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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.

All of the experiments reported here used a version of the object-examining procedure originally developed by Oakes, Madole, and Cohen (1991), which is akin to the visual familiarization paradigm except that the training and test stimuli are 3-D objects with which infants interact rather than 2-D representations of objects presented on a screen. In Experiment 1, participants at 7, 9, and 11 months of age were familiarized to two sets of static 3D objects that embodied a correlation between an object body and an object part as well as those that embodied the correlation between the same object body and a different object part. During the test phase, infants were presented with four objects: two objects that tested their learning of the second-order correlation, one object that tested their ability to learn part locations, and one object that assessed their fatigue and boredom. The objects that tested infants' learning of the second-order correlation both had a novel body: one object was connected to the two parts that were previously associated with the same body (the consistent test object), and another object was connected to the two parts that were previously attached to different object bodies (the inconsistent test object). Longer examining—characterized by clearly focused looking—of either the consistent or inconsistent test object could only result from infants learning the second-order correlations in the familiarization stimuli. Experiment 2 used a similar design to address whether 9-month-olds' second-order correlation learning is facilitated by paired presentation of the test stimuli. Experiment 3 was designed to examine whether 7-month-old's second-order correlation learning is affected by making the familiarization stimuli more distinct, and Experiment 4 was devised to explore the mental representations that 11-month-olds form during the process of second-order correlation learning.

2. Experiment 1

Experiment 1 was designed to assess if infants at 7, 9, and 11 months of age can learn second-order correlations between the external parts of an object without seeing the two parts together. Infants were familiarized with 3D objects that exhibited first-order correlations between object bodies and individual parts such that the same object body was associated with two different parts on different trials. These objects provided sufficient information to learn a second-order correlation between the two parts that were associated with the same body. Following familiarization, infants were tested on new objects with two parts that either conformed to the second-order correlation or violated this correlation. A difference in examining time for these objects indicated that infants were sensitive to the second-order correlation that was not presented directly in the familiarization phase.

2.1. Method

2.1.1. Participants

Infants who were 7 months ($N = 35$), 9 months ($N = 31$), and 11 months of age ($N = 33$) were recruited for the study using birth records provided by a private company as well as the state government. All infants were healthy and full-term. Within the 7-month-old age group, seven infants were excluded from the final sample: three due to experimenter error, two due to low video quality, one due to parental interference, and one due to fussiness that caused the child to go off-camera. Thus, the final sample of 7-month-olds contained 28 infants (15 males, 13 females) who had a mean age of 7.08 months ($SD = 0.32$ months, range: 6.58 to 7.76 months). Within the 9-month-old age group, three infants were excluded from the final sample: one due to equipment failure, one due to parental interference, and one due to experimenter error. The final sample of 9-month-olds was comprised of 28 infants (13 males, 15 females) who had a mean age of 8.98 months ($SD = 0.35$ months, range: 8.28–9.76 months). Finally, five infants were excluded from the sample of 11-month-olds: four due to fussiness and one due to experimenter error. Thus, the final sample of 11-month-olds also contained 28 infants (14 males, 14 females) who had a mean age of 10.99 months ($SD = 0.30$ months, range: 10.55–11.51 months). Parents were compensated for their child's participation by a small gift of either an infant-sized t-shirt or a book.

2.1.2. Materials

Eleven brightly-colored clay objects, between 1 and 2 inches in height, were constructed for the study. Photographs of the objects can be seen in Fig. 1. Four of the objects, two with a blue body[1] and two with a green body, were used during the familiarization phase (panel A of Fig. 1). The remaining seven objects, six with yellow bodies and one with a black body were used during the test phase (panel B of Fig. 1). A camera placed on the opposite end of the table from the infant was used to record the session for later coding. The camera captured a head-on view of the infant and the stimuli. It was adjusted for every infant to capture a view from the top of the infant's head down to about a foot of table surface in front of the infant, where the stimuli were presented. A stopwatch was used to time the individual trials.

2.1.3. Design

The experiment was a mixed design with two independent variables; namely, participant age group and test trial type. Participant age group was a between-subjects variable with three levels: 7, 9, and 11 months. Test trial was a within-subjects variable with four levels: consistent, inconsistent, part switch, and novel. The dependent variable was examining time, in seconds. Examining time was defined as clearly focused looking at an object that was characterized by furrowing of the brows, reduction in extraneous movement, and slow turning over of the object. This definition was adopted in accordance with previous studies that have used examining time as a dependent measure (e.g., Oakes et al., 1991).

2.1.3.1. Familiarization phase. In the familiarization phase, infants were introduced to four objects; two of these objects had one type of body (Body 1), and two had another type of body (Body 2). Each of the four objects had a unique external part; thus the four objects that infants saw were: Body 1 and Part A on top, Body 1 and Part B on the side, Body 2 and Part X on top, Body 2 and Part Y on the side. Objects were introduced one at a time and their order was randomized across participants with the constraint that objects with the same body were always presented in succession.

2.1.3.2. Test phase. In the test phase, infants were tested on four objects that were presented one at a time: consistent object, inconsistent object, part switch object, and novel object. The order of these objects across infants was determined by a Latin square. The consistent object was comprised of a novel body, Body 3, and two parts that previously appeared on the same type of body during the familiarization phase, either Parts A and B or Parts X and Y. The inconsistent object had the same Body 3 as the consistent object but two parts that appeared on different bodies during the familiarization phase, either parts A and Y or parts B and X. Note that Parts A and X and Parts C and Z were never paired to create inconsistent objects because both parts within each pair appeared in the same location during the familiarization phase. Pairing them in the test phase would have violated their placement, which would have generated a potential confound in infants'

[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.

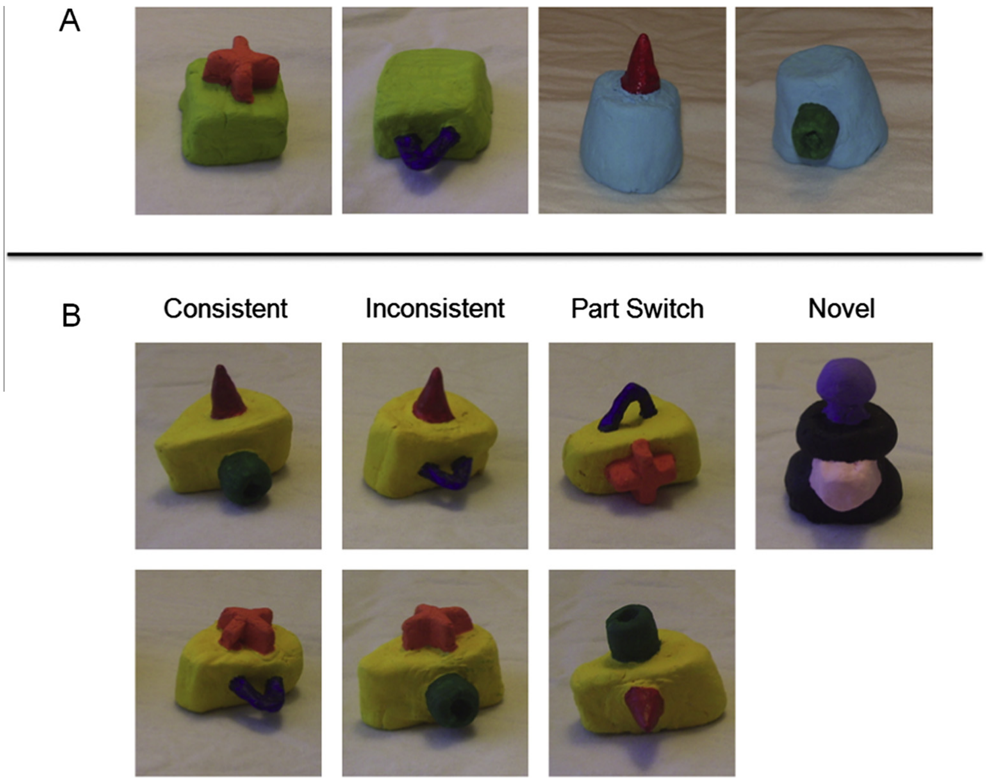

Fig. 1. Stimuli used in Experiment 1. Panel A shows the four familiarization stimuli. Panel B shows the seven test stimuli: two consistent objects, two inconsistent objects, two part switch objects, and one novel object.

examining time. It was predicted that if infants extracted second-order correlation information from the familiarization phase they would show longer examining of the inconsistent object than the consistent object because the former was more dissimilar from the information presented in the test phase than the latter.

The part switch object had the same novel body, Body 3, as the consistent and inconsistent object and two parts that appeared on the same type of body during the familiarization phase, either Parts A and B or Parts X and Y. However, these parts were in new locations: the part that was previously on top was on the side, and the part that was previously on the side was on top. The part switch object was designed to test if infants have learned where the parts were on the body during the familiarization phase. It was expected that if infants learned this information, they would examine longer the part switch object than the consistent object because the former violated the locations of both parts.

Finally, the novel object had a completely different body and parts from the familiarization objects and the other test objects. This object was used to assess whether infants' attention had diminished during the task. It was predicted that infants who disengaged from the experiment would not learn anything about the familiarization objects and would show equal looking to the novel object and the consistent object. In contrast, infants who were engaged during the experiment would learn about the features of the familiarization objects and would show longer examining of the novel object relative to the consistent object.

2.1.4. Procedure

Infants sat in front of a table on the lap of their parent or guardian. The person holding the infant was asked to remain neutral throughout the study. On each trial, the experimenter placed an object in front of the infant within the infant's reach and said "look at this". If the infant did not immediately look at the object, the experimenter tapped the object on the table to get the infant's attention. Once the infant's eyes were on the object, a timer was started. The infant was allowed to interact with the object in any manner, such as looking, picking up, mouthing or sliding. The experimenter did not make eye contact with the infant during the trial and looked down at the stopwatch held in his or her lap, out of view of the infant. After 20 s the timer was stopped and the object was taken away. The experimenter introduced the next object only after the previous object was fully out of view. As discussed above, there were four unique familiarization objects that were presented one-by-one in a particular sequence. This sequence was repeated over three blocks for a total of 12 familiarization trials. The infant proceeded directly to the test phase after the last familiarization trial. The four test objects described above were also presented one at a time for 20 s each; however, the sequence of test objects was presented only once. In sum, there were sixteen 20 s trials. If at any point the object was pushed across the table and out of the infant's reach or if it fell on the floor, the experimenter retrieved the object and placed it in its original starting location within reach of the infant. The timer was not stopped in these cases.

2.1.5. Coding

Examining time—how long infants engaged in focused attention to the object—was coded offline from video recordings by trained coders. Recordings were split into the familiarization phase and test phase. Different coders coded these two phases to ensure that coders' experience with coding the objects during the familiarization phase did not affect their coding of the test objects. A random sample of seven infants in each age group (25% of the total sample) were coded by another judge to assess interrater reliability. Reliability was calculated in two ways. First, the difference between the original coder's examining time and the reliability coder's examining time was calculated for every trial. The average difference was 0.25 s. Second, a Pearson product-moment correlation was calculated between the original coders' scores and the reliability coders' scores. This value was 0.75, which is comparable to that found in other studies with the object-examining procedure (e.g., Oakes & Ribar, 2005; Oakes et al., 1991).

2.2. Results

2.2.1. Familiarization phase

On average, infants examined the objects for a total of 54.12 s ($SD = 29.52$) during the familiarization phase. The average decrement in examining, defined as one minus the ratio of total examining during the last familiarization block to the total examining during the first familiarization block, was 0.44, indicating that infants decreased their examining of the objects by 44% between the first block and the last block. This amounted to a 10.75-s drop in examining, on average. Examining time during the familiarization phase was analyzed using a 3 (age: 7, 9, 11) × 3 (block: first, second, third) mixed Analysis of Variance (ANOVA), with age as a between-subjects variable and block as a within-subjects variable. The analysis yielded a significant main effect of block, $F(2,162) = 52.82$, $p < 0.0005$, $n^2_p = 0.40$. Follow-up paired-samples *t*-tests indicated that infants' examining in Block 1 ($M = 24.34$, $SD = 11.40$) was greater than in Block 2 ($M = 16.18$, $SD = 11.39$), $p < 0.0005$, and Block 3 ($M = 13.60$, $SD = 11.38$), $p < 0.0005$. Examining in Block 2 was also greater than in Block 3, $p = 0.02$. The main effect of age and the interaction between age and block were non-significant, $F(2,81) = 0.46$, $p = 0.63$, $n^2_p = 0.01$, and $F(4,162) = 0.48$, $p = 0.75$, $n^2_p = 0.01$, respectively. This indicates that examining times were comparable across the three age groups.

2.2.1.1. Test phase. A visual inspection of the test trial data indicated non-normality for all four test trials, which was confirmed quantitatively with absolute values of skewness between 0.96 and 1.17. Absolute values of skewness between 0.5 and 1 are considered moderately skewed (Bulmer, 1979). A natural log transformation was applied to normalize the data to ensure that the assumptions of the statistical tests used for analysis were not violated, as has been conducted in previous developmental research that found a skew in infants' looking time data (e.g., Aschersleben, Hofer, & Jovanovic, 2008; Colaizzi, Aubuchon-Endsley, Grant, Kennedy, & Thomas, 2014; Woodward, 1998). The log transformation lowered the absolute values of skewness to the range of 0.09 to 0.56. The log-transformed data were analyzed using a 3 (age: 7, 9, 11 months) × 4 (test trial: consistent, inconsistent, part switch, novel) ANCOVA, which included the drop in examining between the first and last block as a covariate. This covariate was included due to the fact that a habituation procedure was not used. Infants may have reached different levels of stimulus encoding, which could, in turn, influence their preferences in the test phase. In particular, infants could show a familiarity preference instead of a novelty preference if they have not encoded fully the familiarization stimuli. To account for infants' encoding of the familiarization stimuli, we included the drop in examining as a covariate; we assumed that infants who showed a higher drop in examining encoded the stimuli more fully than those who showed a lower drop. The ANCOVA yielded a significant interaction between test trial and drop in examining, $F(3,240) = 3.52$, $p = 0.02$, $n^2_p = 0.04$, which indicated a violation of the homogeneity of regression slopes assumption: the relationship between the covariate and the dependent variable was not consistent across the independent variable groupings.

To mitigate this issue, it was necessarily to split the data into groups along the covariate and conduct separate analyses for the subgroups. A median split on the difference in examining between the first block and the last block was applied to create two subgroups within each age group: infants who showed a high drop in examining and infants who showed a low drop in examining. The drop in examining time for these subgroups can be found in Table 1. Subsequently a 3 (age: 7, 9, 11 months) × 4 (test trial: consistent, inconsistent, part switch, novel) mixed ANOVA was performed for the low-drop subgroup and the high-drop subgroup, with age as a between-subjects factor and test trial as a within-subjects factor. The data for both subgroups at 7, 9, and 11 months are presented in Fig. 2.

For the low-drop subgroup, the ANOVA yielded a significant main effect of test trial $F(3,117) = 5.01$, $p = 0.003$, $n^2_p = 0.11$. The main effect of age and the interaction between age and test trial were not significant, $F(2,39) = 0.12$, $p = 0.89$, $n^2_p = 0.01$ and $F(6,117) = 1.49$, $p = 0.19$, $n^2_p = 0.07$, respectively. Planned comparisons between the consistent test trial and the other three test trials were conducted using paired-samples *t*-tests to explore the main effect of test trial. Infants' log-transformed examining times were significantly longer during the consistent trial ($M = 1.21$, $SD = 0.83$) than during the novel trial ($M = 1.63$, $SD = 0.74$), $p < 0.0005$. For the part switch trial ($M = 1.29$, $SD = 0.80$) and the inconsistent trial ($M = 1.14$, $SD = 0.85$), examining time was not significantly different from the consistent trial, $p > 0.60$ for both. These results suggest that infants who had a low drop in the total examining time between the first familiarization block and the last familiarization block did not learn the second-order correlation or the position of the parts on the object. High examining time of the novel object indicates that a lack of difference between the target test trials was likely not due to fatigue or inattention.

For the high-drop subgroup, the ANOVA yielded a significant main effect of test trial, $F(3,117) = 4.95$, $p = 0.003$, $n^2_p = 0.11$ and a significant test trial by age interaction, $F(6,117) = 4.73$, $p = 0.0002$, $n^2_p = 0.20$. The main effect of age was non-significant, $F(2,39) = 0.36$, $p = 0.70$, $n^2_p = 0.02$. Planned comparisons using paired-samples *t*-tests were conducted separately for each age group to explore the interaction further. Specifically, the log-transformed examining times on the consistent trial were compared to those on the inconsistent, part-switch, and novel trials.

For the 7-month-olds, examining was marginally greater on the consistent trial ($M = 1.42$, $SD = 0.74$) than the inconsistent trial ($M = 1.00$, $SD = 0.92$), $p = 0.06$. The difference between the consistent trial and the part-switch trial ($M = 1.23$, $SD = 0.87$) and the difference between the consistent trial and the novel trial ($M = 1.16$, $SD = 0.84$) were non-significant, $p = 0.56$ and $p = 0.25$, respectively. In contrast to the predictions, these results indicate a familiarity preference for the consistent object over the inconsistent object. This preference is further supported by the fact that infants did not increase their examining when presented with the novel object. A lack of difference in examining between the consistent and the part-switch object suggested that infants did not learn the location of the parts on the familiarization objects.

For the 9-month-olds, no significant differences were found between examining during the consistent trial ($M = 1.38$, $SD = 0.71$) and the inconsistent trial ($M = 1.18$, $SD = 0.77$), part-switch trial ($M = 1.35$, $SD = 0.90$), or novel trial ($M = 1.57$, $SD = 0.84$), *p's* equal to 0.26, 0.85, and 0.26, respectively. These results suggest that infants at 9 months did not learn the second-order correlation or the part location information. A lack of difference in examining time for the consistent and the novel objects could indicate that some of these results may have been due to general fatigue.

For the 11-month-olds, the follow-up tests showed that infants' examining was significantly shorter during the consistent trial ($M = 0.79$, $SD = 0.93$) than the inconsistent trial ($M = 1.37$, $SD = 0.80$), the part-switch trial ($M = 1.33$, $SD = 0.79$), and the novel trial ($M = 2.07$, $SD = 0.35$), *p*s equal to 0.047, 0.027, and 0.001,

Table 1
Mean difference in examining time between the first familiarization block and last familiarization block for the two groups formed by the median split on drop in examining. Standard deviations are given in parentheses.

	Low drop group	High drop group
7-month-olds	0.80 (5.30)	17.01 (6.84)
9-month-olds	5.21 (5.04)	18.20 (9.91)
11-month-olds	2.20 (6.77)	21.06 (7.43)

respectively. These analyses are consistent with the hypotheses and suggest that infants learned the second-order correlation between the two parts and the location of the parts.

2.3. Discussion

The results of Experiment 1 support the notion that infants are able to learn second-order correlations; that is, they can infer an unobserved correlation that is implied by two other correlations that they experience. Following familiarization to stimuli that exhibited two correlations (one between a part and body and the other between a different part and the same body), 7-month-olds exhibited a preference for a consistent test object that incorporated the second-order correlation implied by those stimuli, 9-month-olds exhibited no preference for either of the test objects, and 11-month-olds exhibited a preference for an inconsistent test object that violated the second-order correlation. This developmental pattern—a preference for a familiar stimulus, followed by no preference, and finally a preference for a novel stimulus—is consistent with previous research that demonstrated a similar trajectory in infants at comparable ages to those tested here (Hunter & Ames, 1988; see also Kidd, Piantadosi, & Aslin, 2012). This trend results from the fact that younger infants require longer to encode a stimulus and therefore exhibit a preference to further encode that stimulus when it is presented—in this case, the "consistent" stimulus—whereas older infants encode more rapidly and therefore exhibit a preference for a novel stimulus that violates their existing representation (in this case, the "inconsistent" stimulus). This effect was only found in the high-drop group of infants, which suggests that a certain threshold of processing was required to learn the second-order correlations in the familiarization trials.

That infants as young as 7 months of age—as well as their 11-month-old counterparts—showed a preference for one test stimulus over the other suggests that both age groups had inferred the second-order correlation implied by the familiarization stimuli. In other words, longer looking to one of the test trials relative to the other one could only have resulted from second-order correlation learning because participants were presented with the parts of the consistent and inconsistent stimuli equally during familiarization, and both stimuli also had the same novel body that was not seen during familiarization. In addition, infants were expected to show no preference for either test stimulus if they had processed the features of the familiarization stimuli independently—rather than the correlations among those features—because all of those features were presented equally often and none of the specific feature correlations presented during the test trials were seen previously during the familiarization trials. Thus, although the youngest age group tested here showed a preference for the consistent test item, this behavior could only have occurred if they had encoded to some degree the two correlations presented during the familiarization phase of the study.

Although infants at 7 months of age learned the second-order correlations in the events, they and the 9-month-olds failed to learn the location of the parts on the familiarization objects. One explanation for this finding is that learning the part locations may have been difficult for the younger infants because they manipulated the objects rather than simply observing them in a single position. Thus, there was no defined orientation for each object—and consequently each part location—once it was manually rotated. An alternative explanation is that infants' ability to encode the location of the object parts was superseded by encoding the correlations between the parts of the objects and their bodies. That the oldest age group learned the location of the parts suggests that this latter explanation may be more veridical.

3. Experiment 2

Experiment 2 was designed to assess if paired presentation of the test stimuli could induce second-order correlation learning in 9-month-old infants. Recall that in Experiment 1, 9-month-olds demonstrated no preference for either test object, which implies that they may be in a period of transition between the 7- and

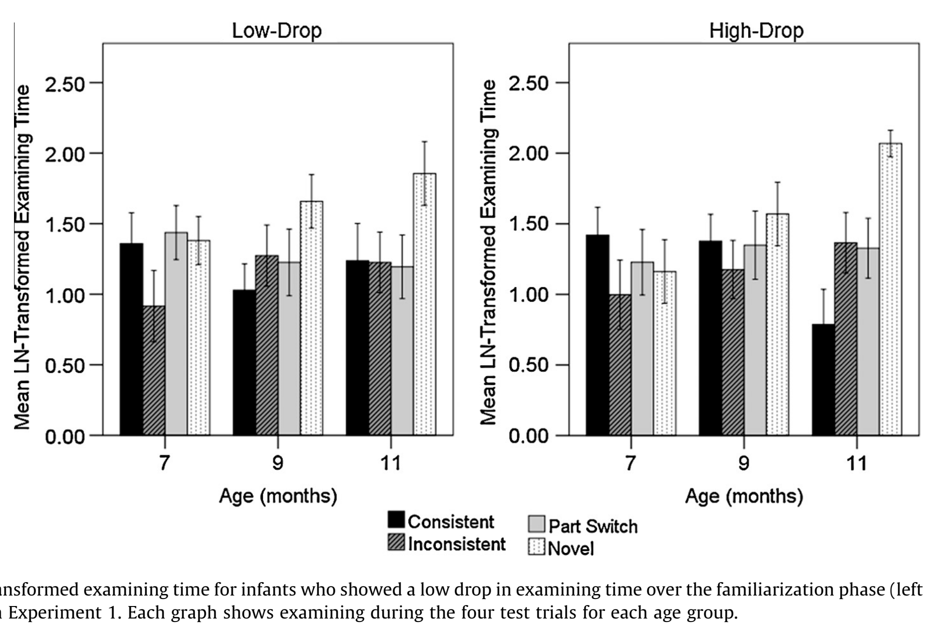

Fig. 2. Mean natural log-transformed examining time for infants who showed a low drop in examining time over the familiarization phase (left panel) and those who showed a high drop (right panel) in Experiment 1. Each graph shows examining during the four test trials for each age group.

11-month-olds who both learned the second-order correlations in the familiarization trials. There is considerable evidence that presentation of stimuli in parallel rather than serially facilitates infant' learning, memory, and categorization because it allows for comparison of those stimuli (e.g., Fagan, 1978; Rose, Gottfried, Mello-Carmina, & Bridger, 1982), and it does so in the object-examining task used here (Oakes & Ribar, 2005). Thus, the current experiment was designed to examine whether presentation of the stimuli in parallel during the test trials would lead 9-month-olds to learn second-order correlations. The experiment was identical to Experiment 1 except for the test phase in which pairs of stimuli were presented instead of a single stimulus. It was hypothesized that if 9-month-old infants are in a transition phase between a familiarity and a novelty preference, then making the test phase easier could induce them to demonstrate a novelty preference for the inconsistent test object.

3.1. Method

3.1.1. Participants

Infants who were 9 months of age were recruited for the study using birth records provided by a private company as well as the state government. All infants were healthy and full-term. Two infants were excluded from the analyses due to experimenter error. Thus, the final sample consisted of 28 infants (16 females, 12 males) who had a mean age of 9.02 months ($SD = 0.24$ months, range: 8.58 to 9.44 months). Parents were compensated for their child's participation by a small gift of either an infant-sized t-shirt or a book.

3.1.2. Materials

The same materials were used in Experiment 2 as in Experiment 1.

3.1.3. Design

A within-subjects design was used with test trial as the independent variable that had four levels: consistent, inconsistent, part switch, and novel. The dependent variable was examining time, in seconds. Examining time was defined the same way as in Experiment 1.

3.1.3.1. Familiarization phase. The familiarization phase was identical to that of Experiment 1.

3.1.3.2. Test phase. Five types of objects were presented during the test phase. Four of them were the same as in Experiment 1: consistent, inconsistent, part switch, and novel. The fifth object was one of the familiarization objects (labeled "familiar").

In contrast to Experiment 1, the test objects were presented in pairs instead of one at a time. Recall from Experiment 1 that there were two possible consistent, inconsistent, and part switch objects. The pairings of these objects were as follows: consistent and inconsistent, other consistent and part switch, familiar, and novel. It was predicted that infants' examining time would be lower for the consistent object in the first pair and second pair, and for the familiar object in the third pair, as compared to the other object in the pair.

There were several constraints that were applied to select the specific objects for each pairing. The objects in the consistent–inconsistent pairing were counterbalanced across infants. The second consistent object that was not used in the consistent–inconsistent pairing was used in the consistent-part switch pairing. In that pair, the part switch object was picked such that it had the same parts as the consistent object in that pairing (e.g., if the consistent object had an orange cross on the top and a blue handle on the side then it was paired with a part switch object that had an orange cross on the side and a blue handle on top). Finally, the familiar object that was paired with the single novel object was picked randomly.

The test trials were delivered in the same order for all infants: consistent–inconsistent, consistent-part switch, and familiar-novel. Because the consistent–inconsistent pairing was of primary interest, this pairing was placed first to ensure that the presentation of the other objects did not interfere with infants' performance. For each test trial, the left and right placement of the two objects was predetermined. The placement of the consistent object in the consistent–inconsistent pair was counterbalanced across infants. The placement of the consistent object in the consistent-part switch pair was the opposite as that in the consistent–inconsistent pair (e.g., if the consistent object was on the left for the first pair, it was on the right for the second pair). The placement of the familiar object was the same as the placement of the consistent object in the consistent–inconsistent pair. This ensured that the location of the object for which examining time was predicted to be lower alternated across trials.

Previous research has shown that pairing objects can allow infants to demonstrate what they have learned in a training phase at a younger age than single object presentation, likely because it facilitates comparison (Oakes & Ribar, 2005). Accordingly, we predicted that the presentation of the test objects side-by-side would allow 9-month-olds to demonstrate similar behavior to that of the 11-month-olds in Experiment 1: that is, they would show greater examining of the inconsistent object as compared to the consistent object, and greater examining of the part switch object as compared to the consistent object.

3.1.4. Procedure

The procedure was the same as in Experiment 1 with the exception of the test phase. The test trials remained 20 s long but consisted of two objects per trial instead of one. The objects were placed within reach of the infant at a diagonal to the right and to the left. Small dots on the table indicated the placement of the objects to ensure that they were equidistant from the infant. The familiarization objects were placed halfway between these dots. The two test objects were placed in front of the infant simultaneously, and the timer was started once the infant looked at one of the objects. If the infant failed to look at either object, both were tapped on the table to get the infant's attention. As described in the *Design* section, above, there were three test trials altogether.

3.1.5. Coding

Examining time was coded the same way as in Experiment 1. A random sample of seven infants (25% of the full sample) was chosen to be coded by another coder to assess interrater reliability. The average difference between the original coder's examining time and the reliability coder's examining time was 0.43 s. The Pearson product-moment correlation between the original coders' scores and the reliability coders' scores was 0.88.

3.2. Results

3.2.1. Familiarization phase

On average, infants examined the objects for a total of 42.29 s ($SD = 21.18$) during the familiarization phase. The average decrement in examining, defined as one minus the ratio of total examining during the last familiarization block to the total examining during the first familiarization block, was 0.25, indicating that infants decreased their examining of the objects by 25% between the first block and the last block. This amounted to a 7.14-s drop in examining, on average. Examining time during the familiarization phase was analyzed using a repeated measures ANOVA with familiarization block (first, second, or third) as the independent variable. The analysis yielded a significant difference, $F(2,54)$

= 8.85, $p = 0.0005$, $\eta^2_p = 0.25$. Specifically, examining during block 1 was higher than during block 2, $p = 0.0001$, and during block 3, $p = 0.008$. Examining in blocks 2 and 3 was not different, $p = 0.83$. On average, infants decreased their examining between blocks 1 and 3 by 24.69%.

3.2.2. Test phase

Each test trial yielded two examining scores for each infant because there were two objects per trial. A preliminary analysis of the examining data indicated skewness (absolute values of skewness between 0.65 and 2.23 for all objects). As in Experiment 1, a natural log transformation was performed on the results, which lowered the absolute values of skewness to between 0.04 and 0.63.

For each of the three test trials, an ANCOVA was performed with test object as the independent variable and difference in examining time between the first block and the last block of familiarization as a covariate. For the consistent versus inconsistent test trial, the analysis did not yield a significant interaction between the independent variable and the covariate $F(1,26) = 1.12$, $p = 0.30$ $n^2_p = 0.04$, or a significant effect of the independent variable, $F(1,26) = 1.59$, $p = 0.22$ $n^2_p = 0.06$. For the consistent versus part switch test trial, the analysis also did not yield a significant interaction with the covariate $F(1,26) = 0.39$, $p = 0.54$ $n^2_p = 0.02$, or a significant effect of the independent variable, $F(1,26) = 0.47$, $p = 0.50$ $n^2_p = 0.02$. Finally, for the familiar versus novel test trial, the analysis did not yield a significant effect of the covariate, $F(1,26) = 0.15$, $p = 0.70$ $n^2_p = 0.01$, but did yield a significant effect of test object, $F(1,26) = 10.95$, $p = 0.003$ $n^2_p = 0.30$. Infants showed significantly longer examining of the novel object than the familiar object, as can be seen in Fig. 3. Taken together, these results suggest that 9-month-old infants did not learn the second-order correlation or the position of the parts, but they did distinguish the novel object from the familiar object in the third trial.

3.3. Discussion

Previous research has suggested that parallel presentation of stimuli facilitates infant performance in the object-examining procedure (Oakes & Ribar, 2005). However, the results of the current experiment reveal that infants at 9 months of age do not learn second-order correlations regardless of whether the stimuli are presented in parallel during the test phase or serially. Infants at this age also do not learn the locations of the parts. However, these results cannot be attributed to lack of attention or fatigue during the familiarization phase. Infants did examine the novel object longer than the familiar object, indicating that they did learn the features of the familiarization stimuli and could distinguish them from an object that they had never seen before.

4. Experiment 3

Experiment 3 was designed to assess whether 7-month-olds would switch their preference at test from one for familiarity to one for novelty if the two pairs of familiarization objects were more different from each other. The rationale for this goal was to establish further that the 7-month-olds' familiarity preference observed in Experiment 1 was the result of second-order correlation learning. To accomplish this, two trays were used during the familiarization phase to present the objects: a dark brown tray and a white tray. Objects with the same type of body were always presented on a tray of the same color. The trays made the two pairs of objects more distinct and provided another feature with which the body parts could be associated.

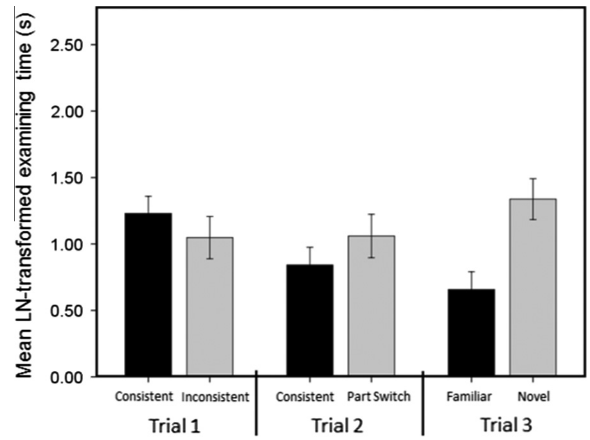

Fig. 3. Mean natural log-transformed examining times during each of the three trials. Within each trial, the black bar represents the object that is expected to be more familiar to the infant, and the gray bar represents the object that is expected to be less familiar to the infant.

4.1. Method

4.1.1. Participants

Infants who were 7 months of age were recruited for the study using birth records provided by a private company as well as the state government. All infants were healthy and full-term. Nine infants were excluded from the analyses: three due to experimenter error, three due to fussiness, and three due to parental interference. The final sample consisted of 20 infants (5 females, 15 males) who had a mean age of 6.98 months ($SD = 0.34$ months, range: 6.44 to 7.43 months). Parents were compensated for their child's participation by a small gift of either an infant-sized t-shirt or a children's book.

4.1.2. Materials

The same materials were used in Experiment 3 as in Experiment 1. Additionally, two circular trays, 3 inches in diameter, were used in the present experiment. One tray was covered in dark brown felt and the other tray was covered in white felt.

4.1.3. Design

A within-subjects design was used with test trial as the independent variable that had four levels: consistent, inconsistent, part switch, and novel. The dependent variable was examining time, in seconds. Examining time was defined the same way as in Experiment 1.

4.1.3.1. Familiarization phase. The familiarization phase was nearly identical to that of Experiment 1. The only difference was that each familiarization object was presented on a tray. The same tray was used to present objects with the same type of body. The pairing of object body and tray color was counterbalanced across infants.

4.1.3.2. Test phase. The test phase was identical to Experiment 1; trays were used only in the familiarization phase but not in the test phase. Trays were not used in the test phase to prevent infants from examining based on the previously-seen correlation between a body part and a tray. If the use of the trays in the familiarization phase made the two pairs of objects more distinct and the task easier, then we expected to see a reversal of the familiarity preference into a novelty preference. Specifically, we predicted that infants would examine the inconsistent, part switch, and novel objects longer than the consistent object.

4.1.4. Procedure

The procedure was the same as in Experiment 1 with the exception of the familiarization phase. Each object was placed on a tray and then presented in front of the infant. Objects were still presented one at a time. If the object or the tray dropped they were returned to their original location, without stopping the timer.

4.1.5. Coding

Examining time was coded the same way as in Experiment 1. A random sample of 5 infants (25% of the original sample) was chosen to be coded by an additional coder to assess interrater reliability. The average difference between the original coder's examining time and the reliability coder's examining time was 1.9 s. The Pearson product-moment correlation between the original coders' scores and the reliability coders' scores was 0.85.

4.2. Results

4.2.1. Familiarization phase

Infants examined the objects for a total of 26.48 s ($SD = 16.79$) during the familiarization phase, on average. The mean decrement in examining between the first block and the last block was 0.54. There was a 7.75 s drop in examining, on average. Examining time during the familiarization phase was analyzed using a repeated measures ANOVA with familiarization block as the independent variable (first, second, or third block). The analysis yielded a significant main effect, $F(2,38) = 14.55$, $p = 0.0002$, $n^2_p = 0.43$. Follow-up paired-samples t-tests indicated that examining was significantly lower during block two ($M = 7.00$, $SD = 4.55$) than block one ($M = 13.61$, $SD = 9.77$), $t(19) = 3.68$, $p = 0.002$. Examining was also significantly lower during block three ($M = 5.87$, $SD = 5.09$) than block one, $t(19) = 4.29$, $p = 0.0004$. Finally, examining was not significantly different between blocks two and three, $t(19) = 1.33$, $p = 0.20$.

4.2.2. Test phase

Preliminary analyses indicated that the examining times during the test phase were not distributed normally (absolute values of skewness between 0.64 and 1.76). Accordingly, a natural log transformation was applied to all test trials, as in Experiment 1, which lowered the absolute values of skewness to between 0.02 and 1.28. To determine if there were differences in examining, an ANCOVA was conducted with test trial as the independent variable (consistent, inconsistent, part switch, and novel) and the drop in examining between the first block and the last block as a covariate. The analysis yielded a significant main effect of test trial, $F(3,54) = 2.83$, $p = 0.05$, $n^2_p = 0.14$. The interaction between test trial and the covariate was not significant, $F(3,54) = 0.99$, $p = 0.41$, $n^2_p = 0.05$, suggesting that there was a uniform pattern of examining time in the test phase, regardless of the amount of examining during the familiarization phase. Follow-up analyses indicated that infants examined the consistent object (natural log-transformed time in seconds: $M = 1.81$, $SD = 0.47$) significantly longer than the inconsistent object ($M = 1.29$, $SD = 0.79$), $p = 0.01$, $n^2_p = 0.30$. They also examined the consistent object significantly longer than the part switch object ($M = 1.30$, $SD = 0.73$), $p = 0.03$, $n^2_p = 0.24$. Infants examined the novel object ($M = 1.69$, $SD = 0.70$) and the consistent object for the same amount of time, $p = 0.34$, $n^2_p = 0.05$. The results can be seen in Fig. 4. These results suggest that infants in this experiment learned the second-order correlation implied by the familiarization stimuli. However, this was exhibited through a familiarity preference, as in Experiment 1 and contrary to our prediction. Infants also learned the location of the parts, which was also exhibited through a familiarity preference for the consistent object.

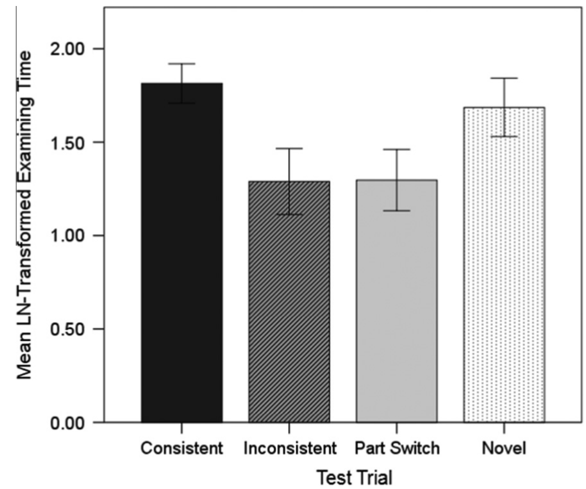

Fig. 4. Mean natural log-transformed examining time during the four test trials of Experiment 3.

4.3. Discussion

This experiment was designed to examine whether infants at 7 months of age would exhibit second-order correlation learning via a novelty preference when the two pairs of familiarization objects were more different from each other than they were in Experiment 1. The current experiment replicated the results of Experiment 1 such that infants exhibited a preference for the test object that incorporated the second-order correlation rather than the one that incorporated a violation of that correlation. However, in contrast to Experiment 1 this behavior was apparent in 7-month-olds regardless of how much time they spent examining the objects during the familiarization phase. This implies that the modification to the task—whereby the familiarization stimuli were adapted to make them more distinct—may have made the stimuli easier to encode.

In contrast to their same age counterparts in Experiment 1, infants in the current experiment learned the location of the two parts on the objects. One explanation for this result is that infants in this experiment were more explicitly oriented towards the correct positioning of the object with respect to which side of the object was the top and which was the side when the object appeared on the tray. This may have facilitated learning because it specified where the parts were located relative to the rest of the object. Alternatively, the fact that the familiarization objects were more distinct may have made it easier for infants to encode the parts' location.

5. Experiment 4

Experiments 1, 2, and 3 examined whether, under what conditions, and at what age infants form second-order correlations. Experiment 4 was designed to examine how infants form second-order correlations. Specifically, the experiment examined if infants are able to form a unique representation of the familiarization bodies with both parts on them, despite only seeing the parts one at a time and never seeing the body with both parts on it simultaneously. We addressed this question by using the same basic methodology as Experiment 1 but used the same object bodies in the test trials that were presented during familiarization; that is, rather than testing infants with a novel object body, we used the same object body that infants had previously experienced. We hypothesized that if infants had represented the objects implied by the second-order correlation—that is, the body and the two parts connected to it—without seeing them previously, then they would treat them as familiar in the test phase and would not examine them extensively.

5.1. Method

5.1.1. Participants

Infants who were 11 months of age were recruited for the study using birth records provided by a private company and the state government. All infants were healthy and full-term. Two infants were excluded from the analyses due to fussiness. Thus, the final sample consisted of 20 infants (8 females, 12 males) who had a mean age of 10.95 months ($SD = 0.37$ months, range: 10.59 to 11.61 months). Parents were compensated for their child's participation by a small gift of either an infant-sized t-shirt or a book.

5.1.2. Materials

The same familiarization stimuli were used as in the previous experiments. Four new objects were created for the test phase. Two of them were labeled "correct parts-body": each of them had one of the bodies from the familiarization phase and the two parts that appeared on that body alone, in their original positions (i.e., blue body with a red cone and green cylinder, green body with an orange cross and a blue handle). The other two were labeled "incorrect parts-body": each of them had one of the bodies from the familiarization phase and the parts that appeared on the other body, in their original positions (i.e., green body with a red cone and green cylinder, blue body with an orange cross and a blue handle). Finally, one of the objects from the familiarization phase and the same novel object from the previous experiments were used.

5.1.3. Design

A within-subjects design was used with test trial as the independent variable that had four levels: correct parts-body, incorrect parts-body, novel, and familiar. The dependent variable was examining time, in seconds. Examining time was defined the same way as in Experiment 1.

5.1.3.1. Familiarization phase. The familiarization phase was identical to that of Experiment 1.

5.1.3.2. Test phase. As in Experiments 1 and 3, infants were presented with four objects in the test phase. These were the correct parts-body object, incorrect parts-body object, novel object, and familiar object. As described in the Materials section, above, there were two possible correct parts-body and incorrect parts-body objects. There were four possible familiar objects as these were the same four objects used in the familiarization phase. Two constraints were applied to select the specific objects that children received in the test phase. First, all test objects that were selected for a given infant, except for the novel object, had the same body. This minimized the noise in examining time among the different test objects that may emerge due to preferences for particular object bodies. Thus, if an infant received the object with the blue body for the correct parts-body object, the infant also received the object with the blue body for the incorrect parts-body and the familiar objects. Half of the infants received objects with the green body in the test phase and half received objects with the blue body. Second, once the body color was identified, the specific familiar object that was selected was counterbalanced across infants (recall that there were two blue objects and two green objects in the familiarization phase): for half of the infants it was the object with the part on the top, and for the other half of the infants it was the object with the part on the side. The order of the test trials across infants was determined by a Latin square.

We made several predictions for the expected pattern of examining in the test phase. Experiment 1 demonstrated that 11-month-olds exhibit a novelty preference in this paradigm. Infants in this experiment were of the same mean age (10.99 months in Experiment 1 and 10.95 months here) and experienced the same familiarization phase, so we anticipated that they would exhibit a novelty preference in this experiment as well. Accordingly, all predictions were made in the direction of longer examining times for less familiar objects. First, it was expected that examining would be longer for the novel object than the familiar object because the former had not been seen during the familiarization phase. Similarly, we predicted that examining would be longer for the incorrect part-body object than the familiar object. The incorrect parts-body object violated the correlations presented in the familiarization phase between the object and its two parts, whereas the familiar object was the same as that presented during the familiarization phase. Finally, we predicted that examining would not be longer for the correct parts-body object than the familiar object if infants have formed an internal representation of a single body with both parts. It is possible that the examining times would be equal for both objects if infants formed internal representations of the individual familiarization objects and joint representations of objects with both parts on them. Alternatively, the examining time of the familiar object could be longer than that of the correct parts-body object if infants did not encode the individual familiarization objects but only a joint or averaged representation of them. Crucially, despite the fact that infants had not seen the correct parts-body object in the familiarization phase but had seen the familiar object, we did not expect them to exhibit longer examining of the former than the latter.

5.1.4. Procedure

The procedure was the same as in Experiment 1 for the familiarization and the test phase. The only difference was in the identity of the test objects, as described above.

5.1.5. Coding

Examining time was coded the same way as in Experiment 1. Five infants (25% of the full sample) were randomly chosen to be coded by an additional coder for interrater reliability. The average difference between the original coder's examining time and the reliability coder's examining time was 3.15 s. The Pearson product-moment correlation between the original coders' scores and the reliability coders' scores was 0.89.

5.2. Results

5.2.1. Familiarization phase

Infants examined the objects for 41.95 s ($SD = 28.73$) during familiarization. Their examining declined by 26.24%, on average, between the first block and the last block, which was equal to a 5.00 s drop. Change in examining throughout the familiarization phase was analyzed using a repeated measures ANOVA with familiarization block as the independent variable (first, second, or third block). The analysis yielded a trend towards a significant main effect, $F(2,38) = 2.41$, $p = 0.10$, $n^2_p = 0.11$. Follow-up paired-samples t-tests indicated that examining was not significantly different between blocks one ($M = 16.38$, $SD = 10.77$) and two ($M = 14.19$, $SD = 11.27$), $t(19) = 0.94$, $p = 0.36$. Examining was marginally lower during block three ($M = 11.38$, $SD = 11.68$) than block one, $t(19) = 2.01$, $p = 0.06$. Finally, examining was not significantly different between blocks two and three, $t(19) = 1.41$, $p = 0.17$.

5.2.2. Test phase

Preliminary analyses indicated that the examining times for the test trials were not distributed normally (absolute values of skewness between 0.31 and 1.10). To correct this, a natural log transformation was applied to each test trial, as in Experiments 1, 2, and 3, which lowered the absolute values of skewness to between 0.18 and 0.67. To determine if there were differences in examining as a result of the test trial, an ANCOVA was conducted with test trial as the independent variable (correct parts-body, incorrect parts-body, familiar, and novel) and the difference in examining between the first block and the last block as a covariate. This analysis indicated that the interaction between test trial and the covariate was not significant, $F(3,54) = 0.72$, $p = 0.55$, $n^2_p = 0.04$. However, the main effect of test trial was significant, $F(3,54) = 3.23$, $p = 0.03$, $n^2_p = 0.15$ (natural log-transformed examining times are shown in Fig. 5). Planned comparisons were conducted to compare the familiar trial to the correct parts-body, incorrect parts-body, and novel trials. The analyses indicated that the natural-log transformed examining time during the incorrect parts-body trial ($M = 1.95$, $SD = 0.58$) and the novel trial ($M = 2.18$, $SD = 0.52$) was significantly greater than the examining time during the familiar trial ($M = 1.56$, $SD = 0.84$), both $ps = 0.01$, $n^2_p = 0.30$ and $n^2_p = 0.31$, respectively. However, examining time for the correct parts-body trial ($M = 1.74$ s, $SD = 0.87$) and the familiar trial was the same, $p = 0.42$, $n^2_p = 0.04$. These results demonstrate that infants learned the pairing of the parts and the body and detected the violation of this pairing in the incorrect parts-body object. The results also suggest that infants may have formed an internal representation of a single object with two parts on it because they showed equal examining of that object and a familiar object, only the latter of which they had seen previously.

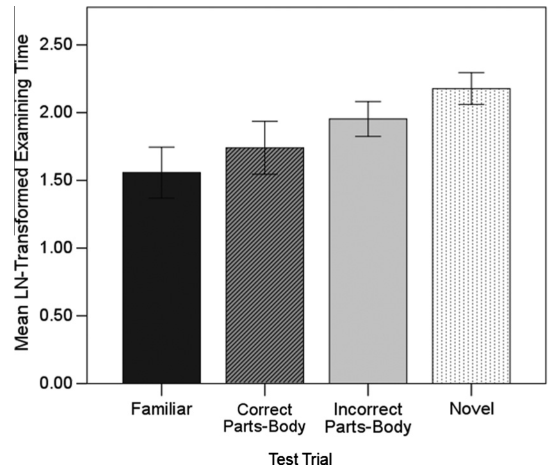

Fig. 5. Examining times during the four test trials of Experiment 4, with a natural log transformation to mitigate normality violations.

5.3. Discussion

The goal of Experiment 4 was to investigate the nature of the representation that infants form when exposed to two correlations that imply a third, unobserved correlation. The question of interest was whether infants form a representation for each of the two objects presented during familiarization that includes their two parts and body. The results of the experiment were consistent with our predictions: Infants examined the novel and incorrect parts-body object longer than the familiar object, and they examined the correct parts-body object and familiar object for a comparable amount of time.

This pattern of data suggests that infants learned the pairing of the parts and the body during the familiarization trials and detected the violation of this pairing in the incorrect parts-body object test trial. Moreover, these results imply that infants may have formed two internal representations of each of the familiarization objects, each with two parts on them. If infants had formed four separate representations, one for each familiarization object, and not prototype representations for those objects then the correct parts-body object should have generated higher looking in the test phase. However, because infants treated equivalently the correct parts-body objects and the familiar object during the test phase and had only experienced the latter previously during the familiarization trials suggests instead that a prototype of the familiarization stimuli was generated during that phase of the study. Note that this null effect—equal examining of the correct parts-body object and the familiar object—was unlikely the result of fatigue or boredom because infants exhibited a preference for the novel object and the incorrect parts-body object over the familiar object. Thus, we propose that the behavior observed in this experiment resulted from infants' ability to form a prototype-like representation of the second-order correlation that included all of the features—the objects and bodies—that were presented in the familiarization phase.

6. General discussion

The goal of the four experiments reported here was to determine whether infants between 7 and 11 months of age are able to infer an unseen correlation from the association between two other correlations, and what representations are formed when they do so, a process that we label second-order correlation learning. Experiment 1 demonstrated that 7-month-olds and 11-month-olds are able to learn second-order correlations, with the younger group exhibiting a preference for an object that embodies those correlations and the older group exhibiting a preference for an object that embodies a violation of those correlations. These effects were found only among those infants who showed a greater drop in examining time during the familiarization phase, thus indicating that they may have encoded the information more fully. Experiment 2 revealed that 9-month-olds—who exhibited no preference for either test object in Experiment 1—fail to show evidence of second-order correlation learning even when the task was made less demanding on information-processing resources by presenting the test stimuli in parallel rather than serially. Experiment 3 showed that 7-month-olds continue to express second-order correlation learning through a preference for a familiar object at test—one that embodies that correlation rather than a violation of it—even when the familiarization objects were made more different from each other. Finally, Experiment 4 suggested that infants at 11 months of age form an internal representation for second-order correlations that includes the objects' parts and body.

These experiments are among the first to investigate whether young infants can engage in second-order correlation learning whereby they extend two learned associative links to a third, unseen correlation. Recall that a preference for either object during the test phase of the study could only have resulted from infants' inference that two of the features—namely, the object parts—were both attached to the same object because all of the individual features of the objects were presented equally during familiarization. Thus, although 7-month-old infants in Experiment 1 and in Experiment 3 showed a preference for a "familiar" stimulus that embodied the second-order correlations and 11-month-olds in Experiment 1 and 4 showed a preference for a "novel" stimulus that violated the second-order correlations, both of these patterns of preference indicate that infants at each of these ages learned the correlation implied by the other two correlations that they experienced during familiarization. That infants as young as 7 months of age are capable of learning second-order correlations is particularly impressive because this is the earliest age at which they have been shown to associate the correlated features of objects that are presented together (Younger & Cohen, 1986). This implies that second-order correlation learning may be a process that develops in parallel with infants' ability to associate the different features of the objects around them. There is also evidence that neonates are capable of learning correlations among features (Slater et al., 1991), and therefore an important unanswered question is whether infants younger than 7 months of age are also capable of second-order correlation learning.

The developmental pattern exhibited by infants across these experiments is entirely consistent with previous work on novelty and familiarity preference in infants in the first year of life. Hunter and Ames (1988; see also Kidd et al., 2012), for example, found that early in processing a stimulus infants demonstrate a preference for that stimulus relative to a novel one, after more exposure to the stimulus they show no preference for it or the novel stimulus, and after additional exposure they prefer the novel stimulus to the familiar one. This trend is thought to arise because infants early in processing require more time to encode the stimulus to enrich their developing representation for it, whereas later in processing infants' somewhat formed representation leads to no preference for either stimuli, and still later in processing they have formed a representation of the stimulus and subsequently prefer a novel one because there is a mismatch between what they observe and the representation they compare it to.

Likewise, we found that 7-month-olds—who take longer than older infants to encode a stimulus—demonstrated a preference for the test object that involved "familiar" feature pairings, 9-month-olds showed no preference for either test object, and 11-month-olds revealed a preference for the test object that involved a "novel" feature pairing. In our view, the familiarity preference exhibited by the 7-month-olds—who had presumably not fully encoded the second-order correlations—occurred because when they were presented with the consistent test item, the relation between the surface features matched the representation they developed for the training objects; however, because the body of the consistent test item was different from their representations of the shapes of the two familiarization stimuli they would have required more time to encode and update this representation. In contrast, the 9-month-olds may have examined longer the inconsistent item than the test item because it violated the second-order correlations among the object parts, which were more fully encoded during training.

It remains an open question whether the 9-month-olds in Experiments 1 and 2 also learned the second-order correlations available in the training stimuli. It is possible—albeit unlikely—that 9-month-olds are unable to encode second-order correlations even though 7- and 11-month-olds possess this ability. More likely, given that 7-month-olds infants showed evidence of second-order correlation learning, the 9-month-olds' preference for novelty and familiarity cancelled out each other which led to no observed preference at test. That we found this failure to demonstrate a preference for either of the two test objects during Experiment 1 and Experiment 2—the latter that attempted to facilitate second-order correlation learning by reducing the memory load through paired presentation—supports this interpretation.

The current data also reveal a developmental pattern for when infants learn the location of two parts on an object. In Experiment 1, neither the 7-month-olds nor the 9-months-olds demonstrated that they had learned the location of the parts, whereas the 11-month-olds' pattern of examining suggested that they had done so. However, 7-month-olds learned the location of the parts when the objects were presented on separate trays during familiarization thus making the objects more distinct. These data suggest that by 7 months of age infants are able to learn not only that two parts are correlated but also where those two parts are situated on an object. That this ability is influenced by the context of the task until at least 11 months of age suggests perhaps that it develops in conjunction with infants' improving information-processing skills.

The finding that infants as young as 7 months of age are capable of second-order correlation learning suggests that it may represent a potentially powerful form of generalization in the first years of life. It could, for instance, help to explain how infants and young children extend their knowledge to novel features, novel objects, and novel category members. There is considerable evidence that infants' earliest representations are grounded in the perceptual, surface features of objects and correlations among those features. For example, infants in the second year of life associate agency, path of motion, and self-propulsion with the external moving parts of objects (Rakison, 2005a, 2005b, 2006). However, it is as yet unknown how infants and young children generalize these associations to other features that are only indirectly related to one of those features. There is evidence, for example, that 18-month-olds inductively generalize specific movement trajectories (e.g., nonlinear movement) to objects with specific parts (e.g., things with legs regardless of category membership) and 22-month-olds generalize the same trajectories to objects from the appropriate category but without such parts (e.g., a snake) (Rakison, 2005b).

One explanation for this developmental pattern is that infants in the second year of life use second-order correlation learning to associate features of objects and events that are not experienced concurrently. 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. This process could lead infants and young children to construct increasingly rich representations for the features and properties of objects and entities in the world. As suggested earlier, this process may represent the developmental emergence of the systematicity principle whereby infants are implicitly guided to discover a large connected systems of relations (Gentner & Smith, 2013). Indeed, once infants have learned second-order correlations for a particular category of objects—for example, that dogs have eyes, legs, tails, and give birth to live young—this may in turn lead them to seek out higher-order relations among that category and others (e.g., mammals). This discovery of higher-order relations has been proposed to provide the foundation for analogical mapping during early childhood, which involves the ability to recognize a common relational system between two situations and to generate additional inferences based on these commonalities (Gentner, 1983; Gentner & Markman, 1997; Holyoak & Thagard, 1989). Thus, we speculate that that second-order correlation learning in infancy signifies the origins and foundation of analogical reasoning in early childhood.

We see no reason why inferences based on second-order correlation learning may not occur across many domains of learning that have a rich correlated structure of input—including language, categorization, and causal learning—and as such it can be considered an as yet unexplored domain-general process for generalization. Indeed, ongoing research in our laboratory suggests that infants are able to use the same process to learn second-order correlations for motion cues as well as for the features of schematic animals. Second-order correlation learning may also represent how infants overcome the *insufficiency of constraints* argument (Keil, 1981). This critique is that associative learning alone cannot act as the foundation for early representations because there are so many correlations in the world to learn that is impossible to know which ones are important and which are not. However, if infants learn that two features are correlated, they may then use second-order correlation learning to incorporate into their representation only those features that are correlated to the two original features. In this way, infants would build increasingly rich representations that incorporate clusters of correlated features.

The ability to learn second-order correlations may also represent the origins of the kinds of deductive reasoning that is observed in older children (e.g., Markovits, Schleifei, & Fortier, 1989). The task faced by young children in the current experiments was a form of *hypothetical syllogism* such that P and Q were paired, P and R were paired, and participants inferred that Q and R were paired. We do not claim that our task was equivalent to hypothetical syllogisms because they require explicit logical reasoning to solve, but instead the current task represents a simpler correlational version of such statements that can be solved using associative learning alone. Thus, we speculate that deductive reasoning observed in older children and adults may be underpinned, in part, by the kind of associatively-based *deductive-like* behavior exhibited by participants in the current experiments. This perspective is consistent with Sloman's (1996) proposal that there are two mechanisms for reasoning, one associative- and one rule-based. An important issue for future research is to examine if and how this form of early associatively-based deductive-like inference is related to the emergence of more explicit logically-based deductive reasoning later in developmental time.

In sum, the current manuscript reports among the first experiments to examine if and when infants are able to learn correlations among features that are never presented simultaneously. The data suggest that this ability emerges by at least 7 months of age, and it improves over time presumably in parallel with infants' developing information processing abilities. We propose that second-order correlation learning is grounded in associative processes, and as such it represents a relatively unexplored domain-general mechanism that may support infants' and young children's ability to generalize their existing knowledge to novel features, objects, and events across a wide range of domains.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2016.03.012.

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