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Seeing the unseen: Second-order correlation learning in 7- to 11-month-olds

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ABSTRACT

We present four experiments with the object-examining procedure that investigated 7-, 9-, and 11-month-olds' ability to associate two object features that were never presented simultaneously. In each experiment, infants were familiarized with a number of 3D objects that incorporated different correlations among the features of those objects and the body of the objects (e.g., Part A and Body 1, and Part B and Body 1). Infants were then tested with objects with a novel body that either possessed both of the parts that were independently correlated with one body during familiarization (e.g., Part A and B on Body 3) or that were attached to two different bodies during familiarization. The experiments demonstrate that infants as young as 7 months of age are capable of this kind of second-order correlation learning. Furthermore, by at least 11 months of age infants develop a representation for the object that incorporates both of the features they experienced during training. We suggest that the ability to learn second-order correlations represents a powerful but as yet largely unexplored process for generalization in the first years of life.

1. Introduction

Associative processes are a crucial part of young infants' ability to represent the world around them (e.g., Fiser & Aslin, 2001, 2002; Gogate & Bahrick, 1998; Madole & Cohen, 1995). In particular, there is considerable evidence that infants are adept at extracting correlational information about the static and dynamic features of things in the world (e.g., Rakison & Poulin-Dubois, 2002; Younger & Cohen, 1986). An important issue that has only been examined in a handful of studies is how and when infants and young children are able to learn about correlations between features that are rarely, if ever, observed together; that is, there is currently little evidence that attests to whether children can learn correlations between features that are never experienced at the same time or that are indirectly correlated. For example, if children learn that objects with legs also have tails and that things with legs have eyes, can they infer on the basis of associations between these features that things with eyes have tails? The aim of the four experiments presented here was to establish whether infants between 7 and 11 months of age can learn such correlations for static features, a process that we label *second-order correlation learning*.

There is now indisputable evidence that infants are sensitive to, and can encode, correlations among features in a variety of contexts and across a range of domains. This ability is present at birth such that newborns who are familiarized to stimulus compounds (e.g., a green vertical stripe and a red diagonal stripe) extract the correlation between the two features (i.e., color and slant) instead of each feature independently (Slater, Mattock, Brown, Burnham, & Young, 1991). There are also data to suggest that infants are able to encode correlations among static features embedded in more naturalistic stimuli. For example, classic work by Younger and colleagues (Younger, 1990; Younger & Cohen, 1986; Younger & Gotlieb, 1988) used the habituation paradigm to demonstrate that 10-month-old infants can extract correlated features in a non-category and category context for a variety of stimuli including artificial and realistic portrayals of animals. Infants in the second year of life—those around 14 months of age—are also able to extract featural correlational information from moving and dynamic stimuli. Thus, following their 1st birthday infants can learn the association between object features and animate motions (Rakison, 2005b, 2006), the relation between a label and an object (Werker, Cohen, Lloyd, Casasola, & Stager, 1998), and that between an object part and its function (Madole & Cohen, 1995; Madole, Oakes, & Cohen, 1993).

There is also considerable evidence that infants can generalize from limited data. For example, Dewar and Xu (2010) found that

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9-month-olds generalize from limited evidence about the contents of a novel box having previously seen the contents of three similar boxes, and Walker and Gopnik (2014) found that 18- to 30-month-olds can use higher-order relations between objects to make causal inferences such that when paired objects (e.g., AA, BB) caused an outcome they expect another novel pair (e.g., DD) to produce the same outcome (Walker & Gopnik, 2014). Likewise, a number of studies on inductive inference have demonstrated that infants in the first and second year of life can generalize action and motion properties to novel objects (e.g., Mandler & McDonough, 1996; Rakison, 2005a), and there is evidence that 3- to 4-month-olds generalize their category representation of cats to a novel cat but not a dog (Quinn, Eimas, & Rosenkrantz, 1993).

It is beyond doubt, then, that infants can learn correlations among features and generalize from their limited experience to a novel one. However, to our knowledge, only a handful of studies have examined whether infants can learn relations between features or objects that were never presented simultaneously. This capacity is important for infants and young children because they can only experience a small fraction of all the possible correlations in the world and therefore must infer those that are rarely presented together or that are only indirectly associated. However, once infants learn that two features are correlated they will start to associate other features—even those that are not directly observed as correlated with one of those features—with them. In this way, over developmental time infants and young children may construct increasingly rich associatively derived representations for the features and properties of objects and entities in the world (Quinn & Eimas, 1997; Rakison & Lupyan, 2008).

This domain-general process may be related to, and underpin, aspects of later analogical processing in early childhood. In particular, according to the *systematicity principle* individuals are guided by an implicit preference to find large connected systems of relations (for a review see Gentner & Smith, 2013). This implicit preference may explain why infants seek out and learn features that they have established are correlated with other features. According to the structural mapping theory (Gentner, 1983), children also seek out second-order relations that are higher level mappings of two or more objects. In principle, second-order correlation learning may be one way in which these mappings are discovered. Moreover, because second-order correlation learning is presumably underpinned by an all-purpose associative learning mechanism, it is plausible that the same kind of inference may occur across many domains for which there is a rich correlated structure of input. Thus, second-order correlation learning may represent a relatively unexplored domain-general process for generalization that is involved in the development of categorical representations (e.g., Sloutsky & Robinson, 2013), language (e.g., Sandoval & Gomez, 2013), and causal learning (see e.g., Walker & Gopnik, 2014), among other things.

One of the reasons why second-order correlation learning has often been overlooked in the literature is because it was previously assumed that two memory retrieval cues become associated because they are both present at the time of the target episode, which was the case in previous research that examined infants' ability to encode clusters of correlated attributes (e.g., Younger & Cohen, 1986). However, it is not necessary that two cues have temporal contiguity for associative learning to occur as demonstrated in *trace conditioning* studies in which the conditioned stimulus is not physically present when the unconditioned stimulus is presented (Pavlov, 1927). This idea has been illustrated by Dwyer, Mackintosh, and Boakes (1998), who showed that rats can associate two cues that were not present simultaneously but that were simultaneously activated in memory.

One of few studies to examine whether infants are capable of this kind of learning was conducted by Cuevas, Rovee-Collier, and Learmonth (2006; see also Barr, Marrott, & Rovee-Collier, 2003). The study used the mobile reinforcement task with 6-month-olds in a design analogous to that used by Dwyer et al. (1998). Infants were taught three sets of correlations: (1) two hand puppets (A and B) that went together; (2) a mobile that was movable by the infant's kicking that went with a particular crib context; (3) one of the hand puppets (A) that went with the crib context. Cuevas et al. found that infants began to associate the other hand puppet (B) with the mobile—despite never being exposed to the two simultaneously—through the activated memories of puppet A and the crib context. In a related vein, there is also evidence that infants can learn nonadjacent dependencies in language that occur over one or more intervening units and require infants to track discontinuous sequential relationships. For example, by 6 months of age infants are able to track nonadjacent dependencies among vowels in natural language, and by 10 months of age they can track nonadjacent relationships among consonants (Gonzalez-Gomez & Nazzi, 2012; for a review see Sandoval & Gomez, 2013). Finally, Mou, Province, and Luo (2014) found evidence that infants at 16 months of age are capable of transitive inference. Thus infants who saw an agent prefer a red object over a yellow object (A > B) and a yellow object over a green object (B > C), inferred that the agent should prefer the red object ahead of the green one (A > C). Although the processes involved in transitive inference are likely different from the associative processes that we posit support second-order correlation learning, this study demonstrates that by 16 months, at least, infants are able to generalize from their experience about an unobserved relationship (in this case, that A > C).

These studies illustrate that infants are able to learn information associated with an object even if that object is not present. However, to our knowledge no research has tested whether infants in the first year of life are able to learn multiple associated features of static objects including those that are never presented simultaneously (though see Sobel & Kirkham, 2006 for related work on causal inference). For instance, if young children learn that features P and Q are associated and that features P and R are associated, will they infer the association between features Q and R? The study by Cuevas et al. (2006) tested a similar aspect of correlational learning but in a conditioning context where one of the to-be-learned features was the effect of infants' own kicking behavior. Regardless, the process of associating two features that are not presented simultaneously is consistent with research that showed that 18-month-old infants associate specific object parts with specific motion types (e.g., legs and walking) and then later, around 22 months of age, generalize this knowledge to objects that do not possess those parts but that have other features that are highly correlated with them (e.g., eyes) (Rakison, 2005a). However, to date there is a lack of research on whether infants are capable of this kind of processing before their 1st birthday.

The goals of the current experiments were threefold. First, they were designed to test whether infants between 7 and 11 months of age can engage in the kind of second-order correlation learning described above. As such, to our knowledge the experiments reported here are the first to address whether infants are able to learn associations for features that they never observe together. Second, they were designed to examine the origins and developmental timetable for the emergence of this ability. The literature suggests that infants as young as 7 months of age are able to encode correlations among two features that are presented simultaneously (Younger & Cohen, 1986), but it remains to be seen whether infants at this age are also able to associate features that are not presented together. Third, the experiments were designed to investigate the mental representation that infants form when they engage in second-order correlation learning.