Analogical Abstraction in Three-Month-Olds

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Abstract

This research tests whether analogical processing ability is present in 3-month-old infants. Infants are habituated to a series of analogous pairs, instantiating either *same* (e.g., AA, BB, etc.) or *different* (e.g., AB, CD, etc.), and then tested with further exemplars of the relations. If they can distinguish the familiar relation from the novel relation, even with new objects, this is evidence that for analogical abstraction across the study pairs. In Experiment 1, we did not find evidence of analogical abstraction when 3-month-olds were habituated to six pairs instantiating the relation. However, in Experiment 2, infants showed evidence of analogical abstraction after habituation to *two* alternating pairs (e.g., AA, BB, AA, BB…). Further, as with older groups, rendering individual objects salient disrupted relational learning. These results demonstrate that 3-month-old infants are capable of analogical comparison and abstraction. Our findings also place limits on the conditions under which these processes are likely to occur. We discuss implications for theories of relational learning.

Keywords: cognitive development, relational processing, infants

Introduction

Analogical ability – the ability to make relational comparisons between objects, events, or ideas, and to see common relational pattern across different sets of objects – is a cornerstone of higher reasoning abilities. Learning by analogy is a powerful way of acquiring and transferring new information. Equally important, analogical comparison facilitates the formation of abstract categories and rules (Doumas & Hummel, 2013; Gentner & Medina, 1998; Gick & Holyoak, 1983). Indeed, recent theoretical perspectives have asserted that analogical ability is the key capacity supporting higher-order cognition and differentiating human cognitive capacity from that of other primates (Gentner, 2003; 2010; Penn, Holyoak, & Povinelli, 2008).

The relational abilities of adult humans are astounding. But there are many contributors to the sophistication of adult cognition. Adults have had the benefit of cultural transmission of knowledge – skills, cultural technologies of various sorts, and symbol systems such as language and mathematics. In addition, adults have broad domain knowledge—another contributor to understanding relations (Gentner, 1988). It is therefore impossible to disentangle the roots/sources of our cognitive power by studying adults. To gain understanding of the nature and origin of our extraordinary relational ability, we must investigate infants who have not yet acquired these resources.

Although little is known about the very early development of human analogical ability, there has been considerable research on the development of analogical ability from preschool to adulthood. Analogical processing shows a relational shift (Gentner, 1988; Gentner & Toupin, 1986; Halford, 1992; Richland, Morrison, & Holyoak, 2006) with young children focusing on object matches and older children focusing relational matches and capable of using relational similarity in problem-solving (Chen, 1996). This shift has been attributed to increases in relational knowledge (Gentner & Rattermann, 1991), to maturational increases in processing capacity (Halford, 1992) and to increases in executive ability, including inhibitory control (Doumas, Hummel, & Sandhofer, 2008; Richland et al., 2006; Thibaut, French, & Vezneva, 2010), and it is possible that all three play a role.

This work has also revealed characteristic patterns of relational learning, including factors that support or hinder it. One signature component of relational learning is that the ability to perceive abstract relational matches can be enhanced by comparing different instances of a relation. For example, Gick and Holyoak (1983) found that comparing two stories that had the same causal structure enabled people to transfer that structure to a further situation. Preschool children have shown similar benefits from comparison (e.g., Christie & Gentner, 2010; Honomichi & Chen, 2006). These findings are consistent with other research suggesting that the act of comparison entails a structural alignment process that highlights the relational commonalities between the compared items (Markman & Gentner, 1993). The influence of structural alignment is a defining characteristic of analogical reasoning in adults (Doumas & Hummel, 2013; Gentner, Holyoak, & Kokinov, 2001), and the evidence of its influence in children as young as 3 years of age suggests that there may be continuity in the signature components of

relational learning through human development.

A second signature component of relational learning is that attention to individual objects can interfere with relational processing. Preschool children perform far worse on relational matching tasks when competing object matches are present (Gentner & Toupin, 1986; Richland et al., 2006), especially if the objects involved are rich and distinctive (Gentner & Rattermann, 1991; Paik & Mix, 2006). The finding that attention to objects can overshadow attention to relations extends to very young age groups (Casasola, 2005; Maguire, Hirsh-Pasek, Golinkoff, & Brandone, 2008).

The following experiments aim to trace the development of relational learning processes in infants. We focused on the *same-different* relation because it is among the simplest and most basic relations in the human repertoire. Additionally, Ferry, Hespos, & Gentner (2015) found that 7- and 9-month infants can learn *same-different* relations from four exemplars of *same* or *different* toy pairs (e.g., AA, BB, CC, DD or AB, CD, BC, DA). The key finding was that infants discriminated between the relation they had experienced and the novel relation, even when both were instantiated with new objects. Further, infants failed to discriminate between the learned relations when the test pairs contained objects that have been rendered individually salient prior to habituation. This was consistent with the findings among older children, for whom object salience interferes with analogical comparison (Gentner & Toupin, 1986; Richland et al., 2006). These findings suggest that by 7 months, infants show the basic characteristics of analogical learning. In the present research, we took this investigation to even younger infants.

Experiment 1

To fully understand the ontogenetic development of relational processes, we need to test for relational abstraction at the earliest age possible. This will this provide evidence as to when in development relational processing becomes possible. Further, it will serve as a base for capturing developmental changes in the learning process across age groups.

The key dependent measure in this study is whether infants can differentiate the familiar relation (e.g., *same* if habituated to *same*) from the unfamiliar one (*different*) when they see test pairs composed of new objects. The specific predictions are that if infants are learning via structural alignment, then (a) relational encoding and abstraction should benefit from comparing a series of exemplars and (b) relational encoding should be hampered for pairs that contain a highly salient object (based on findings that object focus interferes with relational encoding (Gentner & Toupin, 1986; Richland et al., 2006)).

Methods

Participants. The participants were 31 healthy, full-term 3-month-old infants (17 male and 14 female) with an average age of 3 months, 2 days. Sixteen infants were assigned to the *same* condition and 15 to the *different* condition. Seventeen additional infants were tested but eliminated from the final analysis for fussiness (defined as fussy or crying on 4 or more test trials by two independent coders), breaks longer than 8 minutes, or because they looked the maximum amount of time on 7 out of 8 test trials, making their data uninterpretable.

Materials and Procedure. Coding and analysis procedure was closely modeled on Ferry et al. (2015). In Experiment 1, infants received training on either *same* or *different* relations. During test trials, infants saw pairs of objects instantiating the *same* and *different* relations (See Figure 1). The key question was whether infants would differentiate the familiar relation from the novel relation at test. Each infant saw four types of test trials, composing a 2x2 within-subject design. The first type consisted of entirely new objects (*New*). These trials tested the main prediction: whether infants had abstracted the relation across the habituation pairs and applied this relation to new instances. The second test type consisted of objects that had been rendered individually salient in the waiting room prior to habituation, but not shown in habituation trials (*Object Experience only*). These trials investigated whether object salience would disrupt relational processing. The third type was made up of objects that had been rendered individually salient in the waiting room and had subsequently appeared as part of pairs during the habituation trials (*Object Experience + Pair Habituation*). These trials tested whether repeated alignment across pairs would overcome initial object salience. The fourth test trial type was made of objects that were not seen in the waiting room, but were viewed in pairs during habituation trials (*Pair Habituation only*). These trials provided a check on whether infants recognized identical pairs. If infants failed to discriminate between a pair that they had seen in habituation and a novel pair, this would suggest failure to learn the exemplars even at a concrete level.

A small camera captured video of the infant's face while they watched an experimenter raise, lower and tilt a pair of objects in tandem on the stage. Two research assistants in a separate room viewed the image, each pressing a button when the infant attended to events on stage and releasing the button when the infant looked away. A software program recorded the looking times. Each trial ended when the software signaled that the infant had looked away from the stage for more than two consecutive seconds. If coder agreement was less than 90%, recordings of the trials were re-coded by two new coders.

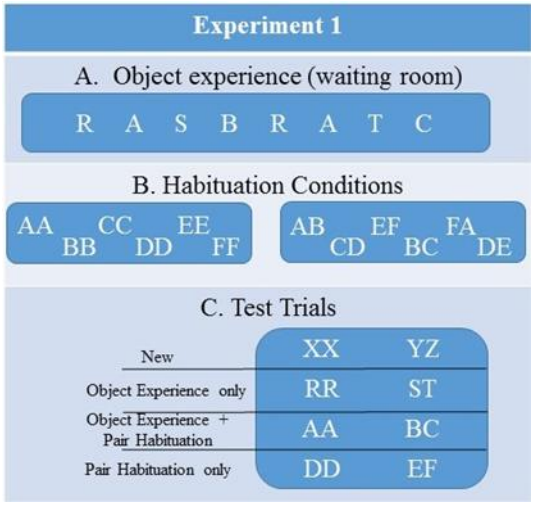


Figure 1. Schematic of events in Experiment 1. A) In the waiting room before the experiment, infants were shown a subset of individual objects used in the experiment. (B) During habituation trials, infants were either shown pairs of *same* objects or pairs of *different* objects. (C) during test trials, infants saw pair of objects presented sequentially. There were four types of test trials that systematically varied the infants' object experience with the objects to measure the influence on performance. To give a sense of the variation across the stimuli, three sets of *same* and *different* pairs are shown in Figure 2.

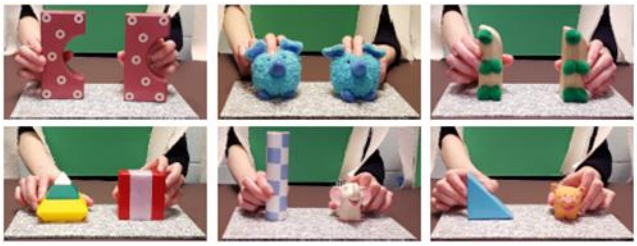


Figure 2 Examples of the same and different pairs.

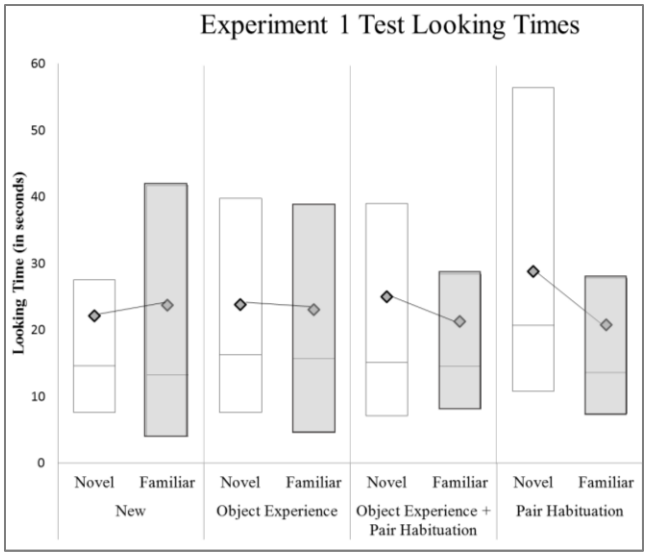
Pair habituation trials. When the screen was raised at the start of every trial, a pair of objects rested on the cardboard tray on the stage. To engage infants' attention, in both habituation and test trials, the experimenter grasped one object in each hand and raised the objects, tilted them to the left and right, then paused on the tray. This 8-s cycle repeated continuously until the trial ended.

Test trials. Infants viewed eight test trials. In each test trial, infants viewed one pair of objects, presented in the same motion pattern as in the habituation trials, while their looking time was recorded. Each infant received test trials with both *same* and *different* pairs of objects, presented in alternation, with order counterbalanced across infants.

Figure 3. Test trial looking times for Experiment 1. Looking durations to novel and familiar pairs for each test type were collapsed across *same* and *different* conditions. The diamonds represent the mean. The horizontal line inside the rectangle represents the median. The area above and below the median represents the 1st and 3rd quartiles respectively.

Results

The results depicted in Figure 3 show no evidence of generalization to new pairs: infants did not distinguish novel from familiar relations on the test pairs with new objects. An



ANOVA testing the between-subject factor of habituation condition (*same* or *different*), and the within-subject factor of relation (novel or familiar) failed to show a significant effect of relation across all test trials, $F(1,30) = .967$, $p = .333$.

Critically, there was no evidence that either group—same or different—had abstracted the relation, because they showed no difference in looking time between novel and familiar relations when the relations were composed of new objects, $t(30) < 1$, $p = .628$. This pattern suggests that infants recognized pairs they had seen previously, but did not generalize the relation.

Discussion

Given infants' failure to generalize the relation to the novel objects in Experiment 1, there are at least three possible interpretations. First, three months-old infants may not yet be able to engage in analogical learning. Second, they may not be able to form abstract relations like *same* and *different*. However, a third possibility is that these young infants do already possess the relational learning processes, but that the training set used in Experiment 1 (i.e., six unique pairs of exemplars) was not adequate. For example, the range of exemplars given in habituation may have been too limited. Perhaps these very young infants need more variation and more exemplars to abstract the relation. This would be consistent with the standard assumption in learning theories that high variability in training enhances transfer, and with evidence that generalization improves when the number and

range of examples increases (e.g. Gerken, 2006; Quinn & Bhatt, 2005; Xu & Tenenbaum, 2007). The six exemplars we showed in Experiment 1, though, is already a larger training set than the four exemplars 7 – and 9-month-olds saw in Ferry, et al. (2015). This larger set did not appear to benefit the 3-month-olds.

A second route—the one we pursued—is to show infants *fewer* pairs during habituation. Although this choice may seem counterintuitive, there is evidence that in early learning, fewer exemplars of a relation can lead to better learning of the relation. For example, Casasola (2005a) found that infants were better able to learn and generalize the spatial category of support when they were given two alternating exemplars of the relation than when they were given six exemplars of the relation (see also Maguire, et al., 2008). This pattern can be understood in terms of the general finding that relational alignment can be impeded by attention to objects (Gentner & Medina, 1998; Gentner & Toupin, 1986; Paik & Mix, 2006)—particularly when the objects are rich and distinctive (Casasola & Park, 2013).

Experiment 2

In Experiment 2, we presented infants with only two pairs during habituation-–either two *same* pairs (alternating between AA and BB) or two different pairs (AB and CD). The idea is that alternating between just two pairs could allow that infants to become familiar enough with the objects to be able to attend to the relation between them. As in our previous studies, prior to habituation we showed the infants some of the objects (singly, not in pairs) in order to render those objects individually salient. This serves as a test of whether object salience disrupts relational learning in 3-month-olds. Thus, this study tests whether 3-month-old infants can abstract the *same-different* relation and generalize it to new test pairs and whether their ability to do so will be impeded for pairs containing high-salient objects (see Figure 4).

Methods

Participants. The participants were 32 healthy, full-term, 3-month-old infants (19 male and 13 female) average age 3 months and 16 days, ranging from 2 months 10 days to 4 months 15 days. Half of the infants were assigned to the *same* condition; the other half, to the *different* condition. Ten additional infants were tested but eliminated from the final analyses (using the same criteria as Experiment 1).

Procedure. As in Experiment 1, there were three types of test trials, varied according to infants' experience with the objects. Because fewer objects were used in habituation, we reduced the number of test trial types from four to three, dropping the *Pair Habituation only* trials (see Figure 4). The remaining test trial types were as in Experiment 1.

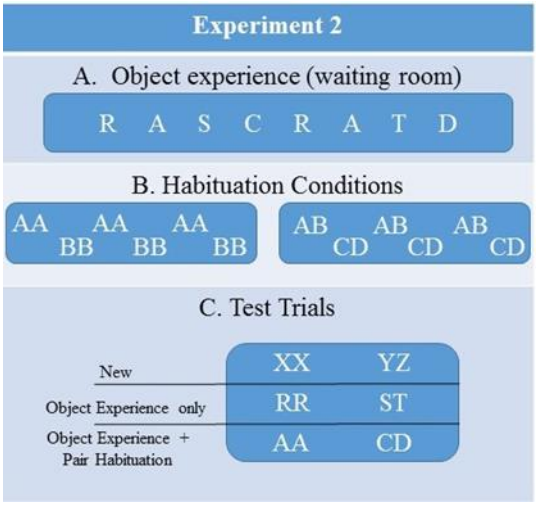


Figure 4. Schematic of events in Experiment 1. A) In the waiting room before the experiment, infants were shown a subset of individual objects used. (B) During habituation trials, infants were shown either alternating pairs of either *same* or *different* objects. (C) During test trials, infants saw six pairs of objects, presented sequentially.

Results

The results (Figure 5) fit the predictions of an analogical learning account. First, infants looked significantly longer at the novel relation than at the familiar relation during test. Critically, this novelty preference held for test pairs containing new objects, demonstrating that the infants had abstracted the relation and could apply it to objects they had not seen before, $t(29) = 3.616$, $p < .001$. Second, as predicted, prior experience with individual objects interfered with noticing the relation: there was no significant difference in looking time between the novel and familiar relations for pairs containing objects seen in the waiting room. This was true whether these salient objects appeared only in test or in pair habituation as well as test.

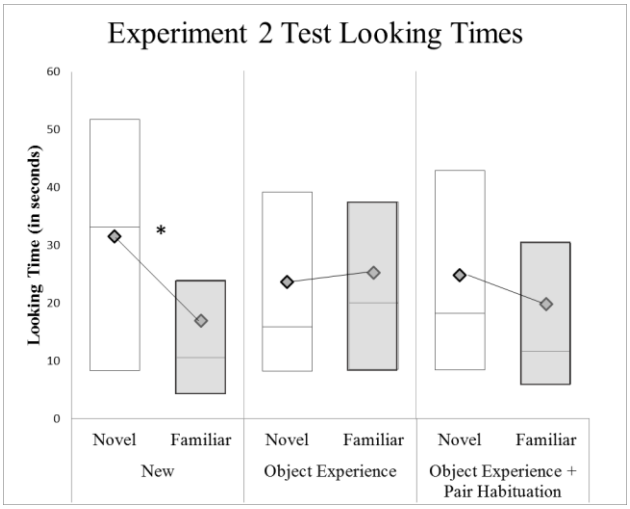


Figure 5. Test trial looking times for Experiment 2. Looking durations to novel and familiar pairs for each test

type collapsed across *same* and *different* conditions. The diamonds represent the mean. The horizontal line inside the rectangle represents the median. The area above and below the median represents the 1st and 3rd quartiles respectively. The * indicates $p < .01$.

Discussion

The findings in Experiment 2 are evidence for early relational learning. Critically, infants were able to distinguish the familiar relation from the novel relation even on pairs composed of new objects—the gold standard for testing whether infants abstracted the *same* and *different* relations. Consistent with other findings on analogical learning, infants performed significantly worse on test trials containing objects that had been seen prior to habituation. These findings show that the key signatures of analogical learning are already present by 3 months of age.

At the same time, the knowledge of the specific relations *same* and *different* in 3-month-olds appears to be learned: Experiments 1 & 2 show strong limits to the situations in which they could generalize these relations. Infants performed best with fewer exemplars. Even then, the infants did not discriminate between novel and familiar relations when they saw pairs that contained salient objects. Unlike with 7-month-olds in Ferry et al. (2015), 3-month-olds failed to overcome their object focus even after seeing the waiting room objects in pairs during habituation.

General Discussion

There are two key findings. First, the results show that analogical learning processes are present in 3-month old infants. In Experiment 2, the infants showed two key signatures of analogical learning: (a) the ability to abstract a common relation across a sequence of pairs and (b) the detrimental effects of individual object salience. These findings suggest that the ability to abstract relations is an innate mechanism in human infants. If so, then analogical processing would join association and other domain-general processes as part of the core cognitive apparatus of humans.

The second key finding is that these young infants showed more learning when given just two pairs during habituation than when given six distinct pairs.

This pattern runs counter to the general finding that increasing the variability within a set of training stimuli increases learners' level of abstraction and therefore the range of transfer (Gerken, 2006; Gómez, 2002; Quinn & Bhatt, 2005).

However, there is precedent for this kind of "less is more" finding (Casasola, 2005; Casasola & Park, 2013; Maguire et al., 2008). What these studies have in common is that the objects participating in the relations are of high salience. Under these conditions, a participant given a series of different exemplars may attend only to the novel objects in each pair, and fail to attend to the relations. In this case, reducing the range of instances so that a small set of exemplars is seen repeatedly may lead to better relational learning. As Casasola and Park (2013) note, although increasing the range of exemplars can help learners to isolate the relevant structures, "… the need for fewer exemplars arises when the relevant features, such as a spatial relation, risk becoming obscured by […] the objects depicting that relation."

The finding then raises the question of *when* this pattern holds. As discussed earlier, many developmental studies have found better learning with more exemplars than with fewer (e.g., Bulf & Johnson, 2011; Casasola & Park 2013; Gerken 2006). Further, in our previous studies we found that 7- and 9-month-olds successfully abstracted *same* and *different* relations when given four repeated exemplars (Ferry et al., 2015). Clearly, a goal for future research will be to understand the range of exemplar variability that best supports early relational learning across development.

Implications for learning theories. As noted above, a surprising finding is that in order for 3-month-old infants to learn the relations, they needed comparison across two repeating pairs rather than comparison across a greater variety of pairs. How do we square this finding with the many findings that greater variability during training leads to greater abstraction and transfer? We think that the key is that the current studies focus on *relational* learning. When the desired abstraction is at the level of overall exemplar similarity (e.g., learning a basic-level category such as *dog*, or learning a distribution of line lengths), then increasing the range of exemplars in learning should increase the level of generalization. However, if the desired generalization is a relational pattern, then it is crucial that the learner be able to compare and align the exemplars (Christie & Gentner, 2010). In this case, whether the learner can align the exemplars may matter more than the amount of information potentially available. This leads us to suggest an amended learning principle: in relational learning, breadth of *alignable* training predicts breadth of transfer.

Summary. Together, the evidence from our experiments points neither to core knowledge of *same* or *different* nor to a process that arises entirely from experience, but to structural alignment as an early learning mechanism that becomes elaborated over development and with increases in language and domain knowledge.

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