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Comparison within pairs promotes analogical abstraction in three-month-olds

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ABSTRACT

This research tests whether analogical learning is present before language comprehension. Three-month-old infants were habituated to a series of analogous pairs, instantiating either the *same* relation (e.g., AA, BB, etc.) or the *different* relation (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 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 learning the relation. These results demonstrate that 3-month-old infants are capable of comparison and abstraction of the *same/different* relation. Our findings also place limits on the conditions under which these processes are likely to occur. We discuss implications for theories of relational learning.

1. Introduction

Analogical processing is a powerful learning mechanism for organizing the world around us. For example, the ability to compare relations across events may be one important route by which categorization and category-based induction occur (Gentner & Markman, 1997; Higgins & Ross, 2011; Markman & Wisniewski, 1997). Mapping from a familiar analog to an unfamiliar situation can facilitate learning and creative problem solving (Gentner & Holyoak, 1997; Gick & Holyoak, 1980, 1983). In line with its demonstrated benefits, performance on a test of analogical ability (the Raven's matrix task) predicts performance on a wide range of intelligence tests (Snow, 1978). Relational ability is arguably the key capacity supporting higher-order cognition (Gentner & Medina, 1998), and recent theories have suggested that our exceptional analogical ability is the central cognitive difference between humans and other primates (Gentner, 2003; Gentner, 2010; Penn, Holyoak, & Povinelli, 2008).

Adults can process analogies with comparative ease. But there are many contributors to the sophistication of adult cognition. Adults have had the benefit of cultural transmission of knowledge, and have acquired symbol systems such as language and mathematics, skills such as perspective-taking, and cultural technologies like written representations. We therefore cannot disentangle whether our relational ability is the root or the result of other cognitive abilities by studying adults. To gain understanding of the nature and origin of our extraordinary relational abilities, we must investigate infants who have not yet acquired these resources.

This brings us to our central question: How does human relational ability arise? We can distinguish two broad positions. One possibility is that analogical ability develops through combining other abilities and experience, and is in no way inherent in human biology. In this position, developing cognitive capacities such as language comprehension, or a vocabulary that can be mapped to categories and concepts might play a critical role in beginning to encode relations. A second possibility is that human infants are born with analogical processing ability, with which they can learn relations from experience before they acquire other capabilities like language.

To track the development of analogical ability in infancy, we need to first characterize the process that underlies this ability in adults and older children. According to structure-mapping theory (Gentner, 1983; Gentner, 2003), comparison entails a process of *structural alignment* that places the representations into correspondence based on aligning like relations (Falkenhainer, Forbus, & Gentner, 1989; Gentner & Markman, 1997; Wolff & Gentner, 2000). One important outcome of this process is that the common relational structure becomes more salient; thus, comparison may result in the extraction of a relational structure that was not apparent in either analog before alignment (Gentner & Hoyos, 2017; Gentner & Medina, 1998; Gentner & Namy, 1999). Promoting

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comparison may be especially helpful for infants and young children whose limited conceptual knowledge of objects leads to a focus on perceptual properties.

1.1. Generalization in infancy

There is abundant evidence that young infants can generalize across a series of objects to arrive at basic-level categories in the first year of life (Bornstein & Arterberry, 2010; Fulkerson & Waxman, 2007; Mareschal & Quinn, 2001; Plunkett, Hu, & Cohen, 2008; Xu, 2002). For example, 3-month-olds exposed to a series of examples can learn basic-level categories like cats and dogs (Quinn, Eimas, & Tarr, 2001). Further, common object labels enhance this process (Fulkerson & Waxman, 2007; Plunkett et al., 2008; Xu, 2002), even among 3-month-olds (Ferry, Hespos, & Waxman, 2010). However, there is comparatively little evidence concerning domain-general relational ability in infancy, despite abundant research on the development of analogical ability from preschool to adulthood. The most compelling evidence for learning abstract relations occurs for linguistic stimuli. These studies show that infants can abstract patterns of syllables such as AAB, ABA and ABB structures in speech from the first days of life and into later infancy (Gervain, Berent, & Werker, 2012; Gervain, Macagno, Cogoi, Pena, & Mehler, 2008; Gómez, 2002; Marcus, Vijayan, Rao, & Vishton, 1999). It is unclear, though, whether language is a privileged domain or whether these findings point to a domain-general relational learning mechanism present in early infancy.

Work that examines domain-general analogical ability in children and adults has revealed key signatures of analogical learning. One such signature is that the perception of abstract relational matches can be enhanced by comparing across instances of a relation. For example, Gick and Holyoak (1983) found that comparing two stories that had the same causal structure enabled people to generalize that structure and to transfer it to a further situation, and adults can abstract relational categories from a series of examples (Kurtz, Boukrina, & Gentner, 2013). Similar effects of comparison have been found for preschool children (e.g., Christie & Gentner, 2010; Gentner, Anggoro, & Klibanoff, 2011; Kotovsky & Gentner, 1996). 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 items compared (Markman & Gentner, 1993).

A second signature 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, Morrison, & Holyoak, 2006), especially if the objects involved are rich and distinctive (DeLoache, 1995; Gentner & Rattermann, 1991; Paik & Mix, 2006). Although adult analogical processing can also be disrupted by competing object matches (Goldstone & Medin, 1994), the tendency to focus on objects is generally stronger in early learning; as relational knowledge increases, children are better able to focus on relational matches (Gentner, 1988; Gentner & Rattermann, 1991). There appears to be continuity in the signature components of relational learning through human development. This raises the question of whether the signature components of analogical processing would be evident in infants.

Recent studies with 7- and 9-month-old infants suggest that the answer is yes. Ferry, Hespos, and Gentner (2015) habituated infants to a series of exemplars of either *same* pairs or *different* pairs, and then tested them with new pairs. Infants looked longer at pairs instantiating the novel relation; for example, infants habituated to *same* looked longer at YZ than at XX. Importantly, this pattern held even when none of the objects had been seen before—evidence of relational abstraction. This is evidence for the first signature—the ability to abstract a relation by aligning across a series of examples. The studies also showed evidence for the second signature—the adverse effects of object salience on relational abstraction. To test this, the experimenter manipulated the salience of some of the objects (e.g., R) by showing them individually to the infants in the waiting room prior to the experiment. When the infants subsequently saw these objects presented as part of *same* or *different* pairs in test trials (e.g., RR), they showed no evidence of abstracting the relations for those pairs—suggesting that the salient objects had disrupted their relational processing. Together, this evidence demonstrates the operation of structural alignment process in infant learning: alignment across multiple exemplars during habituation facilitated analogical generalization and transfer to new items, while individual object salience hindered analogical learning.

This display of analogical learning at 7–9 months is consistent with the position that this ability is available to humans from birth, but it is not conclusive. By 7 to 9 months of age, infants have already demonstrated abilities across a number of domains, such as: encoding others' beliefs (Kovács, Téglás, & Endress, 2010); tolerating punishment for wrongdoing (Hamlin, Wynn, Bloom, & Mahajan, 2011); and comprehending familiar labels for objects and body parts (Bergelson & Swingley, 2012). To understand the ontogeny of analogical processing, we need to test younger infants. Testing younger infants will also allow us to capture any developmental changes and variability in the learning process.

1.2. The current experiment

In the following experiments, our goal was to track the emergence of analogical learning in 3-month-olds—the youngest age we could test with the habituation/dishabituation paradigm. As in Ferry et al.'s (2015) studies, we focused on the ability to abstract *same* and *different* relations. We tested for two signatures discussed above: (a) whether the ability to abstract relations benefits from the comparison of multiple exemplars and (b) whether infants would be less likely to generalize the abstracted relation to pairs containing an object that had been made individually salient, via prior exposure. If infants are learning via structural alignment, they should differentiate the familiar relation (e.g., *same*, if habituated to *same*) from the unfamiliar one (e.g., *different*) for pairs comprised of new objects, but should not discriminate between novel and familiar relations when they are comprised of objects that have been made salient.

We investigated the *same-different* relation because it is arguably the simplest and most basic relation, and therefore likely to be available early in development, and because the perception of sameness is critical to a broad range of cognitive functions, from memory retrieval to categorization. A further advantage of studying the development of *same* and *different* is that it allows us to compare our findings with the rich set of findings from comparative psychology (Fagot & Thompson, 2011; Flemming, Beran, & Washburn, 2007; Premack, 1983; Thompson, Oden, & Boysen, 1997; Wasserman & Young, 2010).

The between-subjects factor of training condition also allowed us to ask whether 3-month-old infants are equally proficient at learning *same* and *different* relations. For example, it could be that *same* is an elemental relation, while *different* is represented as "not same" (Clark & Chase, 1972; Hochmann, Mody, & Carey, 2016). If this is the case for infants, then they should be better at abstracting the *same* relation than the *different* relation. There is some evidence for this with other age groups (Hochmann et al., 2016; Smith, Redford, Haas, Coutinho, & Couchman, 2008; but see Addyman & Mareschal, 2010 who reported cases where *different* is easier). On the other hand, Ferry et al. (2015) found no measurable difference in the likelihood of learning *same* versus *different* in their studies of 7- and 9-month-olds. Still, it is possible that younger infants will show an advantage for *same* over *different*.

In Experiment 1, 3-month-old infants received training on either *same* or *different* relations (see Fig. 1). During test trials, infants saw pairs of objects instantiating both *same* and *different* relations. The design was similar to that used by Ferry et al. (2015) with 7- and 9-month olds. However, based on evidence that generalization improves when