

You Go This Way and I'll Go That Way: Developmental Changes in Infants' Detection of Correlations among Static and Dynamic Features in Motion Events

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Four experiments utilizing the habituation procedure examined 10- to 18-month-olds' ability to detect and encode correlations among features in a motion event ($N = 136$). Infants were habituated to two events in which objects—with distinct parts and a distinct body—moved across a screen along a rectilinear or curvilinear motion path. Infants were then tested with one familiar event and three events in which one feature of the object (parts, body, or motion path) was presented in a novel combination with the other features. The results of the experiments revealed that 10-month-olds process independently static features in an event, but do not process correlations among dynamic features; whereas 14-month-olds detect the correlation between an object's parts and its motion trajectory, but only when the movement of parts is correlated with the motion of the object. Further, the data show that 18-month-olds detect correlations between all three features when the parts of the object move, but they detect only the relation between parts and motion path when the parts do not move. It is proposed that infants develop representations for the static and dynamic properties of objects through a sensitive perceptual system that detects individual features, whole objects, and movement properties, and a domain-general associative learning mechanism that encodes independent features and correlations among features.

INTRODUCTION

Infants' ability to classify objects has been the focus of a considerable amount of research over the past 10 years, with a particular emphasis on the formation of superordinate, global, and basic-level categories. As a result of this line of research, it is now generally agreed that within the first 3 to 4 months of life, infants' perceptual systems allow them to form categories of a number of real-world objects (e.g., Behl-Chadha, 1996; Eimas & Quinn, 1994; Quinn & Eimas, 1996). It is also well established that by the second year, infants can form categories that include objects that adults think of as animals, vehicles, furniture, cars, and cows (e.g., Mandler & Bauer, 1988; Rakison & Butterworth, 1998a).

There is considerably greater contention about the processes underlying the formation of such categories after 9 to 12 months of age. In particular, there is debate about how and when infants start to understand that objects possess abilities and characteristics that are nonobvious; for example, whether an object is self-starting, moves along an irregular motion trajectory, or is goal directed. This problem has proven especially intractable because it is not clear which features should be considered as perceptual and which, as nonperceptual. For example, information specifying functional properties such as dogs' barking or motion properties such as self-propulsion are available in the perceptual array, but only intermittently so (Madole & Oakes, 1999; Mandler, 1997). The experi-

ments reported here examined 10- to 18-month-old infants' ability to represent correlations between different kinds of static and dynamic features of objects in motion events. We hypothesized that infants may start to learn about the motion properties of objects by representing the correlation between those properties—how an object moves from point A to point B, for example—and the dynamic features of the objects that are causally related to those motions.

Despite the considerable database of information on infants' categorizing abilities, relatively little is known about when and how infants understand that different ontological kinds possess particular properties and are capable only of certain actions or motions (for a review, see Rakison & Poulin-Dubois, 2001). To compound the problem, previous studies on these issues have focused on people, rather than the broader category of animals, as an example of an animate entity. It has been demonstrated, for instance, that 7- and 9-month-olds associate self-propulsion with people and not with inanimates (Poulin-Dubois, Lepage, & Ferland, 1996; Spelke, Phillips, & Woodward, 1995), and also that 7-month-olds know that a human hand, but not an inanimate object, cannot pick up a block without contact (Leslie, 1984). These results, although demonstrating that infants associate particular actions with people, are not informative about when and, more importantly, how an understanding

develops concerning the motion properties of different object kinds such as animals and vehicles.

Notwithstanding the relative absence of data on this issue, there are a number of theoretical accounts that describe how infants may develop such knowledge. Mandler (1992) proposed that infants possess two systems for developing knowledge about objects: one that deals exclusively with perceptual information that helps to determine what an object looks like and another, more attention-based process of perceptual analysis that leads to concept formation. According to Mandler (1992), perceptual analysis builds the foundation for infants' knowledge about animates and inanimates in that it recodes information into an abstract, meaningful nonperceptual format (called an image-schema) that encapsulates spatial- and motion-related characteristics of objects. For example, the three image-schemas that Mandler believes form the first concept of animacy embody the way that objects begin to move, the way that objects move with respect to other objects, and the trajectory that objects follow. There is, however, an absence of empirical evidence to support the idea that infants extract motion characteristics from animates and inanimates into image-schemas or that these motion characteristics are represented independently from the appearance of the object from which they were drawn.

In contrast to the conceptually based approach proposed by Mandler and others (e.g., Gelman, 1990), a number of researchers have suggested that conceptual knowledge about different object kinds develops through the continual enrichment of perceptual categories (e.g., Eimas, 1994; Quinn, Johnson, Mareschal, Rakison, & Younger, 2001; Rakison, *in press*; Rakison & Poulin-Dubois, 2001). Among these perceptually oriented accounts, it has been suggested that infants begin to learn about the motion characteristics of animate and inanimate entities by attending to functional object parts, as evidenced in categorization studies with the sequential touching procedure (e.g., Rakison & Butterworth, 1998a; Rakison & Cohen, 1999). Functional object parts are thought to be particularly salient because they tend to be large and, perhaps more crucially, because they move (Tversky, 1989). This movement is thought to capture infants' attention, a view supported by evidence that newborns prefer moving objects over static ones (Slater, 1989), and that adults and infants detect an object's properties more easily when it moves (Burnham & Day, 1979; Washburn, 1993; for a more detailed discussion of the role of movement on infants' attention, see Gibson, 1969). Rakison and Butterworth (1998b) speculated that attention to parts—by virtue of their size and movement—leads infants to notice the correlation between those

parts and the motion properties of the object to which they are attached. In the case of different motion trajectories, for example, infants may form representations of the relation between the path of an object's movement (linear versus irregular) and the object parts that are contemporaneously in motion.

Rakison and Poulin-Dubois (2001) extended this view by describing how the acquisition of this kind of correlation between two dynamic perceptual features may lead to the development of knowledge about properties often thought of as conceptual (see also Thelen & Smith, 1994); for example, self-propelled versus caused-to-start motion. They proposed that infants possess a perceptual system that readily extracts static and dynamic features and finds movement particularly salient, and a learning mechanism that is adept at representing correlations among such static and dynamic features. More specifically, Rakison and Poulin-Dubois speculated that infants initially represent an elementary relation between two dynamic features that is formed online and requires the presence of both features in their original, dynamic form to cue retrieval of the correlation. At this point, the strength of the representation is insufficient to allow an inference about the presence or characteristics of one feature of the correlation based on the detection of the other feature (see Munakata, McClelland, Johnson, & Siegler, 1997). For example, after only a few encounters with things that possess legs, infants would not yet expect those things to walk; yet their attention would be drawn to this part-motion relation when it is available in the perceptual array. Over time, the representation of the correlation becomes strengthened such that it is no longer necessary for both dynamic features to be present to instigate retrieval of the correlation. In other words, if infants perceive an object as possessing a particular part, be it moving or not at that time, this would cue retrieval of the motion properties associated with that part. At the same time, these motion properties start to become associated not only with functional parts but also with whole objects and, eventually, categories of objects.

A similar associative learning process has also been proposed to account for aspects of cognitive development other than categorization. In a series of studies by Madole and colleagues (Madole & Cohen, 1995; Madole, Oakes, & Cohen, 1993) infants between 10 and 18 months were habituated to different objects that displayed distinct form-function correlations. In the test phase, infants were shown objects in which these correlations were either intact or violated. Using this general methodology, Madole et al. (1993) found that 10-month-olds attend to form, 14-month-

olds attend to form and function as independent features, and 18-month-olds attend to the relation between form and function. In a follow-up study, Madole and Cohen (1995) found that 14-month-olds were able to correlate form with function when the relation was embodied within different parts of an object. Importantly, the function of objects in the study involved a moving part such as wheels or a treelike shape that revolved.

It has also been suggested that early word comprehension may involve a similar associative link whereby a linguistic form is recognized and connected to a particular object (Oviatt, 1980, 1982; Werker, Cohen, Lloyd, Casasola, & Stager, 1998). Evidence that infants can form such associative links between objects and labels came from a recent series of studies by Werker et al. (1998) that used the "Switch" design in a habituation procedure (see Cohen, 1992; Younger & Cohen, 1986). In this general design, attribute A¹ is paired with another attribute B¹ in one habituation trial, and attribute A² is paired with attribute B² in another habituation trial. In the studies by Werker et al. (1998), for example, one attribute in each trial was a label (e.g., "Neem") and the other was an object (e.g., "a dog"). In the test phase of the study, infants were presented with one trial in which the attribute pairings experienced during habituation were violated (e.g., attribute A¹ with attribute B²) and another in which the attribute pairings remained the same as that experienced earlier. The strength of such a design is that recovery of visual attention to the switch test trial in comparison with the familiar test trial can only result from infants' detection of a new attribute pairing, rather than the introduction of a novel attribute. Results of the studies by Werker et al. revealed that 14-month-olds associated two distinct labels with two distinct objects, but did so only when the objects moved. In contrast, infants younger than 14 months failed to learn the label-object association, although they processed both of the attributes presented in each event.

This is not to say that infants younger than 14 months are unable to detect and encode dynamic intermodal relations. There is evidence, for example, that 7-month-olds are sensitive to arbitrary intermodal relations, such as the relation between temporally synchronous vocalizations and moving objects (Gogate & Bahrick, 1998). Importantly, this ability seems to be somewhat dependent on the presence of a facilitating cue such as, in the case of a sound and object relation, temporal synchrony, intensity shift, or common rhythm. There is also evidence that infants as young as 6 months of age represent associations between dynamic relations with which they have a

great deal of experience. For example, Woodward (1998) found that 7-month-olds associate hands, but not mechanical claws, with goal-directed action; and Tincoff and Juczyk (1999) found that 6-month-olds associated the words "mommy" and "daddy" with the image of their own parents but not with male and female faces in general. In conjunction, the available literature suggests that although infants' associative learning mechanism allows them to learn relations among dynamic stimuli in the first 12 months of life, it is not yet fully operational until the second year (for an in-depth discussion of this issue, see Gogate, Walker-Andrews, & Bahrick, 2001, and the accompanying commentaries).

Although the evidence from the studies outlined above illustrates that infants are adept at representing relations among invariant features in the environment, it remains to be seen whether they do in fact represent the correlation between an object's parts and the various motions that co-occur with those parts. Furthermore, the notion that infants detect correlations between an object's parts and motion trajectories and only later connect whole objects to motion trajectories remains suppositional. A similar trend of processing parts and then wholes has been found in various studies on infants' detection of correlations among static features (e.g., Younger, 1990; Younger & Cohen, 1986), but it is as yet untested whether the same developmental process applies to the acquisition of correlations among dynamic, perceptual cues. If indeed infants are sensitive to part-motion correlations and then extend the correlation to include whole objects, then this may signal the onset of what is thought of as conceptual knowledge about the motion characteristics of different ontological kinds. Finally, the age at which this ability may develop is under debate. The results of sequential touching studies (e.g., Rakison & Cohen, 1999) suggest that infants as young as 14 months associate an object's functional parts with the motion commonly associated with the object and with those parts; for example, legs with walking and wheels with rolling. This is not the same as demonstrating that infants expect functional parts to be associated with the motion trajectory that an object follows, however; for example, moving from point A to point B along a curvilinear or rectilinear path.

The aims of the experiments presented here were threefold. First, the experiments were designed to investigate whether 10- to 18-month-old infants can extract the correlation between an object's moving parts and its motion trajectory from an event in which a number of feature correlations are available. Second, the experiments were intended to test whether

there is a developmental progression whereby younger infants process dynamic events in terms of individual features, then later process those events in terms of part–motion correlations, and subsequently in terms of correlations that encompass whole objects as well as parts. Finally, the studies were designed to ascertain whether it is the movement per se of object parts that draws infants' attention to correlations between those parts and other invariant aspects of an event. In three of the four experiments presented here, the basic Switch design method was used (Gogate & Bahrick, 1998; Werker et al., 1998; Younger & Cohen, 1986). In contrast to previous studies that employed this design, each of the events shown to infants in the present study had three rather than two features that were correlated. The stimuli in each experiment were novel geometric figures with a distinctive body, parts, and motion trajectory. The rationale for using such figures rather than images of real-world objects was that we wished to test the processes that underlie the way in which infants learn about objects and not their existing knowledge. In addition, by using simple geometric figures it was relatively easy to manipulate the different feature relations among the objects.

EXPERIMENT 1

The first experiment presented here was designed to test 14- and 18-month-old infants' ability to attend to correlations that involve dynamic features in motion events, and to examine whether infants in these age groups are biased to attend to particular correlations in such events. Using the infant-controlled habituation procedure, infants were presented with two events, each with one of two objects that moved across a screen. Each object had a pair of distinctive moving parts, a distinctive body, and a distinctive motion path (rectilinear versus curvilinear). Thus, there were a number of correlations among features in the events to which infants could attend; namely, the correlation between parts and motion path, parts and body, body and motion path, or all three of these features (parts–body–motion path). In the test phase, infants were presented with four similar events, but in each event, the parts, body, or motion of the object was switched with that belonging to the object in the other event. Following research on the development of infants' ability to attend to form–function relations (e.g., Madole & Cohen, 1995), it was predicted that 14-month-old infants would attend only to the correlation between moving parts and motion trajectory, whereas 18-month-old infants would attend to the correlation among all three features.

Method

Participants. The participants were twenty-eight 14-month-old and twenty-eight 18-month-old healthy, term infants. In the 14-month-old group there were an equal number of males and females. In the 18-month-old group there were 11 girls and 17 boys. The majority of infants were White and of middle socioeconomic status. Data provided by 49 additional infants were not included in the final sample, due to failure to habituate ($n = 20$), fussing or crying ($n = 19$; 13 infants at 14 months and 6 at 18 months), experimenter error ($n = 7$), and technical problems ($n = 3$). Infants were recruited through birth lists provided by governmental health agencies.

Stimuli. The habituation and test stimuli were computer-animated events created with Macromedia Director 5.0 for the personal computer (PC) in which an object moved from left to right across a screen. Each object consisted of two features, namely, a body and a pair of external parts (see Figure 1). The body of one object was blue and rectilinear, and the body of the other object was red and curvilinear. In addition, to make the objects more interesting to infants, the blue body had a light blue internal star shape and the red body had a light green internal ring shape. The external parts of an object were either yellow armlike shapes that moved up and down, or they were green diamond shapes that moved in and out. The parts always appeared in pairs such that there was one on each side of the body of an object. The movement of the parts was equivalent in terms of the distance that they moved vertically or horizontally, and the time it took for a complete cycle of motion to be made (up and down for yellow armlike parts, in and out for green diamond parts).

There were two distinct motion paths that an object could follow as it moved across the computer screen from left to right. One of the motion paths was curvilinear, with the object moving up and down twice in each event, and the other motion path was rectilinear,

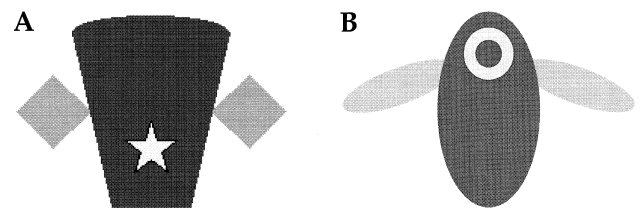


Figure 1 Examples of stimuli used in Experiments 1, 2, 3, and 4. (A) Body was blue with a light blue internal star shape; external diamond shapes were green. (B) Body was red with a light green internal ring shape; external armlike shapes were yellow.

with the object moving up and down four times in each event (see Figure 2). The length of time it took each event to be completed was the same for the two motion paths (8 s), and each event could be repeated up to three times per trial. Individual presentations of each event were separated by a blue screen that descended and ascended over a period of approximately 2 s. For simplicity, the two body features are referred to by their color (red or blue), as are the two part features (yellow or green; see Figure 1 legend). The two motion paths are referred to by their trajectories (rectilinear or curvilinear). Each body (blue or red) could appear with each set of parts (yellow or green) and each motion path (curvilinear or rectilinear). Note that it is important to distinguish between the idea of global motion, which refers to the objects' movement paths (i.e., whether they move along a curvilinear or rectilinear trajectory) and local motion, which refers to the movement of the objects' parts (i.e., whether they are yellow armlike shapes that move up and down or green diamonds that move in and out).

Design. There were four pairs of two events that could be used as habituation stimuli. The four pairs allowed for full counterbalancing of parts–body–motion combinations. For each age group, seven infants were randomly assigned to each one of the four pairs. During habituation, infants might have seen, for example, an object that moved on a rectilinear motion path and possessed a red body and yellow parts and an object that moved on a curvilinear motion path and possessed a blue body and green parts (see Table 1).

After habituation, infants were presented with four test events. In one test event, the parts switch, infants saw one of the same events as that experienced during habituation except that the parts of the object were replaced with the parts of the other object seen during habituation. Thus, following the habituation trials described above, an infant in the parts switch

Table 1 Example of Two Habituation Stimuli and Three Test Stimuli Presented to Infants in Experiments 1, 2, and 3

	Body	Global Motion	Parts	Local Motion
Example habituation trials				
Trial 1	Red	Rectilinear	Yellow	Up/down
Trial 2	Blue	Curvilinear	Green	In/out
Example test trials				
Parts switch	Red	Rectilinear	Green	In/out
Body switch	Blue	Rectilinear	Yellow	Up/down
Motion switch	Red	Curvilinear	Yellow	Up/down
Familiar	Red	Rectilinear	Yellow	Up/down

test would see an object with a red body and green parts moving on a rectilinear motion path. Note that during the test trial the parts moved in the same way as that observed during habituation; that is, the yellow parts always moved up and down and the green parts always moved in and out. In another test event, the body switch, infants were presented with one of the same events experienced during habituation except that the body of the object was switched with the body of the object in the other habituation event. For example, again referring to the habituation stimuli described above, infants would see an object with a blue body and yellow parts moving on a rectilinear trajectory. In a third test trial, the motion switch, infants saw the same body and parts paired together but moving along the motion path that belonged to the other object during habituation. Thus, an infant who was habituated to the two stimuli described above would be presented with an object that possessed a red body and yellow parts moving on a curvilinear motion path. As a fourth test trial, infants were presented with a familiar trial that was identical to one of the two events presented during the habituation phase of the experiment.

To help clarify what a recovery in infants' looking times (relative to the familiar test trial) in the three switch test trials may mean, it is helpful to consider the correlations among features that remain unchanged and the correlations among features that are violated in each switch trial. Table 2 lists the unchanged and violated correlations in the three switch test trials. If infants attended to the relation between parts and motion, they would be expected to look longer at the parts switch and the motion switch test trials than at the familiar test trial. On the other hand, if infants attended to the relation between parts and body, they would be expected to recover visual attention during the parts switch and the body switch test trials. If infants attended to the relation between body

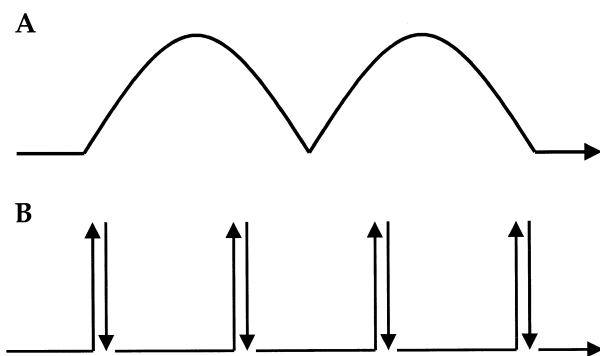


Figure 2 Motion paths of objects in Experiments 1, 2, 3, and 4. (A) Curvilinear motion path; (B) rectilinear motion path.

Table 2 Correlations that Remained Unchanged and Correlations that Were Violated in Each Test Trial

Switch Test Trial	Unchanged	Violated
Parts	Body–global motion	Parts–body Parts–global motion
Body	Parts–global motion	Parts–body Body–global motion
Motion	Parts–body	Parts–global motion Body–global motion

and motion, they would be expected to increase looking to the body switch and the motion switch test trials relative to the familiar test trial. Finally, if infants attended to relations among multiple features, they would be expected to recover visual fixation to all three test trials.

A number of predictions were made about 14- and 18-month-olds' looking times in the switch test trials. First, relying on the idea that dynamic features are particularly salient for young infants and the fact that younger infants have demonstrated that they know that legs "walk" and wheels "roll" (Rakison & Cohen, 1999) but not that "animals" walk or that "vehicles" roll, it was predicted that 14-month-olds would detect and encode the correlation between moving object parts and the motion path of the object, but not the correlation between whole objects or bodies of objects and the motion path of the object. Second, because older infants have suggested that they know that the abilities to walk and roll are linked with animals and vehicles, respectively, it was predicted that 18-month-olds would detect and encode all of the feature correlations in the event and would therefore recover visual attention in all three of the switch test trials.

Apparatus. Each infant was tested individually in a small, quiet, dimly lit laboratory room (approximately 3 m × 2.5 m). During testing, events appeared on a 43-cm computer monitor approximately 80 cm from the infant's face. The monitor stood on a table and was not covered or hidden in any way. Behind the monitor there was a black, three-sided wooden structure that spanned from the floor to the ceiling and from left to right across the infant's visual field. A closed-circuit television camera was situated above and behind the monitor and was hidden from view. This camera allowed the experimenter to observe and code online the infant's visual response to the stimuli. In addition, the camera was used to record each infant's behavior so that a second coder could later establish a reliability score. An Apple G3 computer was used to control the experiment.

An experimenter behind the three-sided wooden construction observed the infant's visual gaze using a television monitor. The experimenter recorded the duration of a gaze by pressing a preset key on a computer keyboard when the infant looked at the visual stimulus and by releasing the key when the infant looked away. Before the very first trial and after each trial, a green circular light on a dark background appeared on the screen to attract the infants' attention. The green circle expanded and contracted, and there was a bell sound that was presented simultaneously. Once the infant's gaze returned to the computer monitor, the experimenter began the next trial by pressing a different preset key on the computer keyboard. Based on the experimenter's key presses, the computer recorded the visual fixations for each trial and determined when the habituation phase had ended and the test phase had begun. The experimenter was blind to the specific trial presented and, once five trials had elapsed, whether any trial was a habituation or test trial.

Procedure. Each infant was placed facing a computer monitor in a baby chair attached to a table. A parent, who was instructed to remain neutral and not interact with the infant verbally or otherwise, sat approximately 60 cm behind the baby chair.

Infants were tested using a version of the criterion habituation procedure. During the habituation phase, infants were presented with two different events that had distinct part–body–motion combinations. The order of the habituation trials was semi-random, with no event appearing sequentially more than twice. Each trial continued until the infant looked away for longer than 1 s or until 30 s of continuous looking had elapsed. The habituation phase continued until an infant's visual fixation time decreased to a set criterion level or until a maximum number of 16 trials were presented. The habituation criterion was met when an infant's looking time on a block of four successive trials was less than 50% of the total looking time on the first four trials. Once this criterion was reached, or when 16 trials had been completed, the four-trial test phase began. The order of the four test trials was counterbalanced across the infants in each age group. Infants who failed to habituate within 16 trials were eliminated from the final analysis.

Coding and analyses. The experimenter coded online the infant's looking time by pressing and releasing the preset computer key. The computer, which recorded the length of each gaze duration and determined when the habituation criterion was reached, was accurate to within .125 s. A second judge, who was trained until coding times were within .3 s of the experimenter, independently coded 25% of the in-

infants' videotaped visual responses during the habituation and test trials. Interobserver reliability was determined by calculating a Pearson product-moment pairwise correlation of the scores coded online and the videotaped trials, and by calculating a mean difference in looking time coded on each trial. Overall coder reliability for infants' looking times in Experiment 1, and in the other three experiments presented here, was $r > .92$, and the mean difference in all three experiments for infants' looking time on each trial was less than .25 s.

Results

To analyze infants' looking times during the test trials, repeated-measures ANOVAs (parts switch versus body switch versus motion switch versus familiar) were performed for the 14- and 18-month-olds' data. (For excellent discussions of the validity of this procedure, and for arguments against the need to perform omnibus ANOVAs on such data, see Howell, 2002; Wilcox, 1987.) The analysis for the 14-month-olds revealed that looking times differed across the four test trials, $F(3, 81) = 3.18, p < .05$. In this, and the other experiments reported in this article, paired samples t tests with Bonferroni correction (one-tailed) were used to examine whether infants' looking times in each of the three switch test trials differed significantly from that during the familiar test trial. As predicted, the 14-month-olds looked significantly longer at the parts switch ($M = 9.88$) than at the familiar test trial ($M = 5.54$), $t(27) = 2.26, p < .017$. There were no other significant differences for the 14-month-olds' looking times between the other switch test trials, body switch: ($M = 6.84$), $t(27) = 1.03$; motion switch: ($M = 6.09$), $t(27) = .66$, and the familiar test trial ($M = 5.54$). These results are shown in Figure 3.

The analysis for the 18-month-olds indicated that looking times were not equivalent across the four test trials, $F(3, 81) = 2.79, p < .05$. Planned comparisons revealed that, as predicted, the 18-month-old infants looked significantly longer at the parts switch ($M = 7.91$), $t(27) = 2.31, p < .017$, the body switch ($M = 7.34$), $t(27) = 3.46, p < .001$, and the motion switch ($M = 7.34$), $t(27) = 2.63, p < .01$, than at the familiar test trial ($M = 4.60$).

Discussion

The pattern of results in Experiment 1 revealed that, as predicted, 14-month-olds looked longer during the parts switch test trial than during the familiar test trial, but they did not look longer at the other two switch test trials than at the familiar test trial. In con-

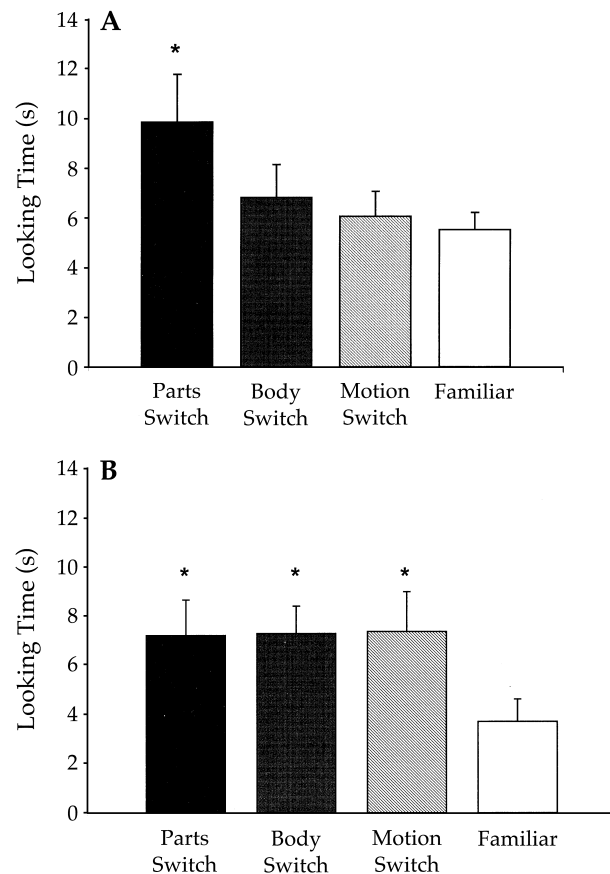


Figure 3 Mean looking time and standard errors during the four test trials for (A) 14- and (B) 18-month-old infants in Experiment 1. The parts of the objects moved in this experiment. *Looking times for this event were significantly different than looking times for the familiar event, at least $p < .034$, one-tailed.

trast, 18-month-olds recovered visual attention during all three switch test trials. How are these results to be interpreted? Given that 14-month-olds recovered visual attention to the parts switch, one might expect that they would have recovered visual attention to the motion switch test trial because the parts–motion path relation was also violated in that event. Infants, however, failed to recover visual attention during the motion switch test trial. One feasible explanation for this finding is that the observed behavior in the parts switch test trial was attributable to infants' detection of the violation in the correlation between parts and body rather than the correlation between parts and motion path. In other words, in the motion switch test trial the correlation between parts and body was not violated, whereas in the parts switch test trial it was. This explanation was discounted, however, because infants failed to increase looking time during the ob-

ject switch test trial; that is, they did not recover visual attention when the correlation between parts and body was violated and the correlation between parts and motion path was not violated.

What then could explain this seemingly anomalous finding? We believe that the attention-grabbing nature of the parts movement caused the 14-month-olds to notice not only the part–motion correlation but also, to a lesser extent, the part–body correlation. Although infants detected in some way the correlation between parts and body, we propose that they did not fully learn this relation. It is likely that infants perceived whether the part–body correlation was violated before they perceived whether the part–motion correlation was violated; that is, the relation between parts and body was evident from earlier in the event. It is therefore possible that because the correlation between parts and body was not violated during the motion switch test trial, infants detected this nonviolation and failed to attend to the remainder of the event. In the parts switch test trial, however, both the correlation between parts and motion path and the correlation between parts and body were violated. In this case, infants would perceive the violation in the parts–body correlation early in the event and would continue to attend to it. This view is supported by the results. Eight infants looked away from the motion switch event before the novel motion was displayed (approximately 3.5 s), whereas 5 infants looked away from the parts switch event and the body switch event within the same time frame. More compelling, 15 infants on the motion switch test trial and 14 infants on the familiar test trial looked away from the event before the object completed one full vertical motion (moving up and down, approximately 5 s). In comparison, only 7 infants looked away from the event in the same time frame on the parts switch test trial. Thus, for the two events in which the part–body relation was not violated, infants may have looked away from the events before the novel motion occurred.

These data suggest that at 14 months, infants are biased to attend to certain relations among features in a motion event. Consistent with previous evidence concerning the salience of movement on infants' attention (Burnham & Day, 1979; Gibson, 1969; Slater, 1989), the results imply that the younger infants, given a number of features to which they could attend, focused on the two dynamic features. At a more general level, the data provide preliminary evidence that in processing events, infants may acquire knowledge about the movement capabilities of different entities by attending to the motion trajectory of an object and the parts that concurrently are in motion. It is

worth noting that these results do not clarify to which aspect of the objects' parts infants attended. For example, it is possible that infants correlated the shape, the color, or the local motion of the parts with the movement path of an object, or it is possible that they represented the relation between more than one of these features and the movement path of the object. We think it most likely that the movement of the parts was fundamental in drawing infants' attention to them and subsequently to the relation between the parts and the motion path; infants may have learned, for example, that "those things with parts moving up and down tend to travel curvilinearly." It is also quite possible that the appearance of the parts was also involved such that infants, for example, learned that "those things with yellow, armlike shaped parts moving up and down tend to travel curvilinearly." This issue is addressed partially in Experiment 2. Nonetheless, the important point here is that the data suggest that infants detected and encoded some aspect of the relation between dynamic parts and the movement trajectory of objects, and they did not attend to the other feature relations in the events.

It is worth highlighting that in this, and the other experiments presented in this article, the number of infants who were excluded from the analyses was high but comparable with the dropout rates in other studies with a similar experimental procedure (e.g., Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Werker et al., 1998). A number of infants failed to complete the study (i.e., fussed or cried), perhaps because they were simply unresponsive to the relatively passive habituation task, a problem that is rife in visual-paradigm studies with infants in the second year of life (for a brief discussion of this issue, see Bornstein, Slater, Brown, Roberts, & Barrett, 1997). The number of infants who failed to habituate ($n = 20$ across the age groups) was unfortunately too low to perform any kind of reliable analyses. Examination of the looking times of the 14-month-old nonhabitua-tors ($n = 13$) during the habituation phase of the experiment suggests that they failed to reach criterion because they looked only briefly at the events on the first four trials ($M = 8$ s), presumably because of initial indifference toward the task. In comparison, those 14-month-olds who habituated tended to look on the first four trials for a considerably longer duration ($M = 14.6$ s). The fact that the nonhabitua-tors demonstrated brief looking times meant that it was moderately unlikely that their looking time on a block of any four subsequent trials would drop to criterion level; that is, these infants had to have four sequential trials in which mean visual fixation was less than 4 s to reach criterion. Thus, we do not believe that our final sample is unrepre-

representative of infants in the age groups tested. Rather, the fact that relatively old infants for the habituation paradigm were tested combined with the type of stimuli used meant that a high dropout rate due to fussiness or failure to attend to the task was not overly remarkable.

Although the findings from Experiment 1 provide initial evidence that 14-month-olds attend to correlations among dynamic features of a motion event, there is an alternative explanation that cannot be eliminated at this point. Recall that the parts of one object were yellow and armlike shaped whereas the parts of the other objects were green and diamond shaped. Thus, infants may not have attended to the movement of the parts in learning the part–motion correlations; instead it is possible that they may have correlated the parts' shape or color with its trajectory. If indeed this were the case, it would undermine the notion that attention to object parts and the movement of those parts is integral to the way in which infants start to learn about the different motion trajectories of distinct objects.

EXPERIMENT 2

This experiment was designed to establish whether infants attended to the motion properties or to the shape or color of the parts manipulated in Experiment 1. In addition, the study was designed to determine the extent to which the movement of object parts directs infants to attend to the correlation between those parts and the motion path of the object to which they are attached. To examine these issues, in the present experiment 14- and 18-month-old infants were habituated and tested with the same events as those used in Experiment 1, with the exception that the parts of the objects no longer moved. Thus, infants were presented with events that contained the same correlations as in Experiment 1; namely, those between parts and body, parts and motion, and body and motion. Following the hypothesis that infants first form elementary relations and then later secondary relations, and given the developmental trend observed in Experiment 1, it was predicted that 14-month-old infants would fail to perceive the correlations available in the events in the absence of moving parts and that 18-month-old infants would attend to the relation between parts and motion.

Method

Participants. The participants in the study were twenty 14-month-old and twenty 18-month-old healthy, term infants. There were 12 boys and 8 girls in the 14-month-old age groups and 11 girls and 9 boys in the

18-month-old age group. Data provided by 28 additional infants were not included in the final sample, due to failure to habituate ($n = 8$), fussing or crying ($n = 13$), and experimenter error ($n = 7$). Infants were recruited through birth lists provided by a government agency.

Stimuli. The stimuli were identical to those used in Experiment 1, with the exception that the parts of the objects in each event did not move. Thus, there were four pairs of two events that could act as habituation stimuli, and any event could act as a test stimulus depending on which events were presented during habituation. The events were again created with Macromedia Director 5.0 for the PC. Each scene of an object moving from the left to the right side of a screen lasted 8 s and was repeated three times. Thus, the total duration of each event, including the blue screen in between each scene, was 30 s.

Apparatus and procedure. The apparatus and procedure were identical to those used in Experiment 1. Infants were habituated to one pair of events—each of which contained a specific part–body–motion correlation—until their looking time across four sequential trials decreased to 50% of their looking time on the first four trials. As in Experiment 1, each event was shown on a computer screen until an infant looked away for more than 1 s or until 30 s elapsed. The order of the habituation trials was semi-random, with no event shown consecutively more than two times. During the test phase, infants were presented with four test trials: parts switch, body switch, motion switch, and a familiar event. The order of the test trials was counterbalanced across participants in each age group.

As in Experiment 1, a number of predictions were made about infants' behavior in the three test switch trials. In line with the idea that the motion of the parts was fundamental in drawing 14-month-old infants' attention to the part–motion path relation in Experiment 1, it was predicted that the younger age group would not learn any of the relations in the events. In contrast, it was predicted that 18-month-old infants, who can use knowledge of part–motion path relations to predict that these features are correlated, would recover visual attention during the parts switch test trial but not during the other two switch test trials.

Results

As in Experiment 1, repeated-measures ANOVAs (test trials: parts switch versus body switch versus motion switch versus familiar) were conducted for the looking times of each age group. The analysis for the 14-month-olds revealed no reliable differences among

the looking times during the four test trials, $F(3, 57) = .52$, *ns*. Thus, infants looked equally long at the parts switch ($M = 5.09$), the body switch ($M = 3.74$), the motion switch ($M = 4.62$), and the familiar ($M = 4.27$) test trials, an interpretation supported by the failure to find any significant effects between the test trials in the planned comparisons. The analysis for the 18-month-olds indicated that looking times on the four test trials were equivalent, $F(3, 57) = 2.38$, $p = .08$. As can be seen in Figure 4, however, the failure to discover a significant difference among the 18-month-olds' looking times on the test trials overall may have been attributable to the fact that infants looked equally long at three of the four trials (see Howell, 2002). Consistent with this interpretation, and the predictions made earlier concerning the older age groups' behavior, planned comparisons (with Bonferroni correction) revealed that 18-month-old infants looked marginally longer during the parts switch test trial ($M = 7.44$) than the familiar test trial ($M = 4.24$),

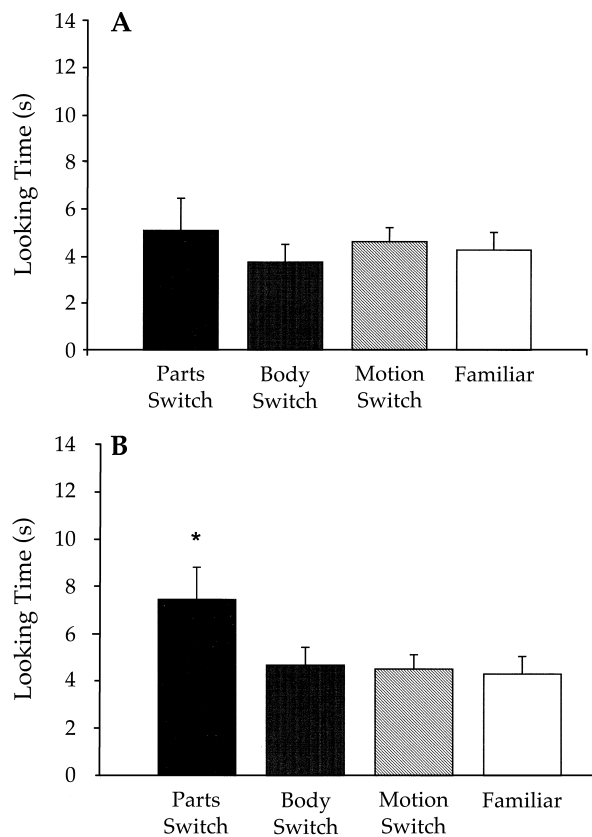


Figure 4 Mean looking time and standard errors during the four test trials for (A) 14- and (B) 18-month-old infants in Experiment 2. The parts of the objects did not move in this experiment. *Looking times for this event were significantly different than looking times for the familiar event, at least $p < .034$, one-tailed.

$t(19) = 1.98$, $p < .034$, but that they looked equally long at the body switch ($M = 4.66$), $t(19) = .37$, and motion switch ($M = 4.50$), $t(19) = .41$, than at the familiar test trial.

To test whether infants' performance in Experiment 1 and 2 differed, a series of two-tailed independent sample tests were performed for each age group (correcting for familywise error and not assuming equal variances across the two ages). The analyses compared the looking times in the three switch test trials in Experiment 1 with those in Experiment 2. For the 14-month-olds, the analyses revealed that infants looked marginally longer at the parts switch test trial when the parts moved ($M = 9.88$) than when they did not move ($M = 5.09$), $t(46) = 2.33$, $p < .034$, and they looked longer at the body switch test trial when the parts moved ($M = 6.84$) than when they did not move ($M = 3.74$), $t(46) = 2.53$, $p < .017$. The difference in looking times at the motion switch test trial in the two experiments was not significant, $t(46) = 1.40$. For the 18-month-olds, there was no significant difference in visual fixation across the two experiments for the parts switch (Experiment 1: $M = 7.91$; Experiment 2: $M = 7.44$), the body switch (Experiment 1: $M = 7.34$; Experiment 2: $M = 4.66$), or the motion switch (Experiment 1: $M = 8.55$; Experiment 2: $M = 4.50$) test trials.

Discussion

The results of Experiment 2 suggest that the motion of parts plays an important role in 14- and 18-month-old infants' ability to attend to relations among features in an event. In events in which parts did not move, 14-month-olds failed to learn any of the available relations that existed among the various features; that is, they looked no longer at the three switch test trials than at the familiar test trial. This pattern of results eliminates the possibility that infants in Experiment 1 attended to the shape or the color of the parts when they learned the relation between moving parts and the motion trajectory of the object. If infants in Experiment 1 had relied on shape or color as the property on which to base a part-motion correlation, the infants in Experiment 2 should have represented the same correlation when the parts did not move.

The data obtained from the 14-month-olds are consistent with the idea that movement—in this case, motion at the local level—captures infants' attention and in so doing, facilitates the ability to discover relations that exist between multiple features. That is, infants at 14 months in Experiment 1 attended to the correlation between parts and motion when the parts in question moved, whereas infants of the same age in Experiment 2 did not attend to that correlation. In-

deed, the younger age groups' failure to recover visual fixation to the part switch suggests that they learned online the correlation between parts and motion in Experiment 1. In other words, at 14 months, infants do not expect static parts to be related to the motion path of an object but nonetheless represent this relation when multiple dynamic features are present, presumably because of the "attention-grabbing" role of movement.

In contrast to the younger age group, 18-month-old infants looked marginally longer at the part-motion violation than at the familiar test trial. Thus, despite the fact that only one aspect of the relation was dynamic, infants at 18 months detected the correlation between object parts and the path of motion of the objects. This suggests that between 14 and 18 months, infants develop an expectation that parts (in our opinion, most likely those that are external and large) are connected with the type of motion in which an object engages. This expectation directs infants to attend to the parts of an object as they follow it across a motion trajectory. Nevertheless, although 18-month-olds can detect correlations between motion paths, whole objects, and objects' parts, infants at this age cannot yet acquire the same kind of expectations about relations involving whole objects and their trajectory in the absence of part motion.

The analysis of infants' behavior across the two experiments revealed that 14-month-olds performed better in Experiment 1 than in Experiment 2 during the parts switch and body switch test trials. Given the idea that these infants learned online the relation between parts and motion paths, and that movement has a particularly facilitating effect on event processing at this age, this is perhaps not surprising. The analysis also revealed that the 18-month-olds performed no differently when the parts of objects moved than when the parts of objects did not move. Such a finding would not have been expected for the parts switch test trials, because infants recovered visual fixation in both the moving and nonmoving parts events. The data from the 18-month-old infants on the other two switch test trials could be interpreted to mean that they performed similarly in both Experiment 1 and 2; however, the fact that these times were reliably different from the familiar test trial in Experiment 1 alone suggests that the 18-month-olds did in fact process relations differently in the two events.

EXPERIMENT 3

Experiments 1 and 2 provided evidence that when viewing a simple motion event, 14-month-old infants are biased to represent the correlation between an ob-

ject's parts and the trajectory of that object when the parts in question move, whereas 18-month-old infants attend to the relation between a whole object and its trajectory, but only when in the presence of moving parts. Furthermore, the experiments suggested that by 18 months, infants expect the motion path of an object to be correlated with its parts, even if those parts do not move. One issue that remains untested concerns the earliest age at which infants attend to part-motion correlations. There is evidence that infants as young as 7 months of age can represent two static correlated visual attributes in the habituation procedure (Younger & Cohen, 1986), and they can represent correlations among simple dynamic features following many exposures to those features (as in the case of the actions of human hands; Woodward, 1998, 1999). Moreover, it has been shown that for 7-month-olds, the existence of one or more facilitating cues—such as synchrony in the case of object movement and a vowel sound—help to highlight a relation and facilitate learning for the relation between attributes (Gogate & Bahrick, 1998). In contrast, other research suggests that it is not until between 14 and 18 months that infants can detect correlations between moving features and functional properties (Madole & Cohen, 1995; Madole et al., 1993), and it is not until 14 months that they can detect the correlation between moving objects and labels (Werker et al., 1998). Although the ability to represent the relation between two static features and, under certain conditions, two dynamic features may therefore be present in the first year, it is not clear at what age infants are able to learn the relation between two or more dynamic features in the absence of any facilitating cues. Experiment 3 was designed to examine this issue by replicating Experiment 1 with 10-month-old infants. Of import was whether infants at this age attend to any of the feature correlations available in the motion events and whether they behave similarly to infants at 14 months by learning the relation between moving object parts and motion trajectory.

Method

Participants. Participants in this experiment were 20 healthy, term, 10-month-old infants. There were 14 boys and 6 girls. Data provided by 10 additional infants were not included in the final sample due to failure to habituate ($n = 5$), fussing or crying ($n = 4$), and technical problems ($n = 1$). Infants were recruited through birth lists provided from a governmental agency.

Stimuli. The stimuli were identical to those used in Experiment 1. The events were created with Macro-media Director 5.0 for the PC. Each scene of an object

moving from the left to the right side of a screen lasted 8 s and was repeated three times. Thus, the total duration of each event, including the blue screen in between each scene, was 30 s.

Apparatus and procedure. The apparatus and procedure were identical to those used in Experiments 1 and 2. Infants received habituation trials until their looking time across four sequential trials decreased to 50% of their looking time on the first four trials or until they saw 16 trials. Each trial consisted of one of two motion events that contained a specific part–body–motion correlation. As in Experiments 1 and 2, each event was shown on a computer screen until an infant looked away for more than 1 s or until 30 s elapsed. The order of the habituation trials was semi-random, with no event shown more than two times consecutively. Infants were presented with four trials during the test phase: a parts switch, a body switch, a motion switch, and a familiar event. The order of the test trials was counterbalanced across participants. Based on the results of Werker et al. (1998) who found that 10-month-olds were unable to learn dynamic relations (in the absence of some kind of facilitating cue; see Gogate & Bahrick, 1998), it was predicted that infants would fail to learn any of the feature relations in the event.

Results

As in the previous experiments, infants' looking times on the four test trials were analyzed with a repeated-measures ANOVA. The analysis revealed that looking times on the four test trials were not reliably different from each other, $F(3, 57) = 1.05, ns$. Thus, infants looked equally long at the parts switch ($M = 6.55$), the body switch ($M = 5.25$), the motion switch ($M = 5.09$), and the familiar ($M = 4.76$) test trials. These results are shown in Figure 5.

Discussion

The results of Experiment 3 suggest that 10-month-old infants did not attend to any of the feature relations available in the two motion events. This finding adds to the growing literature on young infants' ability to detect correlation among dynamic features. There is evidence that infants 10 months and younger are able to form such representations for two types of relations: First, it has been shown that 7-month-olds can learn object–label relations when a facilitating cue, such as temporal synchrony, is present (Gogate & Bahrick, 1998). Second, it has been shown that 6-month-olds can form representations for frequently occurring (i.e., familiar) relations, such as those that

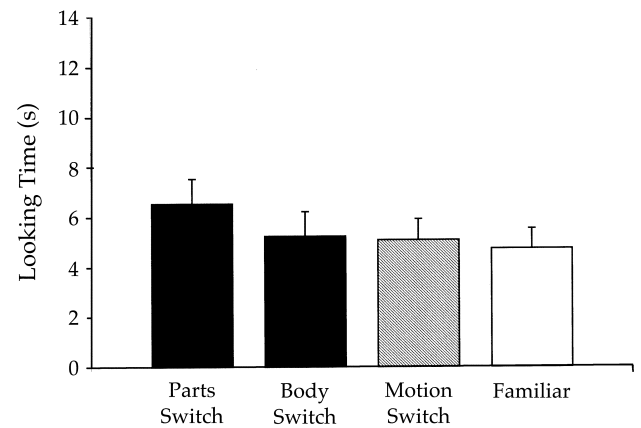


Figure 5 Mean looking time and standard errors during the four test trials for 10-month-old infants in Experiment 3. The parts of the objects moved in this experiment.

exist between the labels “mommy” and “daddy” and their parents' faces (Tincoff & Juczyk, 1999) or hands and objects during a goal-directed action (Woodward, 1998). The present findings, in conjunction with the results of Experiment 1, are consistent with studies (e.g., Madole & Cohen, 1995; Madole et al., 1993) that have shown that the ability to learn correlations between novel dynamic features when no facilitating cue is present does not emerge until after 10 months of age.

EXPERIMENT 4

Infants' inability in Experiment 3 to recover visual attention to any of the test trials relative to the familiar trial failed to illuminate how they processed the different events. It is possible that the events were too complex for 10-month-olds to process, although research in other areas of infant cognition suggests that the ability to process such events is present in the first year (e.g., Baillargeon, 1999; Csibra et al., 1999). As pointed out by Werker et al. (1998), such results can be interpreted to mean that infants attended to just one aspect of the display (e.g., the moving parts) or to multiple features in the events, but failed to detect any correlations among them. The results of Werker et al. (1998, Experiment 6) suggest that infants in this age range are capable of processing features independently, but are unable to combine them together. Thus, Experiment 4 tested whether 10-month-old infants process the events used here in a similar fashion to those in the study by Werker et al. (1998); that is, whether they processed the independent features of the events. In contrast to the previous experiments presented in this article, infants were habituated to

only one of the motion events, after which they were tested with four test events. In three of the test trials, one feature of the event was novel, namely, the parts, the body, or the motion path. In the fourth test trial, infants saw the same event as that used during habituation. Based on the findings of Werker et al. (1998), we predicted that infants would recover visual attention to all three novel features presented in the separate test trials.

Method

Participants. Twenty healthy, term 10-month-old infants participated in the experiment. There were 11 boys and 9 girls. Data provided by 17 additional infants were not included in the final sample, due to failure to habituate ($n = 8$), fussing or crying ($n = 8$), and experimenter error ($n = 2$). Infants were recruited in the same way as in the previous experiments.

Stimuli. The stimuli were the same as those used in Experiments 1 and 3. The events were created with Macromedia Director 5.0 for the PC. In each scene, an object moved from the left to the right side of a screen. The duration of the objects' movement was 8 s and was repeated three times. Thus, the total duration of each event, including the blue screen that separated each scene, was 30 s.

Apparatus and procedure. The apparatus was identical to that used in Experiments 1, 2, and 3. In contrast to the other experiments, however, infants were habituated to a single motion event that contained a part-body-motion correlation. Thus, half the infants in the experiment were habituated to the object with a blue body and green parts that moved on a curvilinear trajectory and the other half of the infants were habituated to the object with a red body and yellow parts that moved on a rectilinear trajectory. As in Experiments 1 and 3, the parts of the object moved for the duration of the event. Infants saw the same event until their looking time across four consecutive trials decreased to 50% of their looking time on the first four trials or until they saw 16 trials. Each event was displayed until the infant looked away for more than 1 s or until 30 s elapsed. Infants were presented with four trials during the test phase: one that was the same as that seen during habituation (familiar) and three in which the event had a novel feature (either parts, body, or motion) in place of that seen during habituation. The order of the test trials was counter-balanced across infants.

In line with the results of Werker et al. (1998), it was predicted that infants would process independently the various features in the event and would therefore recover visual attention to the three novel test trials.

Results

Infants' looking times during the test trials were analyzed with a one-way repeated-measures ANOVA. The analysis revealed that looking times differed significantly across the test trials, $F(3, 57) = 5.87, p < .005$. Planned comparisons (with Bonferroni correction) indicated that infants looked significantly longer, $p < .01$, at the test trial with the novel body ($M = 12.23$) than at the familiar test trial ($M = 5.42$). There was no significant difference between infants' looking times in the test trials with the novel parts ($M = 6.88$) and the novel motion ($M = 7.94$) in comparison with the familiar event ($M = 5.42$). These results are presented in Figure 6.

Discussion

The results of Experiment 4 demonstrate that 10-month-old infants are capable of processing the body of a moving object, but not its moving parts or motion trajectory. Thus, consistent with the findings of Werker et al. (1998, Experiment 6), infants in the present study were able to represent an independent attribute. The present data extend Werker's findings, however, by suggesting that 10-month-olds do not represent dynamic features—both those that are local and global—in motion events. It is important, nevertheless, to note that the processing requirements on the infants in Experiment 4 were ostensibly different and less demanding than those in Experiment 3; that is, infants in the present experiment were habituated only to one stimulus, and consequently did not have to pro-

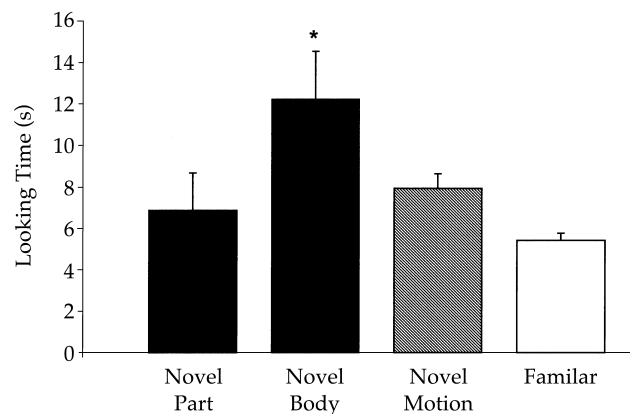


Figure 6 Mean looking time and standard errors during the four test trials for 10-month-old infants in Experiment 4. The parts of the objects moved in this experiment, but infants observed only one event during habituation. *Looking times for this event were significantly different than looking times for the familiar event, at least $p < .034$, one-tailed.

cess two sets of features and the correlations among those features. It is possible that the lower cognitive demands involved in processing a single stimulus allowed infants to detect a single feature in the events in Experiment 4, but the relatively high cognitive demands required to process the events in Experiment 3 may have interfered with the ability to detect any of the features or feature correlations.

The failure of the 10-month-olds to recover visual fixation to the novel parts and the novel motion path could be attributed to a number of factors. One possibility is that the different parts and motion paths taken by objects in the experiments were not discriminated by the infants. Although Experiment 1 demonstrated that this was not the case for infants at 14 months, it is possible that the difference between the sets of features was too subtle for younger infants. In a similar vein, it is possible that infants discriminated the two parts and the two motion paths but treated them as equivalent; after all, in each event there were a set of moving parts and an object that moved from the left side of the screen to the right side of the screen and engaged in a jumping-like action. Finally, it is plausible that the dynamic events used in the experiments in this study placed too high a cognitive demand on the infants, which in turn meant that they were unable to process all the available features and instead attended only to the static features in the events; namely, the body of the objects.

The pattern of results in Experiments 3 and 4 is generally consistent with those found by Werker et al. (1998). In other words, 10-month-old infants' behavior in the present experiments indicates that the ability to process features independently is not limited to the linguistic domain, but rather may reflect a general processing ability. The fact that 10-month-olds were unable to detect correlations among the features of the events in Experiment 3 may have resulted from their failure to process some of the independent features. That is, if infants were unable to process the moving parts or the trajectory of the object, they would have been unable to represent the correlations among the features in the events.

GENERAL DISCUSSION

The four experiments reported here were designed to examine infants' ability to detect and encode correlations among features in a motion event. Experiment 1 revealed that 14-month-olds attend specifically to the relation between the moving parts of an object and its motion trajectory and ignore other relations among features, whereas 18-month-olds attend to the multiple relations that exist between an object's moving

parts, body, and motion trajectory. Experiment 2 indicated that 14-month-old infants do not detect the relation between an object's parts and its motion trajectory when the parts are static, and 18-month-old infants attend to part-motion relations even if only one of the features (i.e., motion path) is dynamic. Experiments 3 and 4 revealed that 10-month-old infants are not yet capable of representing correlations among novel dynamic features in the absence of a facilitating cue, although they are able to process static features in events.

The pattern of results obtained in the present study is generally consistent with the idea that object features are crucial in the development of infants' understanding of the distinct motion paths followed by different object kinds. It was found that 14-month-olds selectively detect and encode the correlation between an object's parts and motion trajectory, but do so only when the parts in question move. Moreover, between 14 and 18 months of age, infants start to expect parts to be correlated with the motion trajectory of an object, and the motion status of these parts within this relation (i.e., moving or not moving) is less important than for younger infants. By approximately 18 months, infants are aware that the parts of an object, perhaps those that are large and external, are involved in the motion of an object, and this relation holds whether the object or the parts are viewed in a dynamic or static state. This knowledge may represent the onset of inductive generalizations about the properties of objects that are not necessarily given in the perceptual input. Infants at this age are, in a sense, predicting the dynamic properties of specific objects based on the recognition that they possess particular static or dynamic features. It remains to be seen whether they will make such inductions about properties to members of the same category that vary in perceptual similarity.

The finding that 18-month-olds attended to all possible relations between moving parts, objects, and motion trajectories suggests that between 14 and 18 months, infants begin to generalize relations involving motion trajectories and object parts to objects as a whole. Infants may therefore progress from the view that "things with moving legs walk" to "things with legs walk" to "things with curvilinear shape walk." This conclusion is coherent with the results of Rakison and Cohen (1999) who found that infants at 14 and 18 months performed functional actions with objects that possessed the parts that afford such actions (e.g., rolling and hopping), but infants at 22 months were just as likely to perform such actions on the basis of parts or category membership. This means that infants initially may represent the relation between functional parts such as legs and wheels with the

motion trajectory of an object—probably by virtue of the relatively invariable relation between such features (e.g., objects with wheels roll) and the attention-capturing character of movement (Slater, 1989). We speculate that with time, this representation would begin to incorporate other features of objects that are not causally related to the initial correlation.

We believe that the learning mechanism proposed in this article is compatible with the notion that categorization develops in a global-to-basic manner (e.g., Mandler, 1992; Mandler, Bauer, & McDonough, 1991). That is, we speculate that infants' earliest division between different entities would be to form broad global-like domains by grouping together those objects that share certain parts and, later, those that move a certain way. Once infants begin to focus on other features of these objects (those that are correlated with various causally significant functions or actions), they would begin to subdivide these broad global domains into increasingly finer categories. It is currently unclear what these other features might be. The present experiments with geometric figures suggest only that 18-month-olds correlate moving parts, body, and motion trajectory; yet in the case of real-world objects there are an abundance of correlated features among category members. One possibility is that infants learn that different external parts (e.g., in the case of dogs, legs, tails, and facial features) are each associated with particular functions, and in due course these relations become incorporated into a single representation. Alternatively, given the large database of evidence on the importance of overall shape on early categorization and labeling (e.g., Imai & Gentner, 1997; Smith, Jones, & Landau, 1992), it is quite possible that infants begin to generalize properties that they have earlier learned (e.g., those related to motion) to novel objects that share overall shape similarity.

Given the vast number of correlations that exist among the members of real-world categories, it is important for infants, children, and adults to focus only on those relations that accurately designate a category. It has been argued previously by Murphy and Medin (1985) that this problem is essentially intractable because the young learner has no way of knowing which relations among features are relevant and which are irrelevant to category membership. To this end, they state that ". . . there are so many possible correlations that it is not clear how the correct ones get picked out" and that consequently, "some additional principle is needed to provide further constraints on category cohesion" (Murphy & Medin, 1985, p. 294). We believe that the present experiments, in conjunction with previous studies on infants' attention to correlations among features (e.g., Madole &

Cohen, 1995; Madole et al., 1993; Werker et al., 1998), suggest two ways in which infants in the second year of life are biased to attend to some kinds of relations among features and not to others.

First, the data suggest that movement, both at a local and a global level, helps infants to be drawn to functionally significant properties by around the beginning of the second year. This view is consistent with the work of Werker et al. (1998) who found that 14-month-olds learn the relation between an object and a label only when the object in question moves, and is also compatible with the results of Madole and Cohen (1995) who found that 14-month-olds attend to correlations among moving parts. Nonetheless, although it has previously been shown that movement is a highly salient property of objects for very young infants (e.g., Burnham & Day, 1979; Gibson, 1969; Slater, 1989), the present experiments extend this finding in that they reveal that the movement of causally relevant features may help infants to distinguish such features from other, less significant features.

Second, the pattern of results obtained across the present experiments suggests that infants in the second year of life are adept at learning correlations between dynamic features and, perhaps more impressively, are selective in the correlations to which they will attend. In all likelihood, this selectivity biases infants to discover, and learn about, only those relations that exist between features that are causally relevant. To go back to the example cited earlier, such a mechanism would prevent infants from associating arm, hand, or head movement with walking or running. Instead, they would probably attend to the most highly correlated, and therefore most causally relevant, feature with which walking and running are associated; that is, legs. Consistent with this view, it has been found that infants as young as 7 months of age associate human hands (presumably one of the earliest perceptually visible moving body parts) with the ability to pick up an object (Leslie, 1984; Woodward, 1998).

We propose that the acquisition of such correlations may act as the foundation for the developing representations of animates and inanimates such as animals and vehicles (see Rakison, in press; Rakison & Poulin-Dubois, 2001), and argue that around 14 to 18 months of age these correlations may become primary as a mechanism of conceptual change, in that learning about which features are involved in which causal actions is the onset of what Mandler (1992, 2000) has called a *meaning*. According to our view, this meaning develops when the represented relation between a feature and a motion or action reaches a certain, as-yet-undefined criterion level. At this point, however, the relation between the two features is

more an expectation than a complex understanding and should not be thought of as conceptual; rather, infants perceive one component of the relation and this activates an expectation about the existence of the other component (see, e.g., Haith, Wentworth, & Canfield, 1993; Roberts, 1998). Indeed, there is evidence that such correlations, and the expectations that result from them, continue to play a role in predictions and inferences about the movement of animate and inanimate objects well after infancy. Massey and Gelman (1988), for example, found that 3- and 4-year-olds judge correctly whether an entity such as a man, a marmoset, a chair, or a bicycle can go up and down a hill "all by itself." Crucially, although the entities were presented as static pictures, children's explanatory comments tended to focus on legs and feet, even if those features were not visible; for example "It can move very slowly . . . it has these little legs" (Gelman, 1990, p. 93).

Although the experiments outlined in this article provide evidence that infants between 10 and 14 months attend to correlations between an object's moving parts and its motion trajectory, some limitations of the experimental design and procedure should be noted. First, it is not clear to what extent infants' processing of geometric figures matches that of more complex real-world objects, which are composed of bundles of correlated features. In the present research, geometric figures were used because the aim of the experiments was to examine the mechanism that underlies infants' acquisition of new information about objects rather than their prior knowledge of specific instances of different kinds of entities. It is possible that the simplicity of the geometric stimuli facilitated or hindered infants' attention to different features and relations among features. The parts and the motion paths of the stimuli used were designed to be somewhat similar to those found in the real world. Nonetheless, additional research with more complex geometric figures and with real-world exemplars that possess moving parts would help to eliminate the possibility that infant behavior in the present experiments was a function of the design of the stimuli.

Second, it should be noted that the results of each experiment included only those infants who habituated successfully to the events. As pointed out earlier, the number of infants excluded from each experiment for this reason was high, but similar to the dropout rates in other studies that have used the habituation procedure, particularly those with infants in the second year of life (e.g., Werker et al., 1998). Unfortunately, the data from the excluded infants were not sufficient to perform reliable analyses, although we see no reason why these infants would have pro-

cessed the motion events differently from those who habituated. Third, the data from Experiments 1 and 2 suggest that 14-month-olds represented the correlation between the movement of object parts, and not their shape or color, with a motion path. The fact that the object parts did not move in Experiment 2 may have meant that infants were less drawn to them and therefore ignored their shape and color. One possible way to address more directly whether infants attended to the motion of the parts in future research would be to switch these motions in the test trials; that is, rather than switching the parts themselves, the parts could have remained in place but their motion could have been that of the other parts seen during habituation. Finally, the experiments reported in this article did not reveal whether 14- or 18-month-olds were capable of forming categories of objects based on correlated dynamic features. If the learning mechanisms described in this article accurately relate how infants construct cohesive concepts of animate and inanimate objects, it is necessary for infants also to categorize as equivalent those entities that are perceptually dissimilar but that share causally significant dynamic relations. To this end, current research in the laboratory of the first author is examining infants' ability to form categories on the basis of part-motion correlations.

In summary, a series of four experiments demonstrated that infants between the ages of 10 and 18 months process differently motion events in which an object moves along a distinct motion path. The data suggest a developmental trend whereby infants at 10 months process independently the parts, body, and motion path of an object; infants at 14 months represent the relation between an object's parts and its motion trajectory; and infants at 18 months represent relations between all three features. The motion of object parts is crucial in this process in that it captures infants' attention, which in turn means that relations between moving parts and other dynamic properties are likely to be discovered. We propose that this process—which is grounded in a sensitive perceptual system and a domain-general associative learning mechanism—may be ultimately instrumental in the development of infants' knowledge about the physical and psychological characteristics of different kinds of objects.

ACKNOWLEDGMENTS

The data in the present study were collected while the first author was at Concordia University in Montreal, Quebec. Preparation of this article was supported by a Faculty Development Grant at Carnegie Mellon

University, a postdoctoral fellowship from the Centre for Research in Human Development at Concordia University, and a grant from the National Sciences and Engineering Research Council of Canada. The authors thank Annika Fasnacht, Kwan Hansongkitpong, and Melissa Stupka for help in preparing the manuscript; and Natacha DeGenna, Rose Matousek, Joanna Vyncke, and Huma Saleem for help with data collection. They are also grateful to Lucy Bonneville for her statistical consultation, and would also like to thank two anonymous reviewers for excellent suggestions concerning data analysis and future directions of the research.

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