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Brief article

Discriminating relational and perceptual judgments: Evidence from human toddlers

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ABSTRACT

The ability to represent *same-different* relations is an important 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 genuine conceptual understanding or may be the result of 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 two object pairs in the "relational" condition. However, the "fused" objects do not provide evidence for the relation 'same.' Using this method with human toddlers in a causal relational reasoning 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 across species, as well as human infants.

1. Introduction

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; Hochmann, Mody, & Carey, 2016; Tyrell, Stauffer, & Snowman, 1991), discriminate and generalize patterns of repeated visual or auditory elements (ABA/AAB/ABB) (Dawson & Gerken, 2009; Johnson et al., 2009; Marcus, Vijayan, Bandi Rao, & Vishton, 1999; Saffran, Pollak, Seibel, & Shkolnik, 2007), and provide a conditioned response to pairs of identical stimuli (Hochmann, 2010; Kovács, 2014). 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 (Hochmann et al., 2016; Martinho & Kacelnik, 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 et al., 2008; Thompson & Oden, 1996).

For example, non-human primates (Wasserman, Fagot, & Young, 2001) and several species of birds (Pepperberg, 1987; Smirnova, Zorina, Obozova, & Wasserman, 2015) have succeeded

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in solving similar relational problems, in the context of multiple trials in reinforcement learning paradigms (Pepperberg, 1987; Smirnova et al., 2015; Wasserman et al., 2001), 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 (Blaisdell & Cook, 2005; Smith, Redford, Haas, Coutinho, & Couchman, 2008; Young & Wasserman, 2001). 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 (Fagot, Wasserman, & Young, 2001; Penn et al., 2008; Wasserman & Young, 2010; Wasserman, Young, & Cook, 2004; Wasserman et al., 2001; Young & Wasserman, 1997; Zentall, Wasserman, Lazareva, Thompson, & Rattermann, 2008). In particular, any visual display can be reduced to "a continuous analog estimate of the degree of perceptual variability between the elements" (Penn et al., 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 variability 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 (Fagot et al., 2001; Smith et al., 2008). 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 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 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 et al., 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. If children are indeed relying upon a low-level perceptual heuristic, they should select the lower entropy pair consistently across both conditions. On the other hand, if children learn the abstract relation 'same,' they should privilege this test pair *only* in the unfused/relational condition, where these is a relation to learn.

Although the current study applies this method to assess human reasoning in a previously published causal learning 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.

2. Method

2.1. 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, $t(1) = 1.21$, $p = 0.23$, 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).

All participants were recruited from a local children's museum. Although we did not collect specific demographic information for each child, the following demographic information describes the population of the recruitment location. The museum visitors include the following racial/ethnic groups: 60% Caucasion, 28% Asian, 1% American Indian or Alaskan Native, 14% Latino or Hispanic, 4% African American, and 13% Mixed racial/ethnic background. The average income for museum visitors is between $100,000 and $150,000 per year.

2.2. Materials

The toy was a $10'' \times 6'' \times 4''$ 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 surreptitiously 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/lower entropy' blocks were identical in color and shape, and the 'different/higher entropy' blocks were distinct in color and shape. An identical set of these eight painted blocks were used to create the "fused" blocks 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 Fig. 1). The pairs of test blocks in each condition were placed on $4'' \times 4''$ plastic trays.

Two 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, cylinders) with a single, solid color. 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.

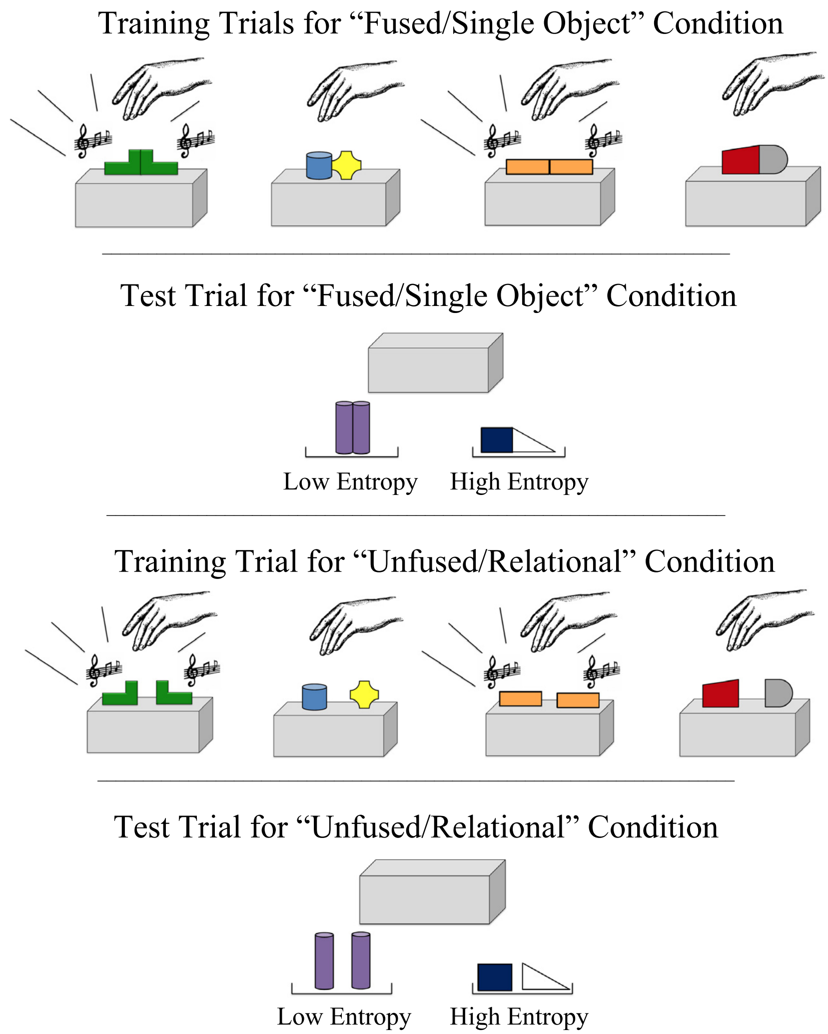

Fig. 1. Schematic of study design (simple set). On training trials, pairs of blocks were placed on the toy. In the *fused/single object* condition, fused, identical/lower entropy objects activated the toy, while fused, distinct/higher entropy objects did not. In the *unfused/relational* condition, pairs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

2.3. Procedure

All children were tested one-on-one with the experimenter in a quiet, private room. Although the testing room was located on the museum grounds, it was used exclusively for research activities and allowed no visual access to the rest of the museum. These conditions were therefore highly controlled and roughly similar to lab testing. Children were seated at a table across from the experimenter. Following a brief warm-up, the experimenter 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 Fig. 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. Both blocks in each of the *unfused/relational* pairs were always placed on the toy simultaneously. 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-lower entropy, B-higher entropy, C-lower entropy, D-higher entropy).

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 ['lower 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 'higher 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' ['lower entropy'] objects and 2 pairs [blocks] of 'different' ['higher 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 presentation of the causal 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.

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 ['lower entropy' block], 1 novel 'different' pair ['higher 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.

2.3.1. Coding

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

3. Results

There was no difference between the *complex* and *simple* sets, in either condition, $\chi^2(1) = 0$, p = 1, $\varphi = 0$ (*fused/single object*); $\chi^2(1) = 0.13$, p = 0.72, $\varphi = -0.06$ (*unfused/relational*). We therefore combined data from the two stimuli sets within each condition for all subsequent analyses. Results of logistic regression show no difference in performance as a result of age (measured in months), χ^2 ($N = 80$, $df = 1$) = 1.27 (Wald), $p = 0.72$. There was also no difference in overall performance as a result of gender, $\chi^2(1) = 0.54$, $p = 0.46$, $\varphi = -0.08$.

There was, however, a significant difference in performance as a result of condition, $\chi^2(1) = 8.58$, $p = 0.004$, $\varphi = 0.33$. In particular, children in the *unfused/relational* condition selected the 'same' test pair more often than chance (73%), $p = 0.006$ (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%), $p = 0.27$ (two-tailed, exact binomial).

4. Discussion

Results demonstrate that when perceptual cues are matched, but no relation is present, toddlers do not learn the abstract concept 'same'. These findings suggest that early relational competence found here and elsewhere (Walker & Gopnik, 2014; Walker et al., 2016) is unlikely to result from reliance on a low-level perceptual heuristic, and provide evidence for genuine conceptual understanding of 'same' at this young age.

It is important to note, however, that this paradigm diverges from previously used methods for assessing attention to perceptual entropy in a relational task. Entropy is generally defined according to the amount of perceptual variance among the elements in an array, and the amount of entropy decreases as the number of items in an array decreases. As a result, almost all of the relevant studies that have been conducted with non-human animals have used large arrays of visually-presented stimuli. However, it is still possible that human toddlers are relying on the perceived perceptual variability of the blocks, even with only two elements versus one.

Most previous studies of entropy have also used separately presented stimuli, such as different objects in an array, rather than testing the perceptual variability of elements in a single object. However, entropy, as a measure of perceptual variability should not be subject to object identity differences, and could also reasonably include the variance among the features of a single object (i.e., colors, edges, angles). In support of this claim, previous research with pigeons (Young, Wasserman, Hilfers, & Darymple, 1999) provides both empirical and computational results demonstrating that sensitivity to entropy remains the critical factor in discriminating *same* and *different* even when individual items were presented in succession (i.e., one at a time, in list form), rather than in an array. Young et al. (1999) note that the particular method of presentation should not matter if the perceptual detector is sensitive to variation among the stimuli.

This novel method therefore 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 claims that, from a very early age, as young as 18 months, humans posess cognitive tools for genuine conceptual understanding of *same-different* relations.

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References

Addyman, C., & Mareschal, D. (2010). The perceptual origins of the abstract Same/Different concept in human infants. *Animal Cognition, 13*(6), 817–833.
Blaisdell, A. P., & Cook, R. G. (2005). Two-item same-different concept learning in pigeons. *Animal Learning & Behavior, 33*(1), 67–77.
Cook, R. G., & Wasserman, E. A. (2007). Learning and transfer of relational matching-to-sample by pigeons. *Psychonomic Bulletin & Review, 14*(6), 1107–1114.
Dawson, C., & Gerken, L. A. (2009). From domain-generality to domain-sensitivity: 4-month-olds learn an abstract repetition rule in music that 7-month-olds do not. *Cognition, 111*, 378–382.

Fagot, J., Wasserman, E. A., & Young, M. E. (2001). Discriminating the relation between relations: The role of entropy in abstract conceptualization by baboons (Papio papio) and humans (Homo sapiens). *Journal of Experimental Psychology: Animal Behavior Processes, 27*(4), 316.

Ferry, A., Hespos, S. J., & Gentner, D. (2015). Prelinguistic relational concepts: Investigating the origin of analogy in infants. *Child Development, 86*(5), 1386–1405.

Flemming, T. M., Thompson, R. K., & Fagot, J. (2013). Baboons, like humans, solve analogy by categorical abstraction of relations. *Animal Cognition, 16*(3), 519–524.

Halford, G. S., Wilson, W. H., & Phillips, S. (1998). Processing capacity defined by relational complexity: Implications for comparative, developmental, and cognitive psychology. *Behavioral and Brain Sciences, 21*(06), 803–831.

Hochmann, J. R. (2010). Categories, words and rules in language acquisition (Doctoral Dissertation).

Hochmann, J. R., Mody, S., & Carey, S. (2016). Infants' representations of same and different in match-and non-match-to-sample. *Cognitive Psychology, 86*, 87–111.

Johnson, S. P., Fernandes, K. J., Frank, M. C., Kirkham, N. Z., Marcus, G. F., Rabagliati, H., & Slemmer, J. A. (2009). Abstract rule learning for visual sequences in 8- and 11-month-olds. *Infancy, 14*, 2–18.

Kovács, Á. M. (2014). Extracting regularities from noise: Do infants encode patterns based on same and different relations? *Language Learning*. http://dx.doi.org/10.1111/lang.12056.

Marcus, G. F., Vijayan, S., Bandi Rao, S., & Vishton, P. M. (1999). Rule-learning in seven-month-old infants. *Science, 283*, 77–80.

Martinho, A., & Kacelnik, A. (2016). Ducklings imprint on the relational concept of "same or different". *Science, 353*(6296), 286–288.

Penn, D. C., Holyoak, K. J., & Povinelli, D. J. (2008). Darwin's mistake: Explaining the discontinuity between human and nonhuman minds. *Behavioral and Brain Sciences, 31*, 109–178.

Pepperberg, I. M. (1987). Acquisition of the same/different concept by an African Grey parrot (*Psittacus erithacus*): Learning with respect to categories of color, shape, and material. *Animal Learning & Behavior, 15*(4), 423–432.

Saffran, J. R., Pollak, S. D., Seibel, R. L., & Shkolnik, A. (2007). Dog is a dog is a dog: Infant rule learning is not specific to language. *Cognition, 105*(3), 669–680.

Smirnova, A., Zorina, Z., Obozova, T., & Wasserman, E. (2015). Crows spontaneously exhibit analogical reasoning. *Current Biology, 25*(2), 256–260.

Smith, J. D., Redford, J. S., Haas, S. M., Coutinho, M. V., & Couchman, J. J. (2008). The comparative psychology of same-different judgments by humans (*Homo sapiens*) and monkeys (*Macaca mulatta*). *Journal of Experimental Psychology: Animal Behavior Processes, 34*(3), 361.

Thompson, R. K. R., & Oden, D. L. (1996). A profound disparity revisited: Perception and judgment of abstract identity relations by chimpanzees, human infants, and monkeys. *Behavioral Processes, 35*, 149–161.

Thompson, R. K. R., & Oden, D. L. (2000). Categorical perception and conceptual judgments by nonhuman primates: The paleological monkey and the analogical ape. *Cognitive Science, 24*(3), 363–396.

Tyrell, D. J., Stauffer, L. B., & Snowman, L. G. (1991). Perception of abstract identity/difference relationship by infants. *Infant Behavior and Development, 14*, 125–129.

Walker, C. M., Bridgers, S., & Gopnik, A. (2016). The early emergence and puzzling decline of relational reasoning: Effects of knowledge and search on inferring abstract concepts. *Cognition, 156*, 30–40.

Walker, C. M., & Gopnik, A. (2014). Toddlers infer higher-order relational principles in causal learning. *Psychological Science, 25*(1), 161–169.

Wasserman, E. A., Fagot, F., & Young, M. E. (2001). Same-different conceptualizations by baboons (*Papio papio*): The role of entropy. *Journal of Comparative Psychology, 115*(1), 42–52.

Wasserman, E. A., & Young, M. E. (2010). Same–different discrimination: The keel and backbone of thought and reasoning. *Journal of Experimental Psychology: Animal Behavior Processes, 36*(1), 3.

Wasserman, E. A., Young, M. E., & Cook, R. G. (2004). Variability discrimination in humans and animals: Implications for adaptive action. *American Psychologist, 59*(9), 879.

Young, M. E., & Wasserman, E. A. (1997). Entropy detection by pigeons: Response to mixed visual displays after same–different discrimination training. *Journal of Experimental Psychology: Animal Behavior Processes, 23*(2), 157.

Young, M. E., & Wasserman, E. A. (2001). Entropy and variability discrimination. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*(1), 278.

Young, M. E., Wasserman, E. A., Hilfers, M. A., & Darymple, R. (1999). The pigeon's variability discrimination with lists of successively presented visual stimuli. *Journal of Experimental Psychology: Animal Behavioral Processes, 25*(4), 475–490.

Zentall, T. R., Wasserman, E. A., Lazareva, O. F., Thompson, R. K., & Rattermann, M. J. (2008). Concept learning in animals. *Comparative Cognition & Behavior Reviews, 3*, 13–45.