because there is a lower amount of perceptual variation among the elements for 'same' displays (AA') than for 'different' displays (AB), toddlers (as well as human infants and non-human animals) may succeed by learning and applying the following rule: *If the variability of the effective training sample is low, select the test pair that also has low variability.*

This attention to variance would also subsume a range of other perceptual cues including symmetry, oddity, and spatial orientation, among others (Cook & Wasserman, 2007). Adult humans show some sensitivity to the amount of perceptual variance in a display, but this evidence is not sufficient to prove that it is responsible for their performance. In fact, previous findings suggest that additional processes of categorization likely play a role in the human conceptualization of "same-different" relations (Smith et al., 2008; Fagot, Wasserman, & Young, 2001). Interestingly, similar findings have been recently found with baboons (Flemming, Thompson, & Fagot, 2013).

Discriminating between conceptual and perceptual learning strategies in non-verbal relational reasoning tasks is a notoriously difficult problem to solve in both developmental and comparative contexts. In the current study, we introduce a novel method designed to directly pit the perceptual and conceptual accounts against one another. The method involves a contrast between one condition relying upon a traditional match to sample task involving *same-different* relations (i.e., matching AA' with BB', not CD, and matching EF with CD, not BB') and a "fused" object condition. Exactly the same objects are used in the two conditions, but in the "fused" condition the objects are physically joined to create a single compound object. Importantly, the amount of perceptual entropy, or variance, as well as other perceptual features such as symmetry is matched between the two conditions. However, only the unfused/relational condition also provides evidence for the higher-order relation 'same.' In the fused/single object case, there is no relation *between* objects to learn – there is only one object present.

As a proof of concept, we applied this method to assess human toddlers in a causal match to sample task originally developed by Walker and colleagues (Walker & Gopnik, 2014; Walker, Bridgers, & Gopnik, 2016). In the current study, children observed two trials in which a pair of "same" objects, or a fusion of those objects, activated a machine, but a pair or fusion of two "different" objects did not. Then, children had to select a novel pair of objects or a novel fused object to activate the machine (see Figure 1). If children are indeed relying upon a low-level perceptual heuristic, they should select the lower entropy pair (i.e., the pair with less variance among its features) consistently across both conditions, whether they are fused or not. On the other hand, if children learn the abstract relation 'same' during the training trials, they should privilege this test pair *only* in the unfused/relational condition, where there is a relation between objects to learn.

Although the current study applies this method to assess human reasoning in a previously published causal reasoning paradigm, this same technique is intended to be used for discriminating perceptual strategies from genuine relational reasoning in a variety of existing paradigms, across species.

Method

Participants

A total of 80 18-30-month-olds participated (M = 24.3 months; SD = 3.6 months; range = 17.9 - 31.1 months; 40 girls), with 40 toddlers randomly assigned to one of two conditions (*fused/single object* or *unfused/relational*). There was no difference in age between conditions, $t(1) = 1.21$, $p = .23$, and approximately equal numbers of males and females were assigned to each. Sixteen additional children were tested but excluded for failure to complete the study (11) or due to experimenter error (5). Children were recruited from a local museum.

Materials

The toy was a 10" x 6" x 4" opaque cardboard box containing a wireless doorbell. When a block or pair of blocks "activated" the toy, the doorbell played a novel melody. In fact, the toy was surrepticiously activated by a remote control. Eight painted wooden blocks in assorted colors and shapes (2 pairs of 'same' blocks and 2 pairs of 'different' blocks) were placed on the toy in pairs during the *unfused/relational* condition training. The 'same/low entropy' blocks were identical in color and shape, and the 'different/high entropy' blocks were distinct in color and shape. An identical set of these eight painted blocks were used to create the "fused" objects to be placed on the toy as single objects in the *fused/single object* condition training. In this condition, each pair of training blocks were glued together to create a single, larger block. Four additional blocks were used during the test phase of each condition, including 1 novel pair of 'same' and 1 novel pair of 'different' blocks. The test blocks either appeared as two pairs of blocks or as two fused, single objects, depending upon condition (see Figure 1). The pairs of test blocks in each condition were placed on 4” x 4” plastic trays.

Two different complete sets of blocks were constructed for each condition. In the *simple* set, all blocks were composed of simple, symmetrical geometric shapes (e.g., cubes, spheres, cylinders) with a single color and no pattern. In the *complex* set, all blocks were composed of asymmetrical, irregular polygons. Half of the children in each condition were randomly assigned to receive each stimuli set.

Procedure

All children were tested one-on-one, seated at a table across from the experimenter. Following a brief warm-up, the experiementer introduced a toy that was placed on the table. The experimenter said, “This is my toy. Some things make my toy play music and some things do not. Let’s try some things on my toy and find out how it works.”

In the *unfused/relational* condition, children observed as the experimenter placed a pair of ‘same’ blocks (AA’) on the toy, causing it to activate and play music (twice). They then observed that a pair of ‘different’ blocks (BC) failed to activate the toy (twice). This procedure was repeated for two additional pairs, one pair of ‘same’ (DD’) and one pair of ‘different’ blocks (EF) (see Figure 1). The ‘same’ pairs (AA’, DD’) were composed of individual blocks that were identical in both color and shape, and the ‘different’ pairs (BC, EF) were composed of individual blocks distinct in both color and shape. In the *fused/single object* condition, children observed an identical presentation with one critical exception: each pair of blocks were glued together to form single objects (A-low entropy, B-high entropy, C-low entropy, D-high entropy) (see Figure 1).

In detail, the experimenter selected the first pair [block], saying, “Let’s try!” and placed them [it] on the toy. Children in both conditions observed the ‘same’ pair [‘low entropy’ block’] activate the toy. The experimenter said, “Music! Let’s try again!”, picked up the pair [block], and placed them [it] back on the toy a second time, and children observed the outcome. The experimenter said, “Music! These ones [this one] made my toy play music.” After this second demonstration, the experimenter removed the pair [block], selected another – a ‘different’ pair or a ‘high entropy’ block – and placed it on the toy. This time, children in both conditions observed no effect. The experimenter said, “No music. Let’s try again!” As with the first pair [block], this was demonstrated a second time. The experimenter concluded, “No music. These ones [this one] did not make my toy play music.”

This procedure was repeated for all 4 pairs [blocks]: 2 pairs [blocks] of ‘same’ [‘low entropy’] objects and 2 pairs [blocks] of ‘different’ [‘high entropy’] objects. All pairs were placed on the toy twice. Therefore, children observed a total of 8 outcomes (4 positive and 4 negative). The order that the individual pairs [blocks] were presented was randomized, however, the order of the presentation pairs was fixed, beginning with a causal pair, and alternating between causal and inert pairs. In all cases, the experimenter placed all pairs of objects on the toy in the same orientation as the objects that formed the fused blocks, so that they were perceptually identical. Except for the particular objects used in the training trials (fused or unfused), there were no other differences in procedure between conditions.

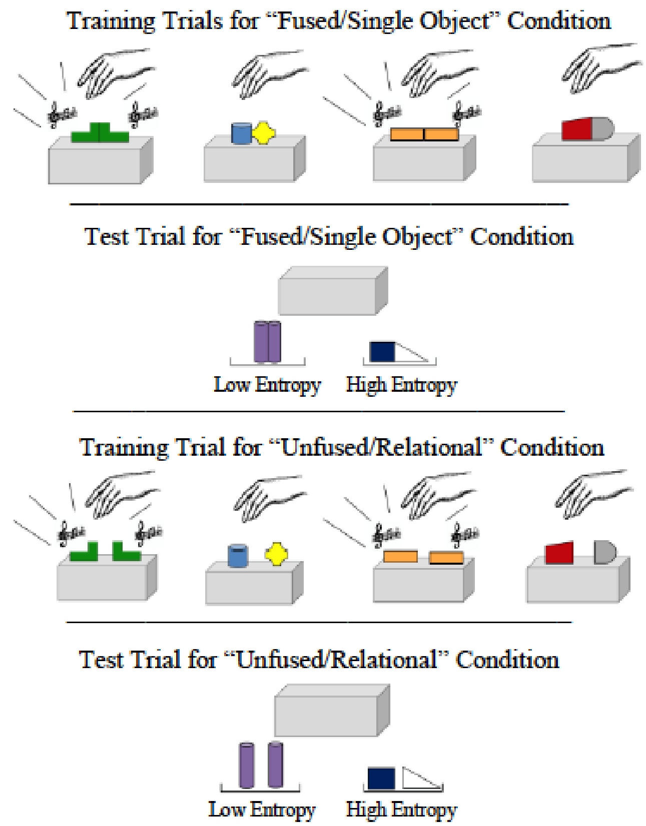

Figure 1: Schematic of study design (simple set). On training trials, pairs of blocks were placed on the toy. In the *fused/single object* condition, fused, identical/low entropy objects activated the toy, while fused, distinct/high entropy objects did not. In the *unfused/relational* condition, pairs of identical/low entropy objects activated the toy while pairs of distinct/high entropy objects did not. Participants observed 4 pairs (2 causal, 2 inert). On each test trial, the child selected between 2 novel pairs (“low entropy [same]” or “high entropy [different]”).

Following the training phrase in both conditions, the experimenter said, “Now it is your turn. Can you help me pick the thing[s] that will make my toy play music?” The experimenter produced 2 pairs of test blocks (1 novel ‘same’ pair [‘low entropy’ block], 1 novel ‘different’ pair [‘high entropy’ block]). In order to avoid a novelty preference, both test pairs were composed of novel objects. The pairs were presented to the child on trays. The experimenter held up the two trays, saying, “I have these [this] and I have these [this]. Only one of these trays has the thing[s] that will make my toy play music.” She then lowered the trays and placed them on opposite sides of the table in front of the child, saying, “Can you point to the one[s] that will make my toy play music?” The side on which the correct pair was placed was randomized between subjects.

Coding The first tray that the child selected (pointing, reaching, picking up objects) was recorded. Children received 1 point for selecting the *low entropy* pair/object that was consistent with their training and 0 points for selecting the *high entropy* pair/object. 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.

Results

Results show no difference between the *complex objects* and *simple objects,* in either condition, $\chi^2(1) = 0$, p = 1, $\varphi = 0$ (*fused/single object*); $\chi^2(1) = .13$, p = .72, $\varphi = -.06$ (*unfused/relational*). We therefore combined data from the two stimuli sets within each condition for all subsequent analyses. Children in the *unfused/relational* condition selected the ‘same’ test pair more often than chance (73%), $p = .006$ (two-tailed, exact binomial). These results replicate previous findings with 18-30-month-olds (Walker & Gopnik, 2014; Walker et al., 2016). However, in contrast with the perceptual account, children of the same age in the *fused/single object* condition selected at chance (40%), $p = .27$ (two-tailed, exact binomial). There was a significant difference between conditions, $\chi^2(1) = 8.58$, $p = .004$, $\varphi = .33$.

Discussion

Results demonstrate that when perceptual cues are matched, but no relation is present, toddlers do not appear to learn and generalize an abstract concept of *‘same’* to a novel set of objects. These findings therefore suggest that early relational competence in humans found here and elsewhere is unlikely to be the result of reliance on a perceptual heuristic, and provide evidence for genuine conceptual understanding of ‘same’ at this young age.

This novel method offers a simple, non-verbal manipulation that may be applied to a variety of existing match-to-sample procedures used to assess *same-different* reasoning to include in future research with non-human animals across species, as well as human infants. If infants or animals show the discriminative pattern of the toddlers in this experiment – generalizing the unfused/relational but not the fused/single objects – that suggests that they genuinely understand the relations. On the other hand, if they respond in the same manner to both conditions, the perceptual hypothesis would gain more weight. The latter pattern would not *eliminate* the possibility that relational reasoning was in play – perhaps children or animals are using different kinds of reasoning in the two conditions. But it would place the burden of proof on the relational claim.

Whatever the results of non-human animals or infants might turn out to be, the present results are consistent with previous claims that, from a very early age, as young as 18 months, humans posess cognitive tools for genuine conceptual understanding of *same-different* relations. These findings are also consistent with the idea that humans may possess a qualitatively different system for abstracting relations.

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