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ARTICLES

Infants' Developing Sensitivity to Object Function: Attention to Features and Feature Correlations

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When learning object function, infants must detect relations among features—for example, that squeezing is associated with squeaking or that objects with wheels roll. Previously, Perone and Oakes (2006) found 10-month-old infants were sensitive to relations between object appearances and actions, but not to relations between appearances and sounds or actions and sounds. In this article the authors probed the development of infants' attention to feature correlations critical for representing function by testing 8- and 12-month-old infants' ($N = 126$) sensitivity to such relations. Eight-month-old infants learned individual features but were not sensitive to the relations between those features. Twelve-month-old infants were sensitive to the relation among the features and significantly responded to violations in learned relations between object appearances and actions and between appearances and sounds. Thus, across development, infants become sensitive to an increasing number of relations with age, supporting an information-processing account of the development of object function.

Understanding the function of objects is important for learning how to act on and categorize objects. Function is considered central to infants' conceptual development (Keil, 1989; Nelson, 1973, 1974, 1979), yet there is no standard definition for function in the field of psychological research.

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Function has been referred to in terms of the *affordances* for action or use of an object (e.g., handles are meant to be grasped; Gibson, 1988), an actor's *goal* of acting on an object (e.g., a telephone is used to call someone; Buxbaum & Saffran, 2002), and actions on objects that produce a particular *outcome* (e.g., an object squeaks when it is squeezed; Perone & Oakes, 2006).

Defining function in these disparate ways makes comparison across studies and synthesizing findings difficult. This problem is exacerbated by the fact that these are all reasonable ways to define function, and yet infants might learn about each of these kinds of function in different ways. Moreover, function is not a single, unitary construct but is better thought of as determined by a combination of features, both perceptual (e.g., appearance, action, sound) and conceptual (e.g., goals of an actor, intentions of the creator) in nature (see Barsalou, Sloman, & Chaigneau, 2005; Oakes & Madole, 2008, for discussions). Considering function as emerging from the interaction of multiple factors also takes into consideration that an individual's knowledge of and experience with objects and his environment will affect his perception of an object's function.

How do infants come to recognize *function* if it is an emergent feature? Researchers often seem to assume that infants perceive function as a unitary feature of objects. For example, studies have examined how infants categorize or imitate actions when an object's function is demonstrated versus when it is not demonstrated (Elsner & Pauen, 2007; Träuble & Pauen, 2007). However, it is not clear whether infants in these studies attended to individual features, the combination of some features, or the adult-defined *functions* as integrated wholes. Indeed, the features that comprise function are attended to at different points in development. For example, Perone, Madole, Ross-Sheehy, Carey, and Oakes (2008) found that following habituation to an event in which a hand reached toward an object and acted on it (e.g., rolled it), resulting in a sound, 6-month-old infants dishabituated when actions (and the accompanying sounds) changed but not when the appearance of the object changed. Seven-month-old infants dishabituated to both kinds of changes but were more attentive to the actions (and the resulting sounds) than to the appearance of the objects. By 10 months, infants represent all these features—the actions performed on objects, the sound resulting from those actions, and the object appearance (Horst, Oakes, & Madole, 2005; Perone & Oakes, 2006). On the one hand, this might be taken as evidence that infants attended to *function* earlier in development than they did the physical properties of objects. However, because function is inextricably linked to the physical properties of objects (Gibson, 1988)—objects can only be squeezed, rolled, shaken, etc., if their physical properties allow such actions—it is not clear if the physical appearance can be separated from the function.

Other work has revealed that not only does attention to the individual features emerge at different points in development, but attention to the *combination* of features that comprise function develops on a different timescale than does their attention to the individual features. Although by 10 months infants encoded multiple individual features that comprise function, they recognized only associations between actions and particular objects (e.g., purple objects can be rolled); they were insensitive to associations between actions and resulting sounds (e.g., squeezing results in squeaking) or between objects and particular sounds (e.g., purple objects squeak; Perone & Oakes, 2006). Because function involves the combination of the action performed, the physical properties of the object, and the consequence of acting on the object, these combined results suggest that infants do not perceive function as a single unified object feature. Rather, infants' perception of function evolves over development, gradually incorporating more of the features and feature combinations that comprise function. This conclusion is based on studies that have each examined only a part of this developmental trajectory, however. The present investigation provides a more complete and definitive understanding of infants' developing sensitivity to the feature combinations that comprise function. We addressed two key questions: 1) Does infants' perception of function develop from attention to individual features to attention to feature combinations?; and 2) How does infants' sensitivity to the relations among those features develop?

The work just described is consistent with infants first perceiving individual features and later in development combining those features. This general developmental trajectory has been observed in other domains ranging from recognizing features of static objects to causal perception to the labels for spatial relations (see Cohen, 1991; Cohen & Cashon, 2003, for discussion). In a now classic set of studies, Younger and Cohen (1983, 1986) found that 4-month-old infants attended only to object features (e.g., the presence of fluffy tails and elephant noses), whereas 10-month-old infants perceived correlations among those features (e.g., animals with fluffy tails had elephant noses) and formed categories based on those correlations. Extending this developmental trajectory to a higher-level conceptual domain, Oakes and Cohen (1990) observed that although 6-month-old infants learned the individual objects present in an event, it was not until 10 months that infants attended to the complex spatiotemporal features of how the objects moved in the events (i.e., specifying whether or not the first object was a causal agent). Thus, this is a very general developmental pattern that has been observed for a wide range of objects and events. Although work described earlier is consistent with this same developmental pattern in the domain of object function, there are gaps in our knowledge. Although Perone et al. (2008) found that 7-month-old infants were sensitive to changes in an action when accompanied by a sound, no studies have tested infants younger than 10 months on their sensitivity to these features individually. The present investigation filled these gaps.

Our second goal was to examine how infants' sensitivity to feature correlations develops. There are multiple correlations among the features that comprise function, and a full understanding of infants' conception of function requires understanding how their encoding of those multiple correlations develops. Two developmental trajectories for infants' changes in sensitivity to feature correlations have been reported. In some domains, infants initially are nonselective in the associations they learn and they become more selective throughout development. Madole and Cohen (1995), for example, found that 14-month-old infants' sensitivity to the relation between the appearance and function of parts of objects was nonselective, but 18-month-old infants were more selective, presumably because their increased world knowledge was applied to their perception of and attention to the features in these events. Specifically, when tested in a condition in which the correlations were *meaningful* (i.e., the appearance of an object's part was related to that part's function), both 14- and 18-month-old infants learned the correlations. When tested in a condition in which the correlations were *arbitrary* (i.e., the appearance of one part of an object was related to the function of a different part of the object), in contrast, only the younger infants learned the relations between the features. Thus, the younger infants attended to more correlations than did the older infants, who presumably selectively attended only to correlations that were characteristic of relations among features in real objects. Similar developmental trajectories have been observed for infants' sensitivity to arbitrary gestures (Namy, Campbell, & Tomasello, 2004), relations involving self-propulsion (Rakison, 2006), and phonemic distinctions (Stager & Werker, 1997). It is therefore possible that when faced with demonstrations of function, infants initially are nonselective and attend to many different kinds of feature correlations, and become more selective in the particular types of feature correlations they attend to over time.

In other domains, infants initially selectively attend to only a subset of the available correlations, and with development, they become able to detect a broader range of correlations among features. For example, Rakison (2004; Rakison & Poulin-Dubois, 2002) found that infants appear to more easily process relations between two dynamic features than relations between one static and one dynamic feature. A series of studies revealed that 14-month-old infants learned associations between two dynamic features (the presence of moving parts and object motion trajectory), whereas 18-month-old infants also learned associations between those features and the static feature of the appearance of the object body (Rakison & Poulin-Dubois, 2002). Similarly, in the domain of infants' matching of visual and tactile information, 4-month-old infants matched tactile information only with shape, whereas 6-month-old infants matched tactile information with both shape and color (Hernandez-Reif & Bahrick, 2001). In terms of function, this trajectory may be predicted from the suggestion that children's ability to integrate information encoded by dorsal visual processing streams (such as action) with information encoded by ventral visual processing streams (such as color or other identity features of objects) develops unevenly, with the integration of some kinds of features occurring before others (Nardini et al., 2008). Thus, infants may first be more selective and detect few correlations among features, and with age, they would detect increasingly more relations among features.

It is also possible that over development, infants become more constrained in the expectations they have for the relations that exist between features (e.g., because of increased experience) and their processing capabilities increase providing them access to a broader range of relations among features. It is not obvious what developmental pattern would be predicted if these two mechanisms work together in the same domain (clearly, they each operate in different domains), but this may be the explanation if we observed that younger and older infants are each sensitive to only a subset of the feature relations present, but infants at different ages attend to different feature relations.

We addressed these questions using the events that have been previously used to investigate infants' emerging attention to, categorization based on, and conceptions of object function (Horst et al., 2005; Perone et al., 2008; Perone & Oakes, 2006). In these events, a hand reaches for a stationary object, grasps that object, and performs some action on it (e.g., rolling it, squeezing it, or pulling a part of it). When the action is performed, the object apparently makes a sound (e.g., it squeaks, clicks, or moos). The *function* in these events has been construed as a combination of the action performed by the hand on the object and the resulting sound. We first examined whether 8-month-old infants encoded all the features (sound, action, and object appearance; Experiment 1). We next examined 8- and 12-month-old infants' attention to and encoding of the relations between those features using the same design as used in Perone and Oakes (2006) (Experiment 2).

EXPERIMENT 1

Our first step was to examine 8-month-old infants' sensitivity to the appearance, action, and sound in these events. Although Perone et al. (2008) found that 7-month-old infants were sensitive to the appearance of an object and to the sound and action combined, they did not test infants' encoding of just the sound or just the action. Thus, it is possible that infants in that previous study were responding to the sound *or* the action, or that their responding reflected recognition of the change in both features. Experiment 1 provided a fuller understanding of infants' attention to these features at 8 months by testing their encoding of each of the individual features. Although the infants tested in these experiments are designated as 8-month-old infants, they are only 10 days older, on average, than the infants in the Perone et al. work and therefore are essentially the same age group as tested in that previous experiment.

Method

Participants. Eighteen 8-month-old infants ($M = 8$ months, 3 days; $SD = 10$ days; range = 7 months, 18 days to 8 months, 17 days; 7 boys and 11 girls) participated. Nine additional infants were tested but not included in the final analyses due to fussiness ($n = 2$), parental interference ($n = 1$), experimenter error ($n = 3$), or failure to meet the habituation criterion ($n = 3$; see Procedure section below).

All infants in this and Experiment 2 were full term, healthy, and typically developing. Infants' names were obtained from the state office of vital records, and letters were sent to parents in the area. Parents who expressed interest in participating were contacted to schedule an appointment when their infant reached the appropriate age for an experiment. Infants received a small toy for participating.

Twelve of the infants in the sample were White, 1 was Asian, 3 were "Mixed race," 1 was listed as "Other" race, and race was not reported for 1 infant. Across these racial groups, 4 infants were Hispanic. All of the mothers had graduated high school, and nine had at least a bachelor's degree.

Stimuli. The stimulus events were digitized movie clips of videotaped events. Each movie clip was 7 seconds in duration and looped to replay continuously for 35 seconds. Each clip began with a stationary object for approximately 1 second, and then a hand appeared from the right and acted on the object for approximately 5 seconds. Each action was accompanied by a temporally synchronous sound (e.g., as the hand squeezed the object, a squeaking sound was heard). The hand then withdrew and the object remained visible and stationary for an additional 1 second. The objects were approximately 12.75 cm (7.30°) wide by 11.5 cm (6.58°) tall, and the actions occurred in a region approximately 18 cm (10.28°) wide by 14.5 cm (8.29°) high.

Each event involved a different combination of three features: object appearance, an action performed on the object, and a sound apparently resulting from that action. The four object appearances were: *purple*, a round purple object topped by a rounded rectangle with eyes on it; *pyramid*, a multicolored pyramidal-shaped object topped by a yellow sphere; *yellow*, a yellow cube-shaped object with a pink circle on its front and a small toy head on its top; and *pink*, a tube-shaped pink object with a black sphere on each end (see Figure 1). Each of the objects sat on a base with wheels and had one part that could be pulled. The four actions were *squeezing* the center of the object, *rolling* the object back and forth, *inverting* the entire object, and *pulling* part of the object. The four sounds were *squeaking, clicking, mooing*, and *whistling*. Each feature was completely crossed with the other two features, resulting in a total of 64 distinct feature combinations. For example, the yellow object could produce any of the four sounds when squeezed, or it could produce a squeaking noise when any of the four actions were performed on it. In each of the experiments reported here, different infants were habituated and tested with different combinations of the appearance, action, and sound features, with each feature occurring with approximately the same frequency across infants. For example, in Experiment 1, each feature was present during habituation for between two and seven infants during habituation, and no two infants received precisely the same combination of features during habituation.

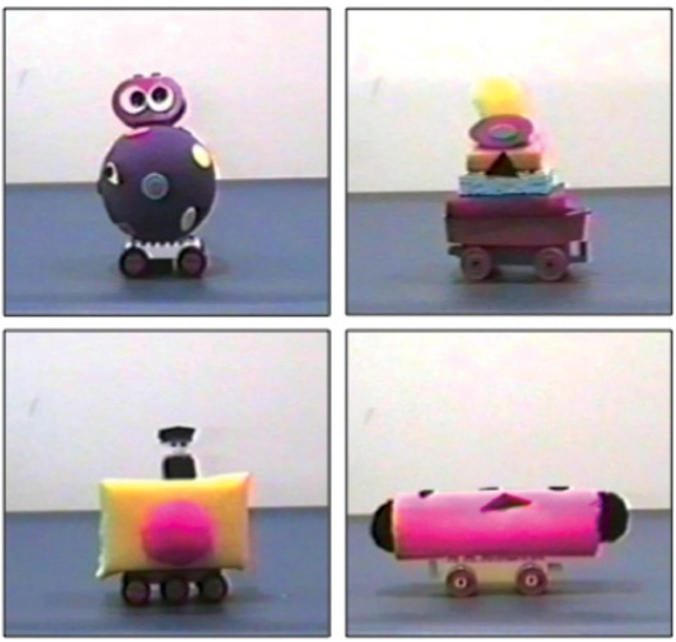

FIGURE 1 Objects in the stimulus events used in all experiments. (Color figure available online.)

Apparatus. Infants were tested in a dimly lit experimental room. Infants sat on a parent's lap approximately 100 cm from a 93.98-cm LCD monitor. The stimulus events were presented on a 61-cm (33.92°) × 46-cm (25.91°) region in the center of the monitor. To minimize bias during the experiment, parents wore glasses lined with felt to occlude their view of the screen and listened to classical music via headphones. A black curtain with openings for the monitor and video camera hung from the ceiling to divide the room. A trained observer sat behind the curtain and observed the infant on a television monitor connected to the video camera. The observer used an Apple G5 computer and specialized software (Cohen, Atkinson, & Chaput, 2004) to present the stimulus events on the monitor and record the duration of infants' looking on each trial.

Design and procedure. Infants were habituated to a single event in which an object was acted upon and a sound was produced. Trials were infant controlled. Prior to each trial, an attention-getting stimulus—a looming circle accompanied by an intermittent chirping—appeared at the center of the monitor. When the observer determined that the infant fixated the attention-getter, he or she pressed a computer key that ended the attention-getter and initiated the stimulus for the trial. When the infant fixated the stimulus, the experimenter pressed and held a second computer key to record the duration of looking. Trials continued until the infant looked away for 1 second (following at least 1 second of looking) or when 35 seconds had elapsed. If the infant did not look at the stimulus in the first 10 seconds, the trial ended and was repeated—this procedure ensured that infants had the maximum time to look at a trial, and that trials that were initiated as infants were distracted from the stimulus display did not adversely affect our measurement of habituation. A second trained observer recorded looking times from the video for 28% of the infants in the experiment. Agreement between the observers for the duration of looking on each trial was high, average $r > .99$, and the mean difference in looking on each trial was low, average $M < 0.69$ seconds.

Habituation was determined by comparing overlapping blocks of 3 trials (i.e., looking on Trials 1 through 3 was compared to looking on Trials 2 through 4, Trials 3 through 5, and so on), and thus infants could habituate in a minimum of 4 trials. The habituation phase continued until looking time on any block of 3 trials decreased to 50% of the looking time on the first 3 trials, or until a maximum of 18 trials had been presented. Infants who completed all 18 trials were only included in the final analyses if the duration of their looking on the last block (Trials 16 through 18) was 50% or less of the duration of their looking on the first block (Trials 1 through 3). Once the habituation criterion was met, or all 18 trials had been presented, we presented infants with five test events designed to assess their learning of the individual features: a *familiar* test event that was identical to the event seen during the habituation phase, an *appearance change* event in which the familiar action and sound from the habituation event were presented with a novel object appearance, an *action change* event in which the familiar object and sound were paired with an unfamiliar action, a *sound change* event in which the familiar object and action were paired with an unfamiliar sound, and a *completely novel* event that consisted of a novel object, action, and sound. The familiar test event was always presented immediately after the infant reached the habituation criterion to provide a measure of baseline looking. The appearance change, action change, and sound change events were always presented next, with order counterbalanced across infants (between two and four infants received each of the six possible orderings of these three events). The completely novel event was always presented last.

Results and Discussion

In all the experiments reported here, we only included in the analyses infants who met the habituation criterion (see Oakes, 2010). On average, infants required 9.17 trials to meet the habituation criterion (see Table 1). To confirm that infants actually habituated, and to establish that the familiar test was a good baseline for assessing infants' dishabituation, we first conducted a series of paired *t*-tests, two-tailed, comparing infants' looking during the familiar test to infants' looking during habituation, and comparing infants'

TABLE 1

Number of Trials to Reach the Habituation Criterion and Duration of Looking (in *Seconds*) for Habituation Trials, Familiar Trials, and Novel Trials for Experiments 1 and 2, by Age and Experimental Condition

Experiment	*Age*	*Trials to criterion*	*First block*	*Criterion block*	*Familiar test*	*Novel test*
Experiment 1	8	9.17 (4.50)	19.60 (8.19)	7.16 (3.61)	7.33 (6.78)	13.56 (9.20)
Experiment 2						
Appearance/Action	8	13.11 (4.07)	23.58 (8.91)	8.25 (3.46)	6.80 (5.87)	21.76 (12.85)
Appearance/Sound	8	12.67 (3.43)	21.57 (9.09)	6.96 (3.06)	4.84 (2.93)	16.96 (12.15)
Action/Sound	8	12.89 (4.01)	22.13 (9.41)	7.30 (3.74)	8.03 (6.53)	20.87 (9.95)
Appearance/Action	12	10.67 (4.17)	19.31 (7.53)	6.77 (2.45)	5.59 (5.09)	27.02 (8.32)
Appearance/Sound	12	12.67 (4.31)	24.78 (7.42)	8.85 (3.98)	7.11 (7.04)	22.68 (10.41)
Action/Sound	12	12.44 (3.07)	23.05 (7.74)	8.13 (3.01)	6.73 (3.84)	21.07 (11.33)

Note. Values in parentheses are standard deviations.

looking to the novel test and their looking to the familiar items (see Table 1). Infants' looking to the familiar test event was not different from their looking during the criterion block (i.e., the block of three trials in which infants' looking was 50% of their looking during the initial block), $t(17) = 0.10$, $p = .92$, $d = 0.02$. In addition, infants looked significantly longer to the completely novel test event than they did to the criterion block, $t(17) = 5.10$, $p < .0001$, $d = 1.20$, or the familiar test event, $t(17) = 4.60$, $p < .001$, $d = 1.09$. In summary, these comparisons confirmed that the infants in Experiment 1 indeed habituated to a repeatedly presented stimulus, their looking to the familiar test reflected this level of habituation, and they recovered their attention to novelty.

Our primary analyses focused on infants' looking to the familiar and change test events. Infants' responding to these tests is presented in Figure 2. Clearly, infants responded to all the changes in the individual features—their looking to each of the events involving a change in one feature was longer than their looking to the familiar test event. Comparisons of the mean looking time to each novel event and the familiar test event with two-tailed t-tests confirmed this impression. Compared with their looking to the familiar test event, infants looked significantly longer to a change in the appearance of the object,

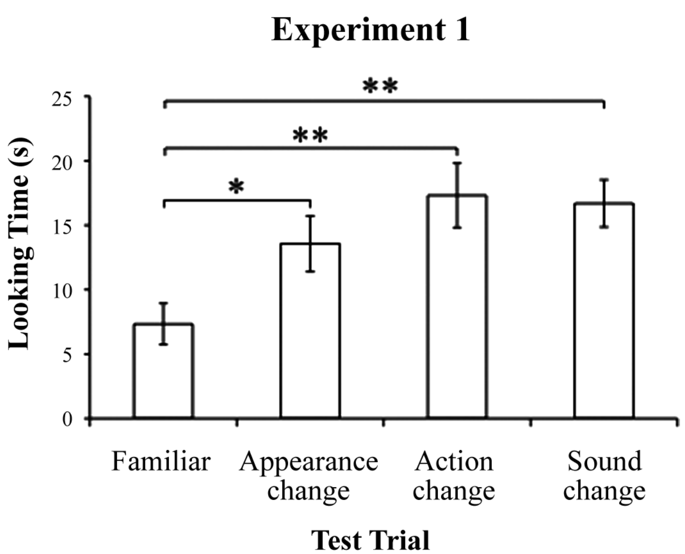

FIGURE 2 Mean looking time to familiar test event and events with changes in individual features by 8-month-old infants in Experiment 1. Significant increases in looking to novel stimuli relative to the familiar test are indicated by an asterisk ($^{*}p < .05$, $^{**}p < .01$). Error bars represent ± 1 Standard Error (SE).

$t(17) = 2.51$, $p < .05$, $d = 0.59$, to a change in the action, $t(17) = 3.63$, $p < .01$, $d = 0.86$, and to a change in the sound, $t(17) = 3.48$, $p < .01$, $d = 0.82$. Twelve infants (67%) looked longer to the appearance change test event than the familiar event, binomial probability, $p = .24$; 17 infants (94%) looked longer to the action change test event than the familiar event, binomial probability, $p = .0001$; and 15 infants (83%) looked longer to the sound change test event than the familiar event, binomial probability, $p = .008$. Thus, infants at this age are sensitive to the individual features of an event.

It is interesting to note that infants were somewhat less responsive to changes in the object appearance than to the action or sound. This pattern is consistent with other studies showing that infants at this age are more attentive to the dynamic properties of events, such as action, than to relatively static properties, such as object appearance (Bahrick, Gogate, & Ruiz, 2002; Bahrick & Newell, 2008; Perone et al., 2008). We did not find here that infants' dishabituation to a novel appearance was significantly less than their dishabituation to a change in action, $t(17) = 1.37$, $p = .19$, $d = 0.32$, or to a change in sound, $t(17) = 1.07$, $p = .30$, $d = 0.25$. Thus, although infants' dishabituation to the change in appearance was not as robust as their dishabituation to other kinds of changes, infants clearly did attend to and encode appearance information and could discriminate the different appearances used here.

EXPERIMENT 2

Experiment 1 showed that infants at 8 months recognize the individual features in these events. One of our primary goals was to establish whether infants first attend to the features in these events and only later in development attend to the correlations among the features. Results of Experiment 1 show that children are attending to each individual feature prior to the age of 10 months, but these results do not inform the developmental trajectory of children's sensitivity to correlations among these features. Our second goal was to address the question of whether infants initially are nonselective and broad in the feature correlations to which they attend, gradually becoming selective, or whether infants initially are selective in the feature correlations to which they attend. To address both of these goals, Experiment 2 examined whether 8- and 12-month-old infants are sensitive to any of the possible feature correlations between object appearance, action, and sound in these events. If infants first attend to the features and only later attend to the correlations, 8-month-old infants in Experiment 2 should be insensitive to the relations among the features, and 12-month-old infants, like the 10-month-old infants tested by Perone and Oakes (2006), should be sensitive to at least some of those relations. Moreover, because 10-month-old infants previously have been shown to attend only to the correlation between the action and appearance in these events (Perone & Oakes, 2006), if infants are initially nonselective in Experiment 2, 8-month-old infants should attend to more feature correlations. If, however, sensitivity to correlations among features develops gradually, we would expect 12-month-old infants to attend to more feature correlations than 8-month-old infants or the 10-month-old infants tested by Perone and Oakes (2006).

Method

Participants. One hundred and eight infants participated, 54 at 8 months ($M = 8$ months, 5 days; $SD = 9.28$ days; range = 7 months, 15 days to 8 months, 19 days; 31 boys and 23 girls) and 54 at 12 months ($M = 12$ months, 19 days; $SD = 9.69$ days; range = 12 months, 4 days to 13 months, 3 days; 30 boys and 24 girls). Fifty-eight additional infants were tested (29 at each age), but their data were not included in the final analyses due to fussiness ($n = 13$), parental interference ($n = 11$), experimenter error ($n = 2$), ceiling looking on the familiar test ($n = 4$), and failure to meet the habituation criterion ($n = 27$; see Procedure section below). None of the infants participated in Experiment 1, and none of the infants were tested both at 8 and 12 months for Experiment 2.

Infants were recruited as in Experiment 1. Seventy-seven infants were White, 4 were Asian, 2 were Black, 1 was American Indian, 18 were "Mixed race," 2 infants were reported as "Other" races, and race was not reported for 4 infants. Across these racial groups, 24 infants were Hispanic. One hundred and five mothers had graduated high school, and 76 had at least a bachelor's degree.

Stimuli and apparatus. The stimuli and apparatus were the same as in Experiment 1.

Design and procedure. In this experiment, infants were habituated to two events in which one feature was the same (e.g., both shared the *purple* object appearance) and the other two features covaried (e.g., on half the trials, the object was squeezed and produced a squeaking sound, and on the other trials, it was rolled and produced a clicking sound). One of the two events was presented on each habituation trial. The events were presented in pseudo-random order, with the constraints that 1) each event was presented twice in each block of four trials, 2) the same event was not presented on more than two trials in succession, and 3) the same event was presented on the last trial of each block (i.e., on Trials 4, 8, 12, and so on). These constraints ensured that infants were equally familiar with each of the four features involved in the correlations, that they did not habituate over a sequence of trials to one of the two events, and that the last habituation event was the same regardless of the block in which infants reached the habituation criterion. The familiar test event (see below, this section) was the event not shown on this last trial.

To further ensure that infants were equally familiar with both events and all features, we used nonoverlapping blocks of 4 trials to calculate habituation. That is, looking on Trials 1 through 4 was compared to looking on Trials 5 through 8, Trials 9 through 12, and so on. Although meeting the habituation criterion is more difficult in this procedure (and as a result the attrition due to failing to meet the habituation criterion is slightly higher when using this procedure), using nonoverlapping blocks is critical to ensure that infants have equal exposure to all the feature values and both feature combinations presented during habituation. The habituation phase continued until looking time on any block of 4 trials decreased to 50% of the looking time on the first 4 trials, or until a maximum of 20 trials had been presented. As in Experiment 1, infants who received all 20 trials were only included in the analysis if their looking time during the last block (Trials 17 through 20) was 50% of their looking time during the first block (Trials 1 through 4).

Once the habituation criterion was met, we assessed infants' learning of the feature correlations in these events using the *switch design* (Werker, Cohen, Lloyd, Casasola, & Stager, 1998). Infants saw three test events. In the *familiar test*, infants saw one of the two events seen during habituation (the one *not* shown on the last habituation trial). In the *switched test*, infants saw one previously unseen test event in which the two features that were correlated during habituation were "switched"—the feature values were combined in a new way. This switched test event was designed to assess whether infants learned the correlation between the features present during habituation. It involved familiar features in a new combination (for example, the object was squeezed and it clicked). Importantly, the constraints we imposed during habituation ensured that each of these individual features was equally familiar—each was presented on precisely half of the habituation events. What was novel in this event was that these features had never been experienced together in the same event. Thus, infants will treat this switched event as novel only if they encoded not just the individual features but also how those features were combined. The order of the familiar event and switched event was counterbalanced across infants. Note that because of the constraints on the order described above, when the familiar test came first, it was always preceded by the other familiar event; infants' looking to the familiar test will therefore not be artificially low because they had just seen that event on the previous trial. Finally, infants were presented with a novel event in which all three features (object appearance, action, and sound) were novel.

Each infant was randomly assigned to one of three experimental conditions that differed in which features were correlated during habituation: 1) *appearance/action*, 2) *appearance/sound*, or 3) *action/sound* (see Table 2). In the *appearance/action* condition, the appearance and action were correlated and the sound was constant; both habituation events shown to any infant in this condition featured the same *sound*, but they had different combinations of object appearances and actions produced on the objects. For example, an infant might be habituated to the events of the purple object that squeaked when it was squeezed and the pink object that squeaked when it was rolled. The switched test event in this condition had a novel combination of appearance and action; for an infant habituated to the two events just described, the switched event was either of the purple object that squeaked when it was rolled or the pink object that squeaked when it was squeezed. In the *appearance/sound* condition, the appearance and sound were correlated and the action was constant. Thus, the two habituation events featured the same *action* but two different combinations of object appearances and sounds. For example, an infant might be habituated to the events of the purple object squeaking when squeezed and the pink object whistling when

TABLE 2
Design of Experiment 2

		Habituation		*Test*		
Condition	*Feature*	*Event 1*	*Event 2*	*Familiar event*	*Switched event*	*Novel event*
Appearance/Action	*Appearance*	Yellow	Purple	Yellow	Purple	Pink
	Action	Roll	Squeeze	Roll	Roll	Pull
	Sound	Click	Click	Click	Click	Squeak
Appearance/Sound	*Appearance*	Yellow	Purple	Yellow	Yellow	Pink
	Action	Roll	Roll	Roll	Roll	Pull
	Sound	Click	Whistle	Click	Whistle	Squeak
Action/Sound	*Appearance*	Yellow	Yellow	Yellow	Yellow	Pink
	Action	Roll	Squeeze	Roll	Squeeze	Pull
	Sound	Click	Whistle	Click	Click	Squeak

Note. In the *appearance/action* condition, object appearance and action are correlated across habituation events, and the outcome (sound) is constant across events. In the *appearance/sound* condition, object appearance and sound are correlated, and the action is constant across events. In the *action/sound* condition, action and sound are correlated and object appearance is constant across events. The particular features included in the table are for illustration purposes only; in reality, all values of the features were used both during habituation and test, and each infant received different combinations of object appearance, action, and sound.

squeezed. The switched test event in this condition featured a switch in the relation between the object appearance and the sound that was produced (e.g., either the purple object that whistled when squeezed or the pink object that squeaked when squeezed). Finally, in the *action/sound* condition, the action and sound were correlated and the appearance was constant. The two habituation events featured the same object *appearance* but different action and sound pairings. For example, an infant might be habituated to two events involving the purple object, one in which it squeaked when squeezed and another in which it whistled when rolled. The switched test event involved a novel combination of an action and sound from each of the habituation events (e.g., either the purple object that squeaked when rolled or the purple object that whistled when squeezed). The completely novel test event in each condition involved three features (appearance, action, and sound) that were completely novel for the infant.

Trials were timed and reliability was established as in Experiment 1. A second trained observer recorded looking times from the video for 27% of the infants. Agreement between the observers for the duration of looking on each trial was high, average $r > .99$, and the mean difference in looking on each trial was low, average $M < 0.68$ seconds.

Results

On average, 8-month-old infants required 12.9 trials and 12-month-old infants required 11.9 trials to meet the habituation criterion. An analysis of variance (ANOVA) conducted on the number of trials needed to meet the criterion with age (8 months vs. 12 months) and condition (*appearance/action, appearance/sound, action/sound*) as between-subject factors did not reveal a main effect of age, $F(1, 102) = 1.67$, $p = .20$, $\eta_p^2 = .02$, or condition, $F(2, 102) = 0.78$, $p = .46$, $\eta_p^2 = .02$. Because only infants who met the habituation criterion were included in the analysis, we know that the decrease in looking is significant.

Infants' looking during the initial habituation block, criterion block, familiar test trial, and completely novel test trial are presented in Table 1. Clearly, infants decreased their looking to the familiar and increased their looking to a completely novel event. To confirm this impression, we compared infants' looking during the last habituation block to their looking to the familiar test event in each condition using a trial type (criterion block, familiar test) × condition × age ANOVA. There was a main effect of trial type, $F(1, 102) = 6.34$, $p = .01$, $\eta_p^2 = .06$, but no interaction between trial type and condition, $F(2, 102) = 0.96$, $p = .39$, $\eta_p^2 = .02$, or trial type and age, $F(2, 102) = 0.28$, $p = .60$, $\eta_p^2 = .003$. The main effect of trial type is explained by infants' lower level of looking to the familiar test event ($M = 6.52$, $SD = 0.52$) compared with the criterion block ($M = 7.71$, $SD = 0.32$), indicating that infants' looking to the familiar event continued to decrease into the test phase. To verify that infants increased their looking to novel items in general, we conducted similar ANOVAs comparing infants' looking to the completely novel test event to their looking to the criterion block and the familiar test event. Each analysis revealed a main effect of trial type, $F(1, 102) = 191.95$, $p < .001$, $\eta_p^2 = .65$, when comparing the completely novel to the criterion block, and $F(1, 102) = 208.90$, $p < .001$, $\eta_p^2 = .67$, when comparing the completely novel to the familiar test, but no interaction between trial type and condition or trial type and age in either analysis, Fs < 3.3. Clearly, as a whole, the infants increased their looking to completely novel events.

Our primary goal was to test infants' learning of the relation between features in each condition. The infants' mean looking times to the familiar and switched test events in each condition are presented in Figure 3. These data reveal that 8-month-old infants looked for approximately the same duration during the familiar and switched test events in each condition, but

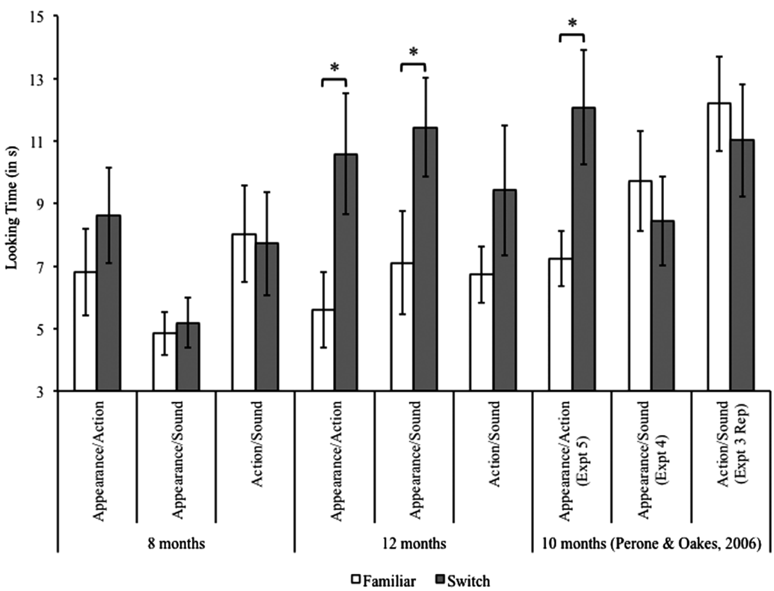

FIGURE 3 Mean looking time to the familiar (white bar) and switched (gray bar) test events by infants in each condition at 8 and 12 months of age. Data from 10-month-old infants tested in Experiments 3 (replication), 4, and 5 as reported in Perone, S. & Oakes, L. M. (2006). It clicks when it is rolled and it squeaks when it is squeezed: What 10-month-old infants learn about object function. *Child Development*, *77*, 1608–1622, are provided for comparison. Significant increases in looking to the switched test event relative to the familiar test event are indicated by an asterisk ($^*p < .05$). Error bars represent ± 1 SE.

12-month-old infants looked longer at the switched than at the familiar event in all three conditions.

We confirmed this impression with an ANOVA on infants' looking to the familiar and switched test events for each condition with age (8 months vs. 12 months) and condition (*appearance/action, appearance/sound, action/sound*) as between-subjects factors. This analysis revealed an overall main effect of trial type, $F(1, 102) = 9.07$, $p = .003$, $\eta_p^2 = .08$, which was qualified by a significant trial type × age interaction, $F(1, 102) = 4.88$, $p = .03$, $\eta_p^2 = .05$. This interaction indicates that 12-month-old infants showed a greater dishabituation to the switched event than did the 8-month-old infants. Indeed, comparison of the infants at the two ages in their looking to each test revealed that 12-month-old infants looked significantly longer at the switched event than did the 8-month-old infants, $t(106) = 2.47$, $p = .02$, $d = 0.48$, but the two age groups did not differ in their looking to the familiar, $t(106) = 0.08$, $p = .94$, $d = 0.02$. Moreover, as a group, averaged across the three conditions, 12-month-old infants looked significantly longer at the switched event than the familiar event, $t(53) = 3.44$, $p = .001$, $d = 0.47$, whereas 8-month-old infants' looking to these two tests did not differ significantly, $t(53) = -0.64$, $p = .53$, $d = 0.09$. This analysis therefore showed that averaged across the three conditions, more robust sensitivity to a switch in the feature pairing was observed at 12 months than at 8 months.

Although no interaction between age, condition, and trial type was observed, we conducted planned comparisons to determine whether there were differences in sensitivity in the different conditions. To evaluate infants' sensitivity to each type of correlation, we conducted two-tailed *t*-tests comparing infants' looking to the switched and familiar events in each of the three conditions separately for each age. None of the comparisons for the 8-month-old infants was significant: *appearance/action* condition, $t(17) = 0.84$, $p = .41$, $d = 0.20$; *appearance/sound* condition, $t(17) = 0.33$, $p > .74$, $d = 0.08$; *action/sound* condition, $t(17) = 0.18$, $p > .86$, $d = 0.04$. Thus, at this age, infants failed to significantly increase their looking to the switch event relative to the familiar test event. Indeed, in the *appearance/action* condition, 11 infants (61%) looked longer at the switched event, binomial probability, $p < .48$. In the *appearance/sound* condition, 7 infants (39%) looked longer at the switched event, binomial probability, $p < .48$. Ten infants (56%) in the *action/sound* condition looked longer at the switched test event, binomial probability, $p = .81$.

The corresponding comparisons for the 12-month-old infants revealed that these older infants looked significantly longer at the switched event in both the *appearance/action* condition, $t(17) = 2.17$, $p < .05$, $d = 0.51$, and the *appearance/sound* condition, $t(17) = 2.32$, $p < .05$, $d = 0.55$. Infants in the *action/sound* condition did on average look longer at the switched test event than the familiar event, but this difference did not meet the threshold for significance, $t(17) = 1.39$, $p = .18$, $d = 0.33$. In the *appearance/action* condition, 15 infants (83%) looked longer at the switched event, binomial probability, $p < .01$. In the *appearance/sound* condition, 13 infants (72%) looked longer at the switched event, binomial probability, $p < .10$. Only 9 infants (50%) in the *action/sound* condition looked longer at the switched test event, binomial probability, $p = 1.0$.

Discussion

The 8-month-old infants tested in this study did not discriminate between events in which individual features (object appearance, action, and sound) were correlated in novel and familiar ways. Their looking to the test events provided no evidence that they were able to learn any of the relations tested. As in Experiment 1, these infants did learn something about the individual features in the events, as evidenced by their significant dishabituation to the completely novel event. Their increased looking at this novel event suggests they detected a change in at least one of the features, and the results of Experiment 1 suggest they may have recognized changes in all three features. Importantly, infants' dishabituation to this novel event indicates that the lack of a significant increase in looking to the switched test does not reflect their inability to learn features of these events under these increased information-processing demands (i.e., when they were habituated to two events rather than just one event as in Experiment 1). Rather, it suggests that as has been found for other types of stimuli (Rakison & Poulin-Dubois, 2002; Younger & Cohen, 1983, 1986), infants first attend to the individual features in events and only later attend to the correlations among those features.

The 12-month-old infants, in contrast, showed evidence of having learned relations among the features in these events. They clearly detected changes in the relation between an object's appearance and an action performed upon it and between an object's appearance and the sound that was produced. They also appeared to be on the verge of demonstrating attention to a switch in the relation between action and sound. Clearly, therefore, the results of the 8- and 12-month-old infants together suggest a developmental trajectory from encoding the individual features of the events to encoding the relations between those features.

How do the data from the present experiment compare to those reported by Perone and Oakes (2006) with 10-month-old infants? To allow a comparison across the two studies, the data from the previous study are presented on the right portion of Figure 3 (recall that the stimuli in this experiment and the previous study were identical, and the procedures were very similar). The 10-month-old infants we tested in the previous experiment clearly show a pattern that represents an intermediate stage of development. Like the 12-month-old infants tested here, the 10-month-old infants tested by Perone and Oakes responded to the association between the action and the appearance. But, like the 8-month-old infants tested here, the 10-month-old infants tested by Perone and Oakes failed to respond to the other associations between the features of the event. Thus, the present results, together with those reported by Perone and Oakes, suggest that infants gradually become sensitive to more relations among the features in these events.

GENERAL DISCUSSION

These results provide answers to our two questions about how infants' representation of the features that comprise function develops. First, we observed the developmental trajectory consistent with a general information-processing model of cognition (Cohen, 1991). As found for other types of stimuli, infants first attended to the individual features in these events, and only later in development did they attend to the correlations among those features. The 8-month-old infants encoded the appearance, action, and sound that resulted from the action and dishabituated when any of these features changed. At this age, infants did not attend to the relations among the features. The 12-month-old infants attended to the relations among the features and dishabituated significantly when feature correlations were violated. Thus, infants appear to first become sensitive to the individual features and later become sensitive to the combinations of features.

Moreover, in combination with previous results reported by Perone and Oakes (2006), our results show that infants are first sensitive to only a few combinations of features, and with development, infants become sensitive to other combinations of features. Our 8-month-old infants were insensitive to any of the feature correlations we tested. Perone and Oakes found that 10-month-old infants were sensitive only to the relation between the action and the object's appearance; at this age, infants did not seem to learn the connection between the sound and the appearance or between the sound and the action. The 12-month-old infants we observed were sensitive to multiple correlations among these features. This developmental trajectory—in which infants are initially narrow or selective in the relations they detect, becoming broader or more inclusive in the relations they detect with age—has been observed in other domains (Hernandez-Reif & Bahrick, 2001; Rakison & Poulin-Dubois, 2002; Younger & Cohen, 1983, 1986). With increased experience, information-processing capabilities, or other aspects of development, infants become aware of an increasingly broad set of connections between the features in events like those used here.

Of course, these data do not answer the question of why sensitivity to the relation between the surface features of an object and the action performed appears to emerge earlier than sensitivity to other relations. Such relations may have privileged status because of their importance for knowing how to act on objects. Often, the appearance of an object conveys information about the affordances of that object (e.g., a handle allows grasping, wheels allow rolling; Gibson, 1988). Indeed, for human adults, information about object appearance and the actions performed on those objects are represented together in the brain (Creem-Regehr & Lee, 2005). In addition, some evidence suggests that the affordances of an object—specifically, whether or not it is graspable—affect how an infant's brain processes that object (Kaufman, Mareschal, & Johnson, 2003). Graspable objects are more likely to be processed by the dorsal "action" stream, and nongraspable objects are more likely processed by the ventral "perception" stream. This difference in processing could help account for infants' relatively early sensitivity to the relation between object shape and action observed in the studies described here.

There are other possible explanations for the developmental priority of the sensitivity to the relation between action and object appearance. For example, there may be a general bias for infants to attend to dynamic features such as actions over static features such as the appearance of objects. Indeed, Bahrick and colleagues observed that 5.5- and 7-month-old infants selectively attend to the actions of an actress, apparently ignoring the features of her face (Bahrick et al., 2002; Bahrick & Newell, 2008). Based on such findings, Bahrick and colleagues propose an attentional salience hypothesis in which actions are more easily and quickly discriminated than static features in events that feature both kinds of information. Thus, infants may be most drawn to the actions in the stimuli events used in our experiments, and as a result, sensitivity to relations involving actions may emerge first developmentally. This hypothesis, however, cannot fully explain the pattern of development we have observed because infants did not selectively attend to *any* relation involving the action. Instead, they attended only to the relation between the action and the appearance of the object, which seems inconsistent with Bahrick and colleagues' attentional salience hypothesis.

Another relevant factor is the modality of the features involved in the correlations. Robinson and Sloutsky's (2004, 2007, 2008) auditory overshadowing hypothesis would predict that correlations between auditory and visual information may be particularly difficult for infants to learn, because for infants, auditory information dominates visual information in multisensory events. Auditory information is more likely to slow down visual processing when the auditory input is unfamiliar, as it was in our stimulus events, and to make the processing of auditory-visual stimuli more difficult (Robinson & Sloutsky, 2007). The processes responsible for the auditory overshadowing effects observed by Robinson and Sloutsky (2004, 2007, 2008) might therefore mean that it is more difficult for infants to learn relations involving auditory information than relations between only the visual elements in the events. Uncovering the contribution of each of these processes is an important goal for future research.

Importantly, these results contribute to our understanding of how infants conceive of object function. Many studies have manipulated object function in an attempt to uncover infants' representations of objects or their categorization processes (e.g., Madole, Oakes, & Cohen, 1993; Träuble & Pauen, 2007). Often in those studies, function is ill-defined. Function is described as a unitary property of an object (i.e., objects *have* a function that can be specified, perceived, and represented). However, the present work adds to a body of literature suggesting that for infants, the components of function are separable, and combining those features is a developmentally sophisticated skill. For infants, function therefore may be quite different than is often assumed, and demonstrating function to infants may not be teaching them the properties of objects assumed by the researchers.

What does this mean for the literature on infants' understanding of, representations of, and categorization based on object function? Clearly, demonstrations of function can have profound effects on infants' cognitions about objects: At 12 months, infants imitate actions that they have observed to have some effect on objects (Elsner & Pauen, 2007); at 11 to 14 months, infants categorize objects differently if they are shown that acting on those objects has some consequence than if the actions are demonstrated but no consequence results (Booth, 2008; Booth & Waxman, 2002; Träuble & Pauen, 2007); and at 10 months, infants recognize commonalities in the actions performed on objects before they recognize other kinds of commonalities in events (Horst et al., 2005). The present results are completely consistent with these findings. However, what the present results suggest is that none of these previous effects likely reflects infants' having detected, learned, and recognized a unitary feature of the object that involved physical properties (e.g., a handle, a hook, wheels), an action performed on the object (e.g., pushing, swinging, tipping), and some consequence (e.g., a bell ringing, sand pouring, clicking sound).

Instead, in these studies, infants might have represented some of these features—perhaps noting some combination of features—and these representations were the basis of infants' imitation, perception, and categorization. For example, infants' imitation of action may be driven by their perception, encoding, and representation of the *actions*, and not their linking of the actions to particular outcomes. Indeed, Elsner and Pauen (2007) found that although 12-month-old infants imitated actions, it was not until 15 months that infants imitated actions to produce particular outcomes. The 12-month-old infants' imitation in this context, therefore, was not motivated by a perception of a unified property of function that includes both the action performed on an object and the resulting outcome. Thus, infants' imitation can be motivated by only some components of what we as adults would consider object function. Similarly, when infants at 10 to 18 months categorize a series of events apparently based on function (Booth, 2006; Horst et al., 2005), they may be detecting similarities in the action performed regardless of the sound or outcome of that action. The point is that what one conceives of as the function of an object emerges from multiple features including the physical properties of the object, the actions of the actor, and the consequence of acting on the object (Oakes & Madole, 2008). What the present studies suggest is that infants' conceptions of function may only gradually incorporate the same multiple factors that we as adults include when we think of object *function*.

In summary, these results add to our understanding of the development of infants' understanding of function. As observed in other domains, infants gradually recognize combinations of the features that comprise function. Importantly, this means that young infants' conceptions of object function are likely quite different from those of older infants, children, and adults. Moreover, by understanding how infants attend to and recognize the combinations of features that together comprise function, we gain a deeper understanding of function and how functional properties are represented across development.

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