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Infants' sensitivity to correlations between static and dynamic features in a category context

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Abstract

Four experiments with the habituation procedure investigated 14–22-month-olds' ability to attend to correlations between static and dynamic features embedded in a category context. In Experiment 1, infants were habituated to four objects that exhibited invariant relations between moving features and motion trajectory. Results revealed that 14-month-olds did not process any independent features, 18-month-olds processed individual features but not relations among features, and 22-month-olds processed relations among features. In Experiment 2, 14-month-olds differentiated all of the features in the events in a simpler discrimination task. In Experiments 3a and 3b, 22-month-olds failed to show sensitivity to correlations between dynamic and static features in a category context. In Experiment 4, 22-month-olds, but not 18-month-olds, generalized the learned feature–motion relation to a novel instance. The results are discussed in relation to infants' developing ability to attend to correlations, constraints on learning, category coherence, and the development of the animate-inanimate distinction.

Keywords: Cognitive development; Concepts; Correlations; Infancy; Features; Attention

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Introduction

One of the fundamental yet seemingly intractable issues within cognitive science is to explain how objects in the world "hang together" in coherent categories (Murphy & Medin, 1985). Why is it, for example, that cats, dogs, and elephants are considered

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to fall into the same category, or likewise that birds, mosquitoes, and planes can be grouped together in some meaningful way? Among the most influential and forceful arguments for how categories cohere was that forwarded by Rosch and colleagues more than 20 years ago (e.g., Rosch, 1978; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). Rosch noted that the attributes of objects are not distributed haphazardly but instead tend to occur in clusters, and she argued that distinctive categories are formed by taking advantage of this nonarbitrary correlational structure in the environment. For example, things with wings and beaks tend to have feathers, and things with wheels and engines tend to have seats.

A good deal of evidence now attests to the fact that infants, as well as adults, attend to clusters of correlated static attributes in a number of contexts. Most notably, work by Younger and colleagues (Younger, 1990; Younger & Cohen, 1983, 1986; Younger & Gotlieb, 1988) revealed that by 10 months of age, infants can extract regularities in novel and realistic animals. For example, in one classic study by Younger and Cohen (1986, Experiment 2), 4-, 7-, and 10-month-olds were habituated to line drawings of novel animal stimuli that possessed a cluster of correlated attributes (e.g., legs and tails). These authors found that infants at 10 months, but not those in the younger age groups, were able to extract the correlations embedded in a category context from the habituation events. This basic result—showing that 10-month-olds are sensitive to correlated attributes in a category context—has since been replicated and extended in habituation studies with realistic color photographs of animals (Younger, 1990) as well as in object-examining studies with three-dimensional wooden animals (Younger & Fearing, 1998).

There is currently little evidence, however, concerning infants' ability to extract correlations between dynamic and static cues embedded in a category context. Many of the previous studies in this area have examined the ability to discriminate two objects that embody some kind of correlation among dynamic cues (e.g., Madole, Oakes, & Cohen, 1993; Werker, Cohen, Lloyd, Casasola, & Stager, 1998), and those that examined categorization directly have used simple point–light displays in which animal and vehicle motion is depicted by local pendular versus circular movement (Arterberry & Bornstein, 2002). Sensitivity to clusters of correlations between dynamic and static cues is crucial regarding infants' developing knowledge about the motion properties of animals, people, vehicles, and furniture if correlational information is indeed the cornerstone of category coherence, as Rosch (1978) suggested. The experiments reported in this article were designed to examine this issue by presenting 14–22-month-olds with various correlations between static and dynamic cues in a situation with more than two exemplars.

Although a considerable number of studies have examined infants' attention to correlations among static features, only relatively recently have researchers begun to focus on early attention to dynamic cues. By 3 months of age, infants prefer a moving point–light display of a human to an unstructured or random point–light display (Bertenthal, 1993), and they can categorize point–light displays of animals as different from point–light displays of vehicles (Arterberry & Bornstein, 2002). The ability to attend to correlations among dynamic cues starts to improve at the beginning of the second year of life, although few, if any, studies have directly examined infants' sensitivity to clusters of dynamic correlated attributes (cf. Kersten & Billman, 1997). Using the same kind of design as that used by Younger and Cohen (1986), Werker et al. (1998) found that 14-month-olds, but not 10-month-olds, can learn the relation between a label (e.g., "Neem") and a moving object (e.g., a truck) when presented with two objects and labels during the habituation phase. Madole et al. (1993), using a similar design with the object examination paradigm, showed that 18-month-olds, but not 14-month-olds, can learn the correlation between the form of an object (e.g., wheels) and a particular dynamic function (e.g., rolling).

More recently, Rakison and Poulin-Dubois (2002) examined whether 10-, 14-, and 18-month-olds selectively attend to particular correlations between dynamic and static cues in a discrimination context. Infants were habituated to two events in which an object moved across a screen. Each object consisted of a pair of distinct moving parts (P), a distinct body (B), and a distinct motion trajectory (M). During habituation, infants may have observed, for instance, a red-bodied object with horizontally moving yellow parts travel along a rectilinear motion path ($P^1B^1M^1$) and a blue-bodied object with vertically moving green parts travel along a curvilinear motion path ($P^2B^2M^2$). During the test phase, infants were presented with four separate events. One event maintained the body–motion correlation but violated the part–motion and part–body correlation (e.g., $P^2B^1M^1$), one event maintained the part–motion correlation but violated the part–body and body–motion correlation (e.g., $P^1B^2M^1$), one event maintained the part–body correlation but violated the part–motion and body–motion correlation (e.g., $P^1B^1M^2$), and one event was the same as that seen during habituation (e.g., $P^1B^1M^1$). Therefore, differential looking at the test trials could be used to determine which correlations infants had encoded and which they had not encoded.

The results of the experiment showed that infants are selective in the correlations to which they attend. Infants at 10 months of age failed to learn any of the correlations in the events. In contrast, 14-month-olds encoded the relation between the objects' parts and their motion path but not the other relations in the events. Finally, 18-month-olds encoded all of the correlations among the attributes in the event; in other words, they learned that objects with particular parts and a particular body moved along a particular motion path. In a subsequent experiment, 14-month-olds did not learn the correlation between object parts and motion trajectory (or any other correlations in the events) when the object parts did not move, and 18-month-olds attended only to the correlation between parts and motion trajectory.

This pattern of results was taken as support for the notion that the ability to attend to and encode correlations among dynamic features may emerge at some point early in the second year and is not limited to the linguistic domain (Werker et al., 1998). Moreover, Rakison and Poulin-Dubois (2001, 2002; see also Rakison, 2003) proposed that the acquisition of such correlations may act as the cornerstone for infants' developing knowledge of the motion characteristics of animates and inanimates. These authors suggested that infants learn about such characteristics by associating them with conjointly moving and causally related features. Infants would learn that the legs of a cat, in a canonical structure with all four legs in a generally vertical position, move when the cat runs and pats a toy—an action that can involve self-propulsion, agency, and nonlinear motion—and that they generally do not move together in such a structural configuration at other times. Therefore, attention to correlations among dynamic features may act as a mechanism of representational change in that infants come to *expect* or predict that an object possesses or is capable of one aspect of the relation even if it is not present in the sensory array.

This view is in accord with the idea that early concept and category development is grounded in a sensitive perceptual system coupled with an associative, statistical learning mechanism (Quinn & Eimas, 1997; Rakison, 2003; Rakison & Poulin-Dubois, 2001, 2002; Smith, Colunga, & Yoshida, 2003). The studies by Rakison and Poulin-Dubois (2002) suggest, albeit tentatively, that in addition to the presence of such a mechanism, infants do not attend equally to all correlations available in the sensory array because certain aspects of the array are found more salient by the attentional system (see also Folk, Remington, & Wright, 1994). In all likelihood, this form of selectivity acts as a learning constraint by directing infants to discover and learn about relations among features that are causally relevant and, therefore, more central in determining category coherence.

There remain, however, a number of issues that need to be addressed. First, it remains to be seen whether infants are able to extract correlations between dynamic and static cues embedded in a category context. That is, there is evidence that infants attend to correlations among dynamic cues in a discrimination context with two exemplars, but there is little evidence that they can attend to correlations among dynamic cues when more than two exemplars are presented. Second, the finding that infants are selective in the correlations to which they attend needs to be replicated within a category context task. The work by Rakison and Poulin-Dubois (2002) provides preliminary evidence that correlational learning does not occur in an unconstrained manner, and it has been suggested that the salience of movement, among other things, plays a particularly important role in this process. (The term *salience* is used here to describe the relative preference for one aspect of the array over another. It is hypothesized that this bias results from an interaction between the nature of the stimulus [e.g., dynamic] and the nature of the attentional system [e.g., tendency to attend to moving things over static ones].) A key question that remains unanswered is whether the same kind of constrained learning occurs when infants are presented with clusters of correlated attributes distributed among multiple exemplars and, if so, whether it is the same that functions during object discrimination. Finally, the developmental trajectory of infants' ability to attend to correlations among dynamic cues has not yet been mapped out.

The experiments reported in this article were designed to examine these issues. Infants at 14, 18, and 22 months of age were presented with the same stimuli as those used by Rakison and Poulin-Dubois (2002) except that the attribute correlations were embedded in a category context. The phrase *category context* is used here and throughout the article to refer to a task in which there are at least two sets, with multiple exemplars within each set, that possess a different cluster of correlated attribute values. For example, once such category context could be $A^1B^1C^1$ and $A^1B^1C^2$ versus $A^2B^2C^1$ and $A^2B^2C^2$, where the letters A, B, and C refer to features (e.g., legs, arms, head) and the superscript values refer to dimensions of those features (e.g., short legs vs. long legs). A *discrimination context*, in contrast, involves only two exemplars that exhibit different feature values (e.g., $A^1B^1C^1$ vs. $A^2B^2C^2$). Geometric figures were used rather than real-world stimuli because the goal of the experiments was to investigate the mechanism underlying infants' acquisition of new information about objects and not their previously acquired knowledge of particular category exemplars. The basic design of the experiments was identical to that developed by Younger and Cohen (1986). Therefore, the experiments act as a replication of that work, although in the context of dynamic and static cues rather than static ones alone.

Experiment 1

Experiment 1 was designed to examine 14-, 18-, and 22-month-olds' sensitivity to the correlation between objects' moving features and their motion path. Infants were habituated to four events, each of which involved an object moving across a screen, where there was an invariant relation between the object's parts and the motion trajectory of the object. During the test phase, the infants were presented with motion events that maintained or violated the part–motion relation or that were completely novel. The experiment was identical in design to that presented by Younger and Cohen (1986, Experiment 2).

Method

Participants

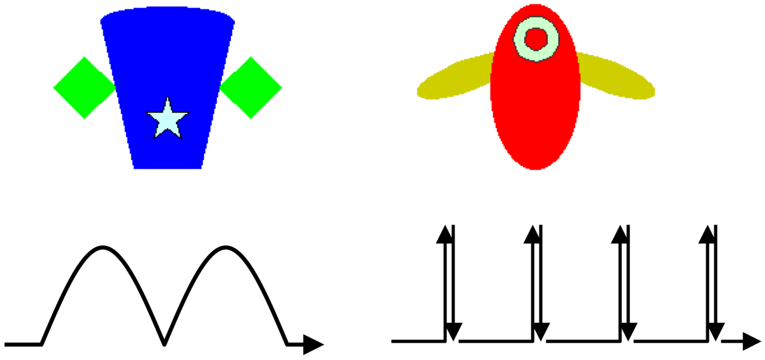
The participants in Experiment 1 were 60 healthy full-term infants: 20 14-month-olds (mean age = 14 months 6 days, range = 13 months 18 days to 14 months 16 days), 20 18-month-olds (mean age = 18 months 5 days, range = 17 months 20 days to 18 months 16 days), and 20 22-month-olds (mean age = 22 months 4 days, range = 21 months 11 days to 22 months 21 days). There were 12 boys and 8 girls in the 14-month-old group, 11 boys and 9 girls in the 18-month-old group, and 10 boys and 10 girls in the 22-month-old group. The majority of infants were White and of middle socioeconomic status. Data from 19 infants were excluded from the final sample: 14 because they failed to habituate (5 at 14 months, 4 at 18 months, and 5 at 22 months) and 5 due to fussing. Infants were recruited through birth lists obtained from a private company and were given a small gift for their participation.

Stimuli

The habituation and test events were computer-animated events identical to those used by Rakison and Poulin-Dubois (2002). The stimuli were created with Macromedia Director 5.0 for PCs. In each event, an object moved from left to right across a screen. Each object possessed a *body* and a pair of external *parts.* The body of one of the objects was a blue rectilinear plant pot shape, and the body of the other object was a red curvilinear oval. To increase the visual attractiveness of the objects, inside the blue body was a star shape and inside the red body was a ring shape. The parts of the objects were either yellow cigar shapes that moved horizontally or green diamond shapes that moved vertically. The parts were always in pairs in that there was one on each side of the body of an object. In the events, the movement of the pairs of parts was identical in terms of the time taken for a complete cycle of motion to be made (up and down for yellow parts, in and out for green parts) as well as the distance that each moved vertically or horizontally. Examples of the stimuli are illustrated in Fig. 1.

Each object could follow one of two distinct *motion* paths across the computer screen from left to right. One of these motion paths was curvilinear in that the object's movement up and down was along a smooth arched trajectory, and the other motion path was rectilinear in that the object's movement up and down was along a vertical trajectory. These two motion paths are presented in Fig. 1. The duration of each event was identical (8.0 s) and could be repeated up to three times

Example habituation and test stimuli



Novel Stimulus and motion path

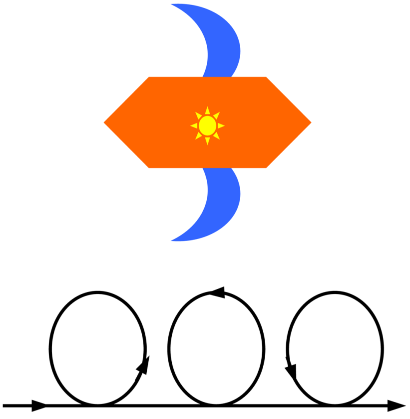


Fig. 1. Examples of the stimuli and motion paths used in the four experiments in this study. To view a color version of this figure, the reader is referred to the Web version of this article. The habituation and test stimuli shown here are based on those developed by Rakison and Poulin-Dubois (2002).

per trial. Between the individual presentations of an event, a blue screen descended and ascended over a period of approximately 2 s. To make discussion of the stimuli and events as straightforward as possible, the two bodies and the pairs of external parts are denoted by their color (red and blue for bodies, yellow and green for parts). Similarly, the two motion trajectories are denoted by their distinct paths (rectilinear and curvilinear). Depending on the set of stimuli required to be presented to each infant, it was possible to pair any given body (blue or red) with any set of parts (yellow or green) or motion path (curvilinear or rectilinear). An additional novel stimulus, also illustrated in Fig. 1, was designed to examine whether infants had attended to the individual features of the habituation stimuli. The stimulus consisted of a completely novel set of parts (pale blue half-moon shapes) and a novel body (an orange hexagonal shape) and moved along a novel motion trajectory (three circular loops).

Finally, to address issues of infant fatigue, one additional stimulus event was used as a pretest and posttest. The rationale for including these events is to determine whether low looking times to all three test stimuli resulted from infants' failure to attend to the computer screen as a result of tiredness. The event was designed to be distinct from those presented during the habituation and test phases of the study. Thus, the pretest and posttest stimulus was a Michotte-like causal event in which a sheep (with moving legs) moved from left to right across the screen and made contact with a table, which then moved to the right until it was off the screen. Each event lasted 8 s, and a blue screen descended and ascended over a period of approximately 2 s between each individual presentation.

Design

All potential correlated pairs of object parts and motion path were used to generate two sets of four events as the habituation stimuli. The two sets allowed full counterbalancing of part–motion combinations with body as a variable factor, and 10 infants in each age group were randomly assigned to one of the two sets. The full design of the stimulus sets is presented in Table 1. It can be seen that values for two of the attributes in the events, parts and motion path, were perfectly correlated in each of the habituation sets. Thus, in each set, a particular pair of parts always co-occurred with a particular motion path. In Habituation Set A, for example, the parts with value 1 always appeared with the motion path with value 1 and the parts with value 2 always appeared with the motion path with value 2.

Infants were habituated to four stimuli, two of which exhibited one part–motion relation and two of which exhibited another part–motion relation. An example habituation and test set are presented in Fig. 2. It can be seen that during habituation, infants may have been presented, for example, with two objects with yellow parts that move along a curvilinear motion path and two objects with green parts that move along a rectilinear motion path. However, the bodies of the two exemplars that had the same parts and motion path were different. For instance, of the two objects with yellow parts that moved along a curvilinear motion path, one had a red body and the other had a blue body.

Table 1
Habituation and test stimuli used in Experiment 1, represented in abstract notation

	Set A			Set B		
	Parts	Motion	Body	Parts	Motion	Body
Habituation stimuli						
	1	1	1	1	2	1
	1	1	2	1	2	2
	2	2	1	2	1	1
	2	2	2	2	1	2
Test stimuli						
Correlated	1	1	2	1	2	1
Uncorrelated	1	2	1	1	1	2
Novel	3	3	3	3	3	3

Note. Each stimulus event possessed three attributes (parts, body, and motion path) that could take one of two values. The values for each attribute are represented here as 1 s and 2 s and were yellow vertically moving parts versus green horizontally moving parts, curvilinear versus rectilinear motion paths, and red curvilinear body versus blue rectilinear body. The test stimuli were composed of familiar attributes that either maintained the correlation observed during habituation (correlated stimulus) or violated that correlation (uncorrelated stimulus). The novel test stimulus was composed of the same attributes as was the habituation stimuli, but the value for each attribute was unique. Note that the feature values of the actual habituation and test stimuli were counterbalanced across infants.

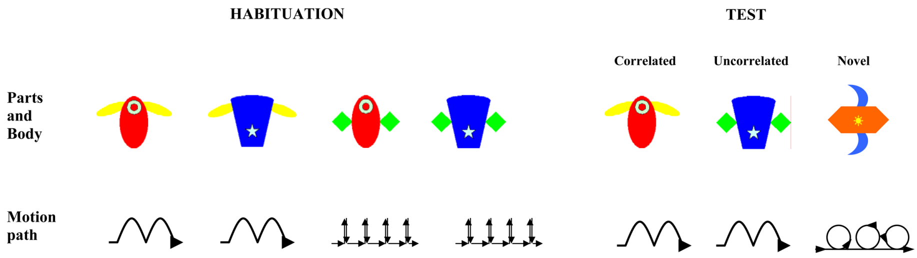


Fig. 2. Example of the habituation stimuli and test trials presented to an infant (excluding the pretest and posttest trials). In the example provided here, two stimuli exhibit one set of feature correlation values, and two stimuli exhibit a different set of feature correlation values. Thus, two stimuli moved curvilinearly and had cigar-shaped parts, and two stimuli moved rectilinearly and had diamond-shaped parts. To view a color version of this figure, the reader is referred to the Web version of this article.

Following habituation, infants were presented with three test events. In one test trial, infants were presented with one of the events observed during the habituation phase (the *correlated* test); therefore, this event maintained the part–motion correlation that was available in the habituation set. For example, infants habituated to the stimuli in Fig. 2 might be presented with the red-bodied object with yellow parts that moved along a curvilinear motion path. In a second test trial, infants were presented with an event that violated the part–motion correlation observed during habituation (the *uncorrelated* test). For example, again referring to Fig. 2, infants might be presented with the blue-bodied object with green parts that moved along a curvilinear motion path. In a third test trial, infants were presented with the novel stimulus that consisted of a novel body, parts, and motion path (the *novel* test). There were six possible orders for the test trials. Therefore, the order of the trials was counterbalanced across 18 infants within each age group, and the order of the six test trials was counterbalanced across the remaining two infants in each age group.

Apparatus

Each infant was tested individually in a quiet, dimly lit laboratory room (approximately 5 × 4 m). The events were presented on a 43-cm computer monitor that was approximately 80 cm from the infant's face. The computer monitor was on a table and was not hidden in any way. Behind the monitor, and surrounding the testing chamber, there was a black curtain that reached from the ceiling to the floor and across the infant's visual field from left to right. A closed-circuit video camera, through which the experimenter monitored and coded the infant's visual responses to the stimuli, was situated above and behind the monitor and was hidden from view by the black curtain. Each infant's looking behavior was recorded for later reliability coding. An Apple G4 computer was used to control the experiment.

An experimenter, who was hidden behind the curtain, observed each infant's visual gaze on a television monitor connected to the video camera. The duration of a gaze was recorded by pressing a key on a computer keyboard when the infant looked at the stimulus on the computer monitor. When the infant looked away from the monitor, the experimenter released the key. Prior to the beginning of the experiment, and after each habituation and test trial, a green circle that expanded and contracted on a dark background was presented on the screen to catch the infant's attention. A bell sound was presented in synchrony with this movement to maximize the attractiveness of the event and capture the infant's visual attention. As soon as the infant's gaze was focused on the computer monitor, the experimenter started the next trial by pressing a preset key on the computer keyboard. The computer recorded the length of each key press, and thus the visual fixations for each event, and it automatically established when the habituation phase ended and the test phase began. The experimenter was blind to the specific event presented and whether the event was part of the habituation or test phase once the first four trials had occurred.

Procedure

Each infant was placed facing the computer monitor on a parent's lap. The parent was instructed to remain neutral, not to interact with the infant verbally or otherwise, and to focus his or her gaze toward but above the computer screen. The infant was tested with a version of the subject-controlled criterion habituation procedure. During the habituation phase of the experiment, the infant was presented with four distinct events that had various part–body–motion combinations as described previously. Within each age group, the order of the habituation trials was determined by a Latin square. Each trial continued until the infant looked away from the event for more than 1 s or until 30 s of uninterrupted looking had elapsed. The habituation phase ended when the infant's looking time decreased to a set criterion level or when 16 trials were presented. To reach criterion, the infant's looking time on a block of three successive trials had to be less than 50% of the total looking time on the first three trials. A sliding block of three trials was used because a pilot study revealed that the infant dropout rate was high with a sliding window of four trials. At the point at which this criterion was reached, or following 16 trials, the test phase began. Infants who did not reach criterion within 16 trials were excluded from the final analysis. Before the habituation events, and after the three test events, infants were presented with the pretest and posttest stimulus.

In line with the predictions made by Younger and Cohen (1986), it was expected that if infants were sensitive to the part–motion correlation in the category context, they would recover visual attention to the uncorrelated and novel stimulus events but not to the correlated stimulus event. In contrast, if infants encoded one or more of the specific features of the habituation stimuli but not the correlations among those features, they would be expected to recover visual attention to the novel stimulus event but not to the correlated and uncorrelated stimulus events (because they contain equally familiar features). Finally, if infants failed to encode any of the available information during the habituation events, or if they encoded the habituation and novel events in terms of "object moves from left to right across the screen," they would be expected to recover visual attention to the posttest event but not to any of the three test events.

Coding and analyses

The duration of infants' visual fixations was coded by the experimenter's key press and recorded by the computer. A second judge was independently trained until able to code within 0.3 s of the primary experimenter, and this second judge independently recoded 25% of the infants' videotaped visual fixations during the experiment. The coders in this experiment, and in the other experiments reported in this article, were naive to the hypotheses under consideration. Interobserver reliability was calculated in two ways. First, a Pearson product–moment pairwise correlation was computed for the scores coded online and the videotaped trials. Second, the mean difference between the experimenter and the second judge for the looking time coded on each trial was analyzed. Reliability for infants' looking times in all of the experiments presented in this article was $r > .94$, and the mean difference between the two judges' coding of infants' looking time on each trial was less than 0.2 s.

Results

The first analysis compared the looking times for infants in the three age groups on the pretest and posttest trials. A significant decrease in looking times to the posttest stimuli relative to those in the pretest trials, in conjunction with low looking times to the three test stimulus events, would suggest that infants became tired in the experiment (Werker et al., 1998). If looking times continue to be high for the posttest trial, low looking times to the three main test events need to be interpreted either (a) in terms of failing to process the feature correlations in the events or (b) in terms of processing all three test events as equivalent in some way. The looking times were analyzed with a three-way mixed-design analysis of variance (ANOVA) with Trials (pretest vs. posttest) as the within-subjects factor and Age (14 months vs. 18 months vs. 22 months) and Sex (male vs. female) as the between-subjects factors. The analysis revealed that across the three age groups, looking times were equivalent for the pretest event ($M = 21.81$, $SD = 9.50$) and posttest event ($M = 22.99$, $SD = 8.38$), $F(1, 54) = 1.05, p > .30$. There was no significant effect for age or sex, and there was no significant interactions between the variables. Moreover, visual fixation times to the two events were high for the 14-month-olds (pretest $M = 18.33$, $SD = 9.85$; posttest $M = 21.22$, $SD = 8.71$), 18-month-olds (pretest $M = 22.24$, $SD = 9.86$; posttest $M = 23.99$, $SD = 8.51$), and 22-month-olds (pretest $M = 24.87$, $SD = 7.97$; posttest $M = 23.77$, $SD = 8.05$).

The primary set of analyses examined infants' looking behavior during the three test trials and the posttest trial. The looking times were entered into a 4 (Test Stimulus: correlated vs. uncorrelated vs. novel vs. posttest) × 3 (Age: 14 months vs. 18 months vs. 22 months) × 2 (Sex: male vs. female) mixed-design ANOVA. The analysis revealed a main effect of test stimulus, $F(3, 162) = 54.73, p < .001$, which was mediated by a significant interaction between test stimulus and age, $F(6, 162) = 2.23$, $p < .05$. There were no further significant main effects or interactions. To investigate further the pattern of visual fixation by infants within each age group, separate 2 (Sex: male vs. female) × 4 (Test Stimulus: correlated vs. uncorrelated vs. novel vs. posttest) ANOVAs were performed on the 14-, 18-, and 22-month-olds' data. The mean looking times during the three test trials for each of the three age groups are presented in Fig. 3. In this experiment and the other experiments presented in this article, planned comparisons were used to evaluate only the contrasts that were fundamental to the experimental hypotheses: infants' looking times to the correlated versus uncorrelated test events, the correlated versus novel test events, and the uncorrelated versus novel test events. All other comparisons were calculated with Bonferroni correction.

The analysis for the 14-month-olds' fixation times revealed a main effect for test stimulus, $F(3, 54) = 26.62$, $p < .001$. Planned comparisons showed that infants looked equally long at the correlated ($M = 6.56$, $SD = 6.69$), uncorrelated ($M = 6.99$, $SD = 6.49$), and novel test stimuli ($M = 8.78$, $SD = 7.14$). However, they looked significantly longer at the posttest event ($M = 21.22$, $SD = 8.71$) than at the correlated, $F(1, 19) = 37.50$, $p < .01$, uncorrelated, $F(1, 19) = 31.86$, $p < .01$, and novel test events, $F(1, 19) = 35.97, p < .01$. There was no main effect for sex and no significant interaction between sex and test stimulus. The analysis for the 18-month-olds yielded a significant main effect of test stimulus, $F(3, 54) = 22.84, p < .001$. Planned comparisons revealed that infants looked equally long at the correlated ($M = 7.07$, $SD = 7.06$) and uncorrelated stimuli ($M = 8.05$, $SD = 6.15$), but they looked significantly longer at the novel event ($M = 16.47$, $SD = 9.33$) than at the correlated, $F(1, 19) = 17.42$, $p < .001$, and uncorrelated stimulus events, $F(1, 19) = 12.10$, $p < .001$. The 18-month-olds also visually fixated longer on the posttest event ($M = 23.99$, $SD = 8.51$) than on the correlated, $F(1, 19) = 45.49$, $p < .01$, uncorrelated, $F(1, 19) = 73.14$, $p < .01$, and novel test events, $F(1, 19) = 8.89$, $p < .05$. There was no significant main effect for sex or an interaction between sex and test stimulus in the analysis.

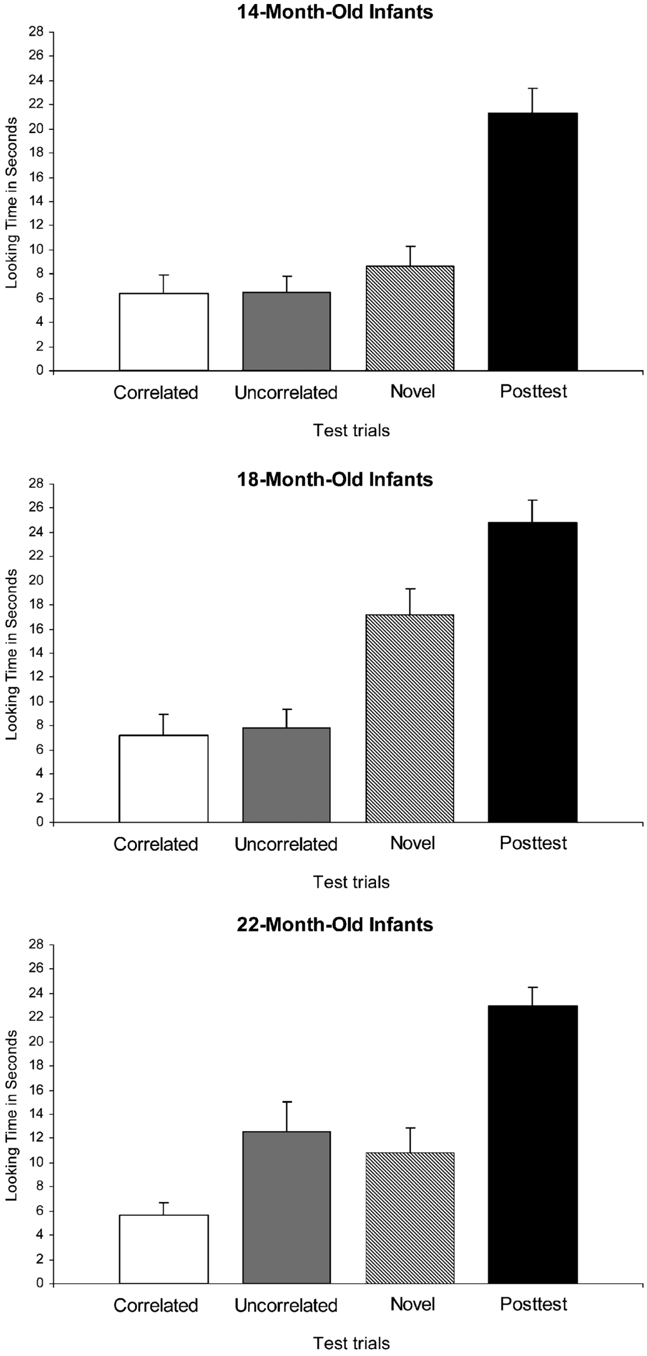


Fig. 3. Mean looking times and standard errors during the four test trials for 14-, 18- and 22-month-olds in Experiment 1. The correlated features among the habituation stimuli were object parts and motion path.

Finally, the analysis for the 22-month-olds revealed a significant main effect of type of test stimulus, $F(3, 54) = 13.89$, $p < .001$. Planned comparisons revealed that infants' visual fixation of the uncorrelated stimulus ($M = 12.60$, $SD = 10.69$), $F(1, 19) = 6.82$, $p < .025$, and novel stimulus ($M = 10.83$, $SD = 8.92$), $F(1, 19) = 5.93$, $p < .025$, significantly exceeded visual fixation toward the correlated stimulus ($M = 5.69$, $SD = 4.71$). Looking times for the uncorrelated stimulus and novel stimulus were not reliably different, $F(1, 19) = 0.34$, $p > .50$. As with the two younger age groups, the 22-month-olds looked significantly longer at the posttest stimulus ($M = 23.77$, $SD = 8.05$) than at the correlated, $F(1, 19) = 67.85$, $p < .01$, uncorrelated, $F(1, 19) = 11.27$, $p < .05$, and novel test events, $F(1, 19) = 24.31$, $p < .01$. There was no significant effect for sex or an interaction between sex and looking at the stimulus events.

Discussion

The pattern of results suggests that sensitivity to correlations among dynamic features embedded in a category does not emerge until between 18 and 22 months of age. Moreover, the data suggest that infants undergo a developmental trajectory in their sensitivity to dynamic feature correlations in a category context similar to that recorded by Younger and Cohen (1986) for static features. Infants at 14 months of age failed to recover visual attention to any of the three test stimuli. There are a number of plausible explanations for this pattern of behavior. Most likely, the 14-month-olds failed to process any of the individual features of the events (parts, bodies, and motion paths) and instead processed the stimulus events as "object moves across the screen." This explanation is particularly compelling given that infants failed to recover visual attention to the novel stimulus, which differed from the habituation stimuli in terms of the shape and color of the body; the shape, color, and movement of the parts; and the motion trajectory that the object followed. This finding is particularly noteworthy because 14-month-olds in a simpler discrimination task were able to extract the correlations in the events. Thus, sensitivity to correlations among dynamic cues at 14 months of age is contingent on the number of exemplars that are presented.

Infants at 18 months of age also did not extract the dynamic feature correlations in the events. However, the 18-month-olds looked significantly longer at the novel test trial than at the correlated and uncorrelated test trials, suggesting that they processed one or more of the individual features in the events but were unable to detect or encode the relation between the parts and motion of the objects. The performance of the 22-month-olds—looking longer at the uncorrelated test event than at the correlated test event—revealed that they are sensitive to clusters of correlations among multiple exemplars. That this ability emerges between 18 and 22 months of age is somewhat consistent with previous work on infants' attention to correlations among dynamic features showing that infants between 14 and 18 months of age become increasingly sensitive to such correlations in a discrimination task (e.g., Madole & Cohen, 1995; Madole et al., 1993; Rakison & Poulin-Dubois, 2002). In other words, it would be expected that infants' sensitivity to dynamic feature correlations in the presence of four objects would develop after their sensitivity to such correlations in a simpler discrimination context.

Experiment 2

One possible explanation for 14-month-olds' failure to recover visual attention to the uncorrelated stimuli in Experiment 1 is that they were unable to discriminate the various parts, bodies, or motions of the objects. That is, if infants could not discriminate one kind of feature from another (e.g., blue body from red body), they would be unable to extract the feature correlations from the events. Moreover, before claiming that older infants are sensitive to specific feature correlations, it is necessary to show that they (or younger infants) can discriminate the various features in the events. To address this issue, in Experiment 2 infants were habituated only to one of the events used in Experiment 1, after which they were tested with four test events. In three of the test trials, one feature of the event was novel (either the parts, the body, or the motion path). In the fourth test trial, infants saw the same event as that used during habituation. Previous work by Rakison and Poulin-Dubois (2002) showed that infants at 18 months of age are sensitive to correlations involving all three of the features involved in the events, a corollary of which is that they are able to discriminate those features. Therefore, in the current experiment, 14-month-olds were tested.

Method

Participants

The participants in Experiment 2 were 20 full-term 14-month-olds. There were an equal number of boys and girls. Data from 9 additional infants were excluded from the final sample: 6 because they failed to habituate, 2 due to fussing or crying, and 1 due to experimenter error. Infants were recruited in the same way as in Experiment 1.

Stimuli, apparatus, and procedure

The stimuli and apparatus were identical to those used in Experiment 1; however, in contrast to Experiment 1, infants were habituated to a single motion event. In the current experiment, half of the infants were habituated to the object with a blue body and green parts that moved on a curvilinear trajectory, and half of the infants were habituated to the object with a red body and yellow parts that moved on a rectilinear trajectory. Infants observed the same event until their visual fixation across three consecutive trials decreased to 50% of that recorded during the first three trials or until 16 trials were presented. Each event was displayed until the infants looked away for more than 1 s or until 30 s had elapsed. Infants were presented with four trials during the test phase. One event was the same as that presented during the habituation phase (*familiar*), and the other three events included a novel feature—either parts, body, or motion—that was not seen during habituation. The order of the test trials was counterbalanced across infants.

Based on previous findings (e.g., Rakison & Poulin-Dubois, 2002), it was predicted that infants at 14 months of age would process independently the various features in the event. Thus, it was expected that infants would recover visual attention to all three of the novel test trials.

Results

Infants' looking times in the four test trials were analyzed with a one-way repeated-measures ANOVA. The analysis revealed that looking times differed significantly across the test trials, $F(3, 57) = 4.63$, $p < .01$. Planned comparisons indicated that infants looked significantly longer at all three test trials with a novel feature than at the familiar test trial. That is, infants looked longer at the trial with the novel parts ($M = 8.56$, $SD = 6.53$), $F(1, 19) = 7.65$, $p < .01$, novel body ($M = 11.54$, $SD = 8.76$), $F(1, 19) = 9.15$, $p < .01$, and novel motion ($M = 8.30$, $SD = 7.17$), $F(1, 19) = 7.63$, $p < .01$, than at the familiar test trial ($M = 4.36$, $SD = 2.54$). These data are presented in Fig. 4. Importantly, infants' looking times to the novel part, novel body, and novel motion events were not significantly different from each other, all *ps* > .20.

Discussion

The results revealed that infants at 14 months of age are able to process independently the various features in the events when they are presented outside of a category context. The pattern of looking showed that they discriminated the two object parts, two object bodies, and two object motions in the events. It is worth noting that discrimination of the parts, body, and motion changes following habituation to a single event does not necessarily imply that the different feature values were discriminated by the 14-month-olds in Experiment 1. However, the results of the current experiment do suggest that, under certain conditions, 14-month-olds are capable of discriminating the different kinds of features in the events. Consequently, the view taken here is that the 14-month-olds in Experiment 1 were able to discriminate the features in the events but were unable to encode the relations among those features when multiple exemplars were presented.

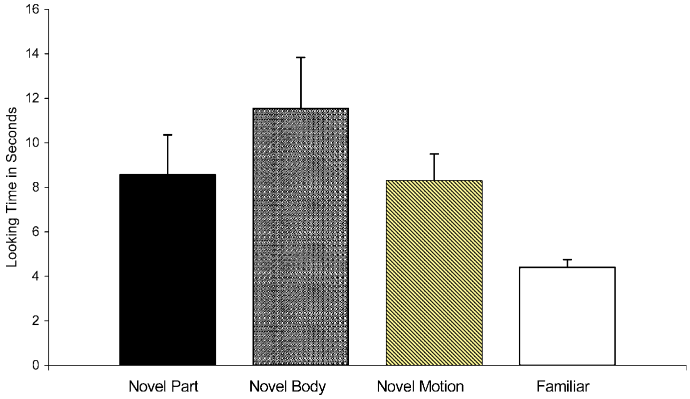


Fig. 4. Mean looking times and standard errors during the four test trials for 14-month-olds in Experiment 2. Infants in this experiment observed only one event during habituation. To view a color version of this figure, the reader is referred to the Web version of this article.

It is also possible that there is a discontinuity such that 14-month-olds, but not older infants, are able to discriminate the features in the events. However, the findings of Rakison and Poulin-Dubois (2002) cited earlier suggest that 18-month-olds can discriminate all three features in the events, and it is unlikely that infants as old as 22 months would subsequently be unable to do so, particularly when such discontinuities have never been reported in the object categorization literature. Finally, the results suggest that the various features in the events were equally discriminable or salient, at least in a simple differentiation task; that is, infants attended to all of the features in the events. Therefore, sensitivity to certain correlations and not others in the presence of multiple exemplars is unlikely to arise from an inability to attend to those features per se or because the difference between any set of feature pairs (e.g., the two bodies) was greater than that between any of the other feature pairs.

Experiments 3a and 3b

A next question of import concerns whether infants are equally sensitive to all kinds of feature relations in a category context. Rakison and Poulin-Dubois (2002) found that infants at 14 months of age selectively attend to and encode the relation between object parts and the motion trajectory of an object. It was hypothesized that the increased salience of the relation between such dynamic features results from an *attention bias* (Rakison, 2003) on the part of the infants. This bias, in conjunction with other biases (e.g., to object parts), acts to direct infants to causally relevant information about the objects and events around them. (The term *salience* is used here to describe the relative preference for one aspect of the array over another.) Such a view is supported by newborns' visual preference for moving stimuli over static stimuli (Slater, 1989) and the finding that infants between 2 and 5 months of age orient to a small moving object in a visual field of static objects (Dannemiller, 2000). Furthermore, there is evidence that infants, as well as adults, detect an object's properties more easily when the object moves than when it is still (Burnham & Day, 1979; Kellman & Spelke, 1983; Washburn, 1993; Werker et al., 1998). Indeed, Kellman (1993) argued that the role of motion in specifying an object's characteristics is an innate or maturational *primitive process.*

It remains to be seen, however, whether infants attend to relations among dynamic features when multiple exemplars are presented and not to other feature relations (i.e., those involving static features). It is possible that infants will just as likely attend to relations between a static feature and a dynamic feature (e.g., those between object parts and the body of an object) as to relations among dynamic cues or that at some point in development they will simply learn any and all correlations that are available in the input. In the work of Younger and colleagues (e.g., Younger, 1990; Younger & Cohen, 1983, 1986), although they were not tested directly, infants at 10 months were just as likely to learn any of the correlations among the various attributes of the novel animals. However, the stimuli in these earlier studies were static images.

In Experiments 3a and 3b, separate groups of infants at 22 months of age were habituated to one of two sets of objects that contained clusters of correlations. In Experiment 3a, infants were habituated to four stimuli that exhibited an invariant relation between the moving parts and the body of an object. In Experiment 3b, infants were habituated to four stimuli that exhibited an invariant relation between the body of an object and that object's motion trajectory. Thus, in contrast to Experiment 1, infants in the current experiments were habituated to the correlation between a dynamic cue (moving parts or motion trajectory) and a static one (body type). During the test phase, infants were presented with one event that preserved the correlation observed during habituation, one event that violated the correlation observed during habituation, and a completely novel object and motion. Infants were tested at 22 months of age because this was the earliest age in Experiment 1 at which infants were able to form categories based on the part–motion path relation. If infants are more sensitive to relations among such dynamic cues than to relations between static and dynamic cues, it would be expected that infants in the current experiments would fail to show sensitivity to the correlations embedded in the categories. Conversely, if infants at 22 months of age develop a general ability to extract regularities in the input, they would be expected to show sensitivity to the relations presented in the events.

Experiment 3a

Method

Participants

The participants in Experiment 3a were 20 infants at 22 months of age (mean age = 22 months 6 days, range = 21 months 16 days to 22 months 20 days). There were 11 males and 9 females. The majority of infants were White and of middle socioeconomic status. Data from 4 additional infants were excluded from the final sample: 2 because they failed to habituate and 2 due to fussing or crying. As in Experiment 1, infants were recruited through birth lists from a private company and were given a small gift.

Stimuli

The habituation and test stimuli were the same geometric figures and motion paths used in Experiment 1. However, infants were habituated to stimuli that embodied a correlation between object parts and object body type. There were two sets of four events that could act as habituation stimuli, and any event could act as a correlated or an uncorrelated test stimulus depending on which events were presented during habituation. The events were created with Macromedia Director 5.0 for PCs. Each scene of an object moving from the left to the right side of a screen lasted 8 s and was repeated three times with a blue screen in between each individual presentation. The total duration of each event, including the blue screen, was 30 s. The novel stimulus event and pretest/posttest stimulus event used in Experiment 1 were again employed in the current experiment.

Design

All of the potential correlated pairs of object parts and object body were used to generate two sets of four events as the habituation stimuli. The two sets allowed complete counterbalancing of the correlational combinations. Because the correlation among features in the events involved the parts and the body of the objects, the motion path of the object was a variable within- and across-category factor. A total of 10 infants were randomly assigned to one of the two habituation sets. The full design of the stimulus set is presented in Table 2, and it can be seen that values for two of the attributes in the events, object parts and body, were perfectly correlated for each of the habituation sets.

Apparatus and procedure

The apparatus and procedure were the same as those used in Experiment 1. Infants in each condition were habituated to four events, each containing a specific correlation between a static feature and a dynamic feature, until visual fixation across

Table 2
Habituation and test stimuli used in Experiments 3a and 3b, represented in abstract notation

	Set A			Set B		
	Parts	Motion	Body	Parts	Motion	Body
Experiment 3a: Parts and body relation						
Habituation stimuli						
	1	1	1	1	1	2
	1	2	1	1	2	2
	2	1	2	2	1	1
	2	2	2	2	2	1
Test stimuli						
Correlated	1	1	1	1	2	2
Uncorrelated	1	2	2	1	1	1
Novel	3	3	3	3	3	3
Experiment 3b: Motion path and body relation						
Habituation stimuli						
	1	1	1	1	1	2
	2	1	1	2	1	2
	1	2	2	1	2	1
	2	2	2	2	2	1
Test stimuli						
Correlated	1	1	1	1	1	2
Uncorrelated	1	1	2	1	1	1
Novel	3	3	3	3	3	3

Note. Each stimulus event possessed three attributes (parts, body, and motion path) that could take one of two values. The values for each attribute are represented here as 1 s and 2 s and were yellow vertically moving parts versus green horizontally moving parts, curvilinear versus rectilinear motion paths, and red curvilinear body versus blue rectilinear body. The test stimuli were composed of familiar attributes that either maintained the correlation observed during habituation (correlated stimulus) or violated that correlation (uncorrelated stimulus). The novel test stimulus was composed of the same attributes as were the habituation stimuli, but the value for each attribute was unique. Note that the feature values of the actual habituation and test stimuli were counterbalanced across infants.

three sequential trials decreased to 50% of that measured across the first three trials. Each event was presented until infants looked away for more than 1 s or until 30 s had elapsed. The order of the habituation trials was generated with a Latin square. Following the habituation phase, infants were presented with three further trials: an event that maintained the correlation seen during habituation (correlated stimulus event), an event that violated the correlation observed during habituation (uncorrelated stimulus event), and a novel stimulus. Before the first habituation trials, and immediately after the three test events, infants were presented with the pretest and posttest stimulus.

Results

The first analysis compared infants' looking times for the pretest and posttest stimulus in the two conditions. The data were entered into a mixed-design ANOVA with Trial (pretest vs. posttest) as the within-subjects factor and Sex (male vs. female) as the between-subjects factor. The analysis showed that infants' visual fixations to the pretest ($M = 24.77$, $SD = 7.56$) and posttest stimuli ($M = 24.96$, $SD = 8.56$) were not reliably different, $F(1, 19) = 0.36$, $p > .70$. There was no significant main effect for the sex of the infant and no significant interaction between sex and trial type.

The main analysis examined infants' looking behavior across the correlated, uncorrelated, novel, and posttest events. The data were entered into a 2 (Sex: male vs. female) × 4 (Test Stimulus: correlated vs. uncorrelated vs. novel vs. posttest) mixed-design ANOVA. Infants' looking times across the four test trials are presented in Fig. 5A. The analysis revealed a main effect for test stimulus, $F(3, 54) = 15.26$, $p < .001$. Planned comparison showed that infants' looking times for the correlated ($M = 7.78$, $SD = 6.23$) and uncorrelated ($M = 11.31$, $SD = 9.45$) stimulus events were not reliably different, $F(1, 19) = 1.67$, $p > .30$. In addition, infants looked significantly longer at the novel stimulus event ($M = 14.56$, $SD = 9.75$) than at the correlated stimulus event, $F(1, 19) = 4.74$, $p < .05$, but they looked equally long at the novel and uncorrelated stimulus events, $F(1, 19) = 1.45$, $p > .10$. Finally, infants looked longer at the posttest event than at correlated, $F(1, 19) = 12.35$, $p < .01$, and uncorrelated events, $F(1, 19) = 15.67$, $p < .01$, but they looked at the posttest and novel stimulus events for comparable lengths of time.

Experiment 3b

Method

Participants

The participants in Experiment 3b were 20 infants at 22 months of age (mean age = 22 months 8 days, range = 21 months 24 days to 22 months 24 days). There were 9 males and 11 females in the final sample. The majority of infants were White and of middle socioeconomic status. An additional 7 infants were excluded from the final

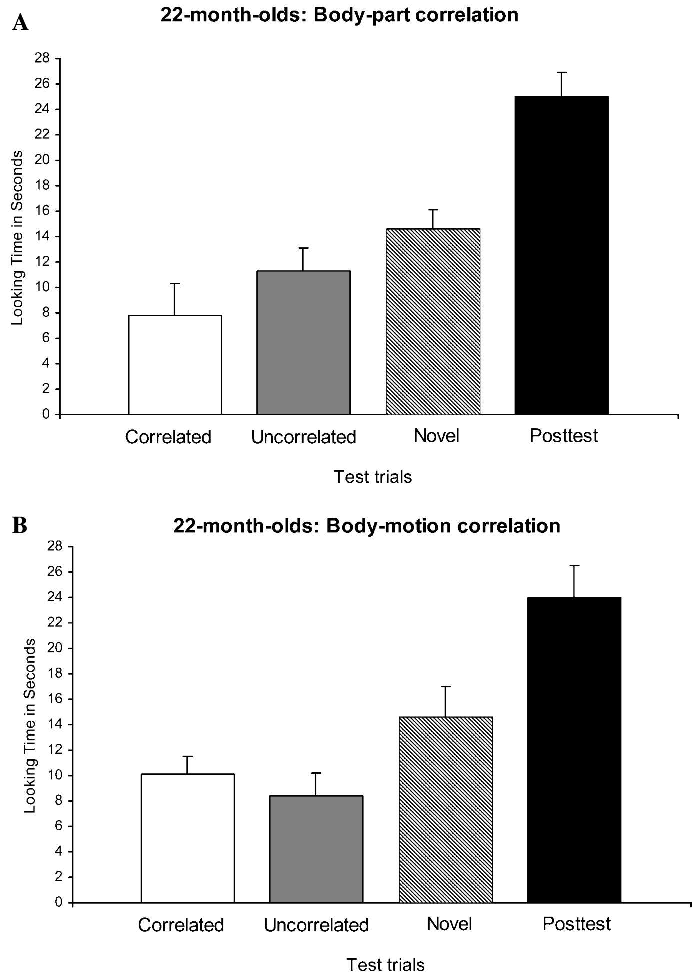


Fig. 5. Mean looking times and standard errors during the four test trials for 22-month-olds in Experiments 3a and 3b. (A) Looking times for infants who were habituated to stimuli that exhibited the correlation between object parts and object body. (B) Looking times for infants who were habituated to stimuli that exhibited the correlation between object body and object motion path.

sample: 3 because they failed to habituate, 3 due to fussing or crying, and 1 due to experimenter error. Infants were recruited through birth lists obtained from a private company and were given a small gift for their participation.

Stimuli, design, apparatus, and procedure

All aspects of the current experiment were identical to those of Experiment 3a except that the stimuli presented to infants during the habituation phase of the experiment embodied the correlation between object body type and object motion trajectory. Thus, all of the possible correlated pairs of object body and motion path were used to create two sets of four events to be used as the habituation stimuli, and the parts of the object was a variable within- and across-category factor. A total of 10 infants were randomly assigned to one of the two habituation sets. The design of the stimulus set is presented in Table 2.

Results

Preliminary analysis revealed that infants looked equally long at the pretest ($M = 26.76$, $SD = 9.67$) and posttest events ($M = 23.45$, $SD = 8.75$), $F(1, 19) = 0.67$, $p > .50$. There was also no significant effect for the sex of the infants or a significant interaction between the test trial and sex variables. The main analysis revealed that looking times were reliably different across the four test trials, $F(3, 54) = 11.35$, $p < .001$. These data are presented in Fig. 5B. Planned comparisons revealed that infants looked equally long at the correlated ($M = 10.08$, $SD = 9.54$) and uncorrelated test trials ($M = 8.45$, $SD = 7.56$). Somewhat surprisingly, the lengths of infants' visual fixation for the correlated and novel test trials ($M = 14.87$, $SD = 9.34$) were comparable, $F(1, 19) = 1.21$, $p > .20$, and infants looked only marginally longer at the novel test trial than at the uncorrelated test trial $F(1, 19) = 4.25$, $p < .54$. Finally, as in the other experiments reported in this article, infants' visual fixation for the posttest stimulus event significantly exceeded that for the other three test trials, all ps $< .01$.

Discussion

Experiments 3a and 3b were designed to examine whether infants at 22 months of age are sensitive to specific clusters of correlations, namely, relations between objects' moving parts and bodies and relations between objects' bodies and their motion trajectory. The results of the experiments revealed that infants at 22 months of age failed to look significantly longer at the uncorrelated stimuli than at the correlated stimuli when habituated to object sets containing either kind of relation. Thus, infants failed to encode the parts–body correlation or the body–motion path correlation available in the events. These data, in conjunction with those from Experiment 1, support the notion that infants may be more sensitive to the relations among dynamic cues than to those between static and dynamic cues. That is, infants at 22 months of age extracted relations between two dynamic cues that are embedded in a category structure, but they did not extract relations between a static cue and a dynamic cue in a similar structure.

These results appear to contradict those of Arterberry and Bornstein (2002), who found that infants at 9 months of age could generalize from dynamic point–light displays of animals or vehicles to static images of members of those categories. Such results could be interpreted to mean that infants processed the relation between dynamic and static cues. However, it is worth pointing out that infants in these authors' experiments needed only to detect commonalities between the habituation stimuli (e.g., rotary motion) and a feature of the static image (e.g., wheels). Moreover, their experiments were not designed to examine whether infants can detect dynamic correlations embedded in a category context. The point–light displays were dynamic at the local level (e.g., rotary motion) but not at the global level; that is, they moved in place.

Experiment 4

The results of Experiment 1 revealed that infants at 22 months of age can attend to correlations among dynamic features that are embodied among multiple exemplars. However, there are two related limitations of the design of Experiment 1 that prevent strong conclusions from being drawn at this point. First, the correlated test item was one of the four stimuli presented during habituation. As a consequence, short looking to this stimulus relative to looking to the uncorrelated stimulus could have occurred because infants recognized the former as one that was presented previously. Second, Experiment 1 does not reveal whether infants would generalize the correlation learned during habituation to a novel category exemplar, and this is generally agreed to be necessary before concluding that multiple exemplars are represented as equivalent in some way. It could be argued, therefore, that infants show sensitivity to certain correlations embedded in a category but that they would not necessarily apply these learned correlations to newly encountered exemplars.

To address this issue, Experiment 4 employed an identical design to that developed by Younger and Cohen (1986, Experiment 4). Infants at 18 and 22 months of age were habituated to three exemplars (two drawn from one category and one drawn from the other) and were then tested with three novel test events. In one test event, the exemplar possessed the familiar correlated feature values but the specific exemplar was not seen during habituation. In the second test event, the novel exemplar possessed violated correlated features values. In the third test event, the exemplar possessed three previously unseen feature values. Recovery of visual attention to the uncorrelated stimulus compared with the correlated stimulus could not occur from recognition of the correlated stimulus, and it would also show that the correlation learned during habituation is generalized to the novel stimulus that exhibits the same feature relation.

Method

Participants

The participants in Experiment 4 were 16 infants at 18 months of age (mean age = 18 months 3 days, range = 17 months 19 days to 18 months 14 days) and 16 infants at 22 months of age (mean age = 21 months 29 days, range = 21 months 14 days to 22 months 15 days). There were 8 males and 8 females in both age groups. An additional 7 infants were excluded from the final sample: 3 because they failed to habituate (1 at 18 months and 2 at 22 months), 2 due to fussing or crying, and 2 due to equipment failure. Infants were recruited in the same way as in the other experiments reported in this article.

Stimuli, design, apparatus, and procedure

All aspects of Experiment 4 were identical to those of Experiment 1 except that infants were habituated to three stimuli rather than four stimuli that exhibited an invariant relation between object parts and a motion trajectory (Table 3).

As in Experiment 1, values for the external parts and motion path were perfectly correlated in each of the habituation sets, but because three stimuli were presented during the habituation phase, infants saw two stimuli that shared the same correlated feature values (e.g., part value 1 and motion value 1) and one stimulus that had a different set of correlated feature values (e.g., part value 2 and motion value 2). Following habituation, infants were presented with three test events and the posttest event. The three test events were identical to those in Experiment 1 in that there were correlated, uncorrelated, and novel stimuli, but the correlated stimulus was not one of those stimuli that were presented during habituation. All other aspects of the experiment were identical to those of the other experiments reported in this article.

Results

As in the previous experiments, the first analysis compared infants' looking to the pretest and posttest stimulus events. The analysis revealed no significant difference in 18- and 22-month-olds' visual fixations to the pretest ($M = 24.35$, $SD = 8.75$) and posttest stimuli ($M = 22.31$, $SD = 9.53$), $F(1,30) = 1.45$, $p > .30$. There was no significant main effect for the sex of the infants and no significant Sex × Trial Type interaction.

Infants' visual fixations to the test trials were first investigated with a 2 (Age: 18-month-olds vs. 22-month-olds) × 2 (Sex: male vs. female) × 4 (Test Stimulus: correlated vs. uncorrelated vs. novel vs. posttest) ANOVA. The analysis revealed a main effect of test trial, $F(3,84) = 22.14$, $p < .001$, but no further significant main effects or interactions. In all likelihood, the relatively high looking times to the novel ($M = 13.89$,

Table 3
Habituation and test stimuli used in Experiment 4, represented in abstract notation

	Set A			Set B		
	Parts	Motion	Body	Parts	Motion	Body
Habituation stimuli						
	1	1	1	1	2	1
	1	1	2	2	1	1
	2	2	1	2	1	2
Test stimuli						
Correlated	2	2	2	1	2	2
Uncorrelated	1	2	2	2	2	2
Novel	3	3	3	3	3	3

Note. In contrast to Experiments 1, 3a, and 3b, infants were habituated to three exemplars that embodied the relation between an object's parts and its motion trajectory. The correlated test stimulus was not one of those presented during habituation and, according to Medin and Schaffer's (1978) context model, was the most similar overall to the habituation exemplars. The feature values of the actual habituation and test stimuli were counterbalanced across infants.

SD = 8.64) and posttest events overshadowed the more critical comparisons between the correlated (*M* = 8.02, *SD* = 6.54) and uncorrelated events (*M* = 9.23, *SD* = 7.12). Consequently, separate analyses were performed on each age group's looking times.

The pattern of looking by infants in each age group was investigated by a 2 (Sex: male vs. female) × 4 (Test Stimulus: correlated vs. uncorrelated vs. novel vs. posttest) ANOVA. The 18- and 22-month-olds' looking behavior in the three test trials and the posttest trial is presented in Fig. 6. The analysis for the 18-month-olds showed that looking times to the four events differed significantly, $F(3, 42) = 16.36$, $p < .001$. Further analyses revealed that infants' visual fixations to the correlated (*M* = 10.43, *SD* = 8.53) and uncorrelated stimulus events (*M* = 8.61, *SD* = 7.12) were not reliably different, $F(1, 15) = 0.42$, $p > .40$; however, infants did look significantly longer at the novel test event (*M* = 14.39, *SD* = 9.53) than at the uncorrelated test event,

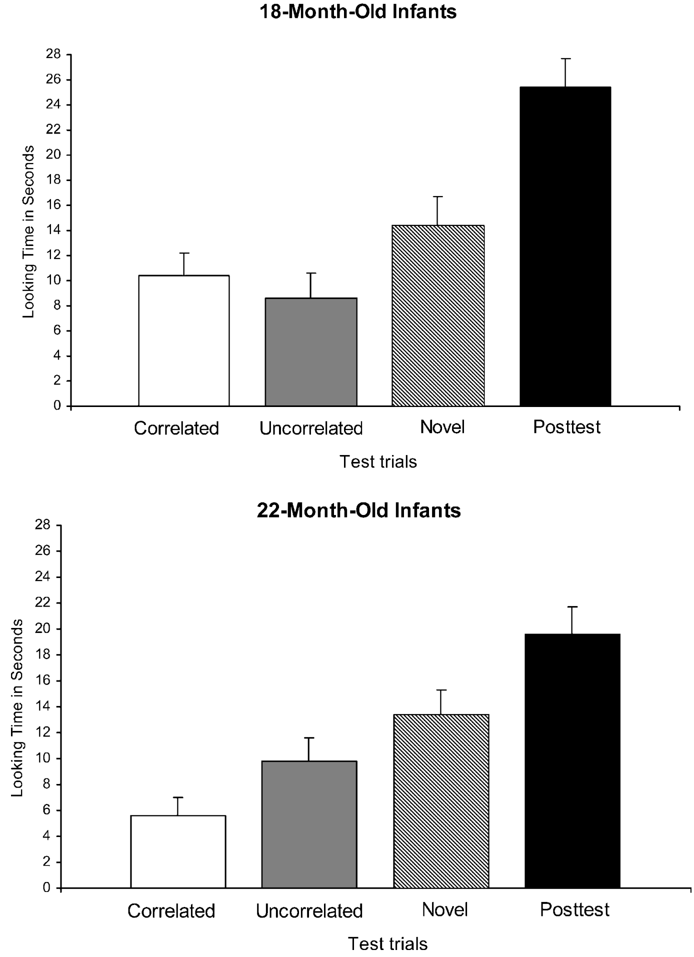


Fig. 6. Mean looking times and standard errors during the four test trials for 18- and 22-month-olds in Experiment 4. The correlated features among the habituation stimuli were object parts and motion path.

$F(1,15) = 8.59, p < .01$. Infants at 18 months also looked longer at the posttest event than at the correlated, $F(1,15) = 29.17, p < .01$, uncorrelated, $F(1,15) = 30.73, p < .01$, and novel events, $F(1,15) = 9.31, p < .01$. The analysis produced no further significant effects.

The analysis for the older age group yielded a reliable main effect for test stimulus event, $F(3,42) = 8.03, p < .001$. Planned comparisons revealed that infants looked significantly longer at the uncorrelated ($M = 9.83$, $SD = 7.67$), $F(1,15) = 5.77$, $p < .05$, and novel stimulus events ($M = 13.40$, $SD = 8.53$), $F(1,15) = 8.28, p < .025$, than at the correlated stimulus event ($M = 5.61$, $SD = 4.34$). Infants looked equally long at the novel and uncorrelated stimuli, $F(1,15) = 2.29, p > .10$. Consistent with the behavior of the infants in all of the experiments reported in this article, the 22-month-olds looked significantly longer at the posttest stimulus event than at the other three test events.

Discussion

Experiment 4 was designed to examine whether infants will generalize a learned correlation among dynamic cues to a previously unseen exemplar. The results are consistent with those found in Experiment 1 in that infants at 22 months of age recovered visual attention to the uncorrelated stimulus relative to attention to the correlated stimulus, whereas infants at 18 months of age looked equally long at the correlated and uncorrelated stimulus events. Recall that the correlated stimulus was not presented during the habituation phase; thus, the 22-month-olds' pattern of behavior could not have resulted from recognition of the correlated stimulus. Rather, infants at 22 months of age showed sensitivity to correlations among dynamic cues embedded in a category context and generalized to a novel instance, whereas infants at 18 months of age did not.

It could be argued that a weakness of the current experiment is that infants' generalization to the correlated stimulus was based on a representation built on one habituation stimulus. However, it is important to bear in mind that the claim here is not that infants in the task necessarily formed two categories on the basis of the feature correlations in the events. Instead, the results in the current experiment, and those in Experiment 1, suggest that infants are capable of extracting the relations among dynamic cues from multiple objects and that they can generalize those relations to a novel instance that exhibits the same correlational structure.

General discussion

The four experiments reported in this article were designed to investigate 14–22-month-olds' sensitivity to correlations between dynamic and static features embedded in a category context. As such, they constitute one of the first systematic examinations of infants' attention to dynamic and static cues while at the same time acting as a replication for classic work by Younger and Cohen (1986). The pattern of results across the experiments suggests that sensitivity to relations among dynamic cues does not emerge until between 18 and 22 months of age. That is, 22-month-olds in Experiments 1 and 4, but not 18-month-olds in the same experiments, looked longer at the uncorrelated stimulus event than at the corrected stimulus event, suggesting that they had extracted the available correlational regularities despite variation of a feature (body type) within and across the categories. The data also suggest, however, that infants at 22 months of age do not attend to any and all regularities available in the input.

These findings are consistent with previous work on this issue that has explored sensitivity to such relations in a discrimination task (Rakison & Poulin-Dubois, 2002). Taken together, these studies suggest that relations between globally and locally dynamic features may be easier for infants to learn and, therefore, may be primary in the development of representations about the movement of objects and entities in the world. Why would relations among dynamic features be primary in infants' representations of object motion? The most likely explanation is that infants' attentional system is biased to orient to movement; consequently, dynamic cues and relations involving such cues stand out in an array of predominantly static features. As discussed earlier, this view is consistent with a body of research showing that even very young infants' attention is drawn to moving stimuli (Dannemiller, 2000; Slater, 1989) and that movement is crucial to the ability to detect an object's properties (Kellman & Spelke, 1983; Werker et al., 1998). It is also consistent with research with adults showing that stimulus salience—in particular, movement rather than, for example, color—plays an important role in attentional capture (Folk et al., 1994). It is not claimed here that infants selectively attend to relations among dynamic features and that, consequently, these relations are more salient in discrimination and category context tasks. Instead, it is posited that in the real world, and analogously in the kind of task used in these experiments, movement in the perceptual array at the global and local levels attracts infants' attention, and relations among features that exhibit such movement are more likely to be encoded than are those that do not exhibit such movement.

This is not to say, however, that infants completely ignore or are unable to encode static features, relations among such features, or relations between static and dynamic features. In cases where there are no dynamic features present, it would be predicted that infants would attend to other relations that are available if they were sufficiently salient. In the work of Younger and Cohen (1986), for example, infants as young as 10 months of age showed sensitivity to relations among static features. One might similarly expect that infants would attend to clusters of correlations between dynamic and static features if they were available. Somewhat surprisingly, then, 22-month-olds in Experiments 3a and 3b showed little evidence that they were sensitive to category-embedded relations between object parts and body type or between object motion and body type. This finding does not mean that infants will fail to demonstrate sensitivity to such relations in all contexts; however, it is possible that by 22 months of age, infants have learned that relations between a static feature and a dynamic feature are not as predictive of an object's category membership (for moving objects at least) as are those between two conjointly dynamic features.

The finding that infants are more sensitive to some correlations than others can be taken as tentative evidence against the *insufficiency of constraints* argument that has been levied against similarity-based formulations of concept coherence (Keil, 1981, 1991; Murphy & Medin, 1985). This argument is centered on the assumption that all information in the environment is equally salient. However, the studies reported in this article, in conjunction with earlier related work (Rakison & Poulin-Dubois, 2002), provide preliminary evidence to the contrary. I speculate that by virtue of the interaction between a perceptual system attuned to orient to particular kinds of information (e.g., motion) and the presence of such information in the array, infants (and presumably older children and adults) selectively attend to certain features and relations among features and ignore others. It is probably no accident that in the real world these features and feature relations tend to be those that are causally relevant and good predictors of category membership. The human mind has evolved to carve nature at its joints in an economical, dynamic, and veridical manner.

The developmental trajectory of infants' sensitivity to correlations observed in the current experiments is parallel to that found in studies on the ability to discriminate stimuli on the basis of relations among dynamic features (e.g., Rakison & Poulin-Dubois, 2002; Werker et al., 1998) and in work on young infants' sensitivity to relations among static features (e.g., Younger & Cohen, 1986). These and other studies (e.g., Quinn, Slater, Brown, & Hayes, 2001) suggest a general developmental progression with regard to infants' processing of objects and events. That is, irrespective of the type of features involved (i.e., static or dynamic), infants are initially unable to parse individual features of objects or events, after which they are able to extract individual features but not relations among those features, and finally they are able to encode relations among features. A plausible explanation for the fact that this progression is observed across a variety of stimuli is that it is a result of increasing sensitivity to features available in the input coupled with the development of increasingly powerful information processing abilities related to associative learning (e.g., enhanced memory capacity).

Oakes and Madole (1999, 2003) proposed precisely such an explanation for changes in early categorization abilities. They argued that increasingly sophisticated categorizing behaviors observed in infants results not from the emergence of new classification processes but rather from ever increasing access to different types of information by way of general development in cognitive, motor, and linguistic skills. For example, Oakes and Madole (2003) suggested that the emerging ability to integrate spatiotemporal information allows infants to learn about functional, or dynamic, properties at around 14–18 months of age.

Finally, the studies presented in this article provide indirect support for the view that infants initially may learn about the characteristic motion properties of animates, and to a lesser extent of inanimates (e.g., regular vs. irregular trajectory), by associating those properties with their causally relevant, conjointly moving object parts. Infants in the current experiments showed sensitivity to relations between moving parts and a motion trajectory and not to correlations between dynamic and static attributes. This seems to be a plausible process for how infants learn about the motion characteristics of objects in the real world. The legs of cats, dogs, and other land mammals are generally in motion when such entities move along an irregular motion path, act as agents, and engage in self-propulsion and other animate-specific motions. Likewise, the wheels of land vehicles rotate when they travel along a regular motion path and are caused to move (by their drivers). This does not mean that infants have no representation for objects around them when they start to learn about dynamic, motion-related properties. There is considerable evidence, for example, that young infants attend to, and categorize on the basis of, object attributes such as shape and texture (e.g., Jones & Smith, 1993), object parts (e.g., Rakison & Cohen, 1999), and facial features (e.g., Quinn & Eimas, 1996). Rather, the claim here is that motion properties become associated with specific object features, and it is not until a later point in development that this relation between dynamic cues begins to include other features of objects that might not be directly related to motion (e.g., body type, facial features).

This view avoids the need to postulate specialized processes to deal with information considered by many to be "conceptual" (Mandler, 1992). Instead, I suggest that infants represent the properties of objects that are available intermittently in the perceptual array (i.e., those related to motion) through the same associative learning mechanism that is involved in the acquisition of constantly available static features. In other words, the representational format of associations involving dynamic features (e.g., agency, self-propulsion) need not be any different from that of associations involving static features (e.g., legs, facial features, shape). Thus, categorization that is often labeled "conceptual" in the literature—because it relies on information not currently available in the sensory array—need not be considered qualitatively different from that thought of as perceptual.

In summary, the experiments reported in this article are among the first to provide evidence that infants are sensitive to the relations between two dynamic features in a category context, namely, object parts and a motion trajectory. The results of the experiments suggest that this ability does not emerge until some point between 18 and 22 months of age. The experiments also suggest that infants are sensitive to some correlations but not to others. These experiments help to further map out the developmental trajectory of infants' ability to attend to correlations among dynamic features. That the developmental progression observed here matches that found in younger infants tested with correlations among static features (Younger & Cohen, 1986) suggests that the same associative learning mechanism may underlie attention to clusters of correlations among dynamic cues during at least the first 2 years of life. An important implication of such a conclusion is that there is no qualitative division between the processes involved in extracting information from static external features and those involved in extracting information from less often observable dynamic features.

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