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Developing knowledge of objects' motion properties in infancy

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Abstract

Three experiments with a novel variation of the inductive generalization procedure examined 18- and 22-month-olds' knowledge of objects' motion properties. Infants observed simple air and land movements modeled with an appropriate category member (e.g. dog) or an ambiguous block and were allowed to imitate with one or more of four exemplars. The experiments show that 18-month-olds' knowledge of land motions is grounded in causally relevant object parts, whereas 22-month-olds relate such motions more broadly to appropriate category members. Infants' basis for generalizing air motions suggested that at 22 months they have little knowledge about objects from that domain. The results are discussed in relation to the early development of the animate–inanimate distinction and the nature of the inductive generalization task.

Keywords: Infant cognition; Concept formation; Inductive deductive reasoning; Animacy

1. Developing knowledge of motion properties in infancy

The acquisition of a concept of animacy is thought to be one of the cornerstones of cognitive development (e.g. Gelman, 1990; Leslie, 1995; Mandler, 1992; Rakison & Poulin-Dubois, 2001). Not only does it allow various object kinds to be categorized into two broad groups—for instance, animals, insects, and people as animate and vehicles, plants, and tools as inanimate—but it also allows the attribution of different properties to members of each of those groups; for example, animates are alive and are self-propelled, inanimates are recipients of actions and are not self-propelled. In the case of adults and

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children, a fully developed notion of animacy and inanimacy is thought to involve an understanding—sometimes conceptualized as a naïve theory (Gopnik & Meltzoff, 1997)—of the biological, psychological, and physical characteristics of objects. Thus a concept of an animate entity may include information about its biological composition (e.g. whether it has blood, a brain), its possible psychological states (e.g. whether it has desires, goals, and beliefs), and its motion capabilities (e.g. whether it is self-propelled and moves nonlinearly).

Theoretical approaches of the early concept acquisition for animates and inanimates are often ground on aspects of object movement. Premack (1990), for example proposed that almost at birth infants are sensitive to the distinction between self-propelled motion and caused motion. He argued that attention to this aspect of motion leads to the expectation that self-propelled objects engage in goal-directed action that is ultimately perceived as intentional. Similarly, (Gelman, 1998; see also Gelman, Durgin, & Kaufman, 1995) suggested that infants possess *skeletal causal principles* that help them to discriminate animates from inanimates by directing attention to objects' composition and motion. However, Gelman argued that because the perception of motion can be ambiguous and misleading, infants also acquire conceptual schemes for the energy sources and materials that relate to objects' motion and composition.

Mandler (1992, 1998, 2000, 2003), in the presentation of a more comprehensive theory of conceptual development, proposed that infants form rudimentary concepts for animacy—called *image-schemas* or *conceptual primitives*—that act as the building blocks for infants' knowledge about the "kinds of things" objects are (Mandler, 1992; Mandler & McDonough, 1993). According to Mandler (1992), three image-schemas encapsulate important abstract characteristics of objects' spatial structure and movement, and together they form the first concept of animacy. These image-schemas embody the way that objects begin to move, the trajectory that objects follow, and the way objects move with respect to other objects. Accordingly, animate objects can be summarized by image schemas representing self-motion, nonlinear motion, and causing action at a distance, whereas inanimate objects can be summarized by image-schemas representing caused-motion, linear motion, and caused motion through contact.

As an alternative view of the acquisition of knowledge for motion properties, it has been suggested that early concept acquisition is a process of continuous representational enrichment that relies on a sensitive perceptual system and a domain general associative learning mechanism (Eimas, 1994; Quinn & Eimas, 1996, 1997; Quinn, Johnson, Mareschal, Rakison, & Younger, 2000; Rakison, 2003; Rakison & Poulin-Dubois, 2001, 2002). According to this more perceptually-oriented view, infants acquire knowledge about the motion characteristics of objects as a result of an increasing sensitivity to detect and encode local and global dynamic feature correlations (Rakison & Poulin-Dubois, 2001, 2002). The result is a representation of an associative link between perceptual cues that encapsulates information that is only intermittently available in the perceptual array and that has been labeled "conceptual knowledge" by some theorists (e.g. Mandler, 1992, 2003). I have suggested that these associations should be considered in terms of an *expectation*, such that the perception of one constituent of the correlation elicits anticipation about the presence of the other (for a different but related discussion of expectations see Haith, Wentworth, & Canfield, 1993; Roberts, 1998). For example, it is hypothesized that infants may associate a perceptual feature such as legs with a sporadically perceptually available motion characteristic to which it is causally related (e.g. self-propulsion) (Rakison & Poulin-Dubois, 2002).

The mechanism that underlies learning about such properties is hypothesized to be the same as that involved in learning other correlations involving static features alone (e.g. Younger & Cohen, 1986). It is predicted that those object features that are static will be learned earlier than those that are dynamic even though dynamic features are inherently more salient (Rakison, 2003). For example, in the case of animals it is expected that relations among features such as legs, eyes, color, and shape will be represented before relations involving motion characteristics. The foundation for this prediction is twofold. First, infants' attentional, perceptual, and cognitive abilities are initially limited and consequently they are unable to encode all of the information to which they are exposed (Oakes & Madole, 2003). For instance, infants of a certain age may observe a dog run and jump but they may be unable to process all the information in such an event, particularly the dynamic cues; consequently, they would be expected to encode a lower or simpler aspect of the event such as the surface appearance of the dog. In support of this view there is evidence from studies with schematic and geometric figures that 4-month-olds cannot extract correlations among static features (Younger & Cohen, 1986) and 10-month-olds cannot extract correlations among dynamic features (Rakison & Poulin-Dubois, 2002) even though both can encode individual features.

Second, it is suggested that static surface features, as well as those that are locally dynamic (e.g. legs) are more often available in the perceptual array. For example, the shape, features, and texture of a dog are in view when the dog is static as well as when it is dynamic. This is not to say that static features are always available in the input or that, on occasion, dynamic cues may be available but static cues may not; the legs of a dog may be obscured from view when it sits or lies down or may be blurred in low levels of light. However, it is reasonable to assume that infants will observe static features relatively frequently and will therefore be more likely to encode them than features that are sporadically observable in the input.

It is worth noting that the claim here is not that young infants are unable to detect and encode dynamic relations. By 7 months infants can learn the relation between temporally synchronous vocalizations and moving objects (Gogate & Bahrick, 1998), associate hands with goal-directed action (Woodward, 1998), and associate the words 'mommy' and 'daddy' with the image of their parents (Tincoff & Jusczyk, 1999). The evidence suggests that this ability is contingent on the presence of *facilitating cues* (e.g. temporal synchrony, intensity shift, or common rhythm), a high level of experience (as in the case of hands or faces), and that relatively simple events are involved. In the case of the movement of animates and inanimates these aspects are often not present and thus young infants would initially be unable to associate different object kinds with their motion properties (for discussion of dynamic cue discrimination versus association see Rakison & Poulin-Dubois, 2001).

Evidence to support this perceptually-oriented view of the development of knowledge about motion properties was obtained in a recent series of studies with the habituation paradigm in which 10- to 18-month-old infants were shown motion events of geometric figures with dynamic or static features (Rakison & Poulin-Dubois, 2002). The studies revealed that infants at 14 months attended only to the relation between object parts and the motion trajectory of an object (curvilinear or rectilinear) but did so only when the parts of the object moved. In contrast, infants at 18 months attended to all of the correlations available in the events and attended to the relations between parts and motion trajectory when the parts did not move. Thus, it appears that at least for novel stimuli, 14-months-olds are biased to attend to ostensibly causal relations between object parts and global motions, and 18-month-olds have developed an expectation about the components of this relation such that if only one component is present in the input the other one is inferred to exist. This is not to say, however, that infants have yet learned similar relations of real world entities and objects; instead, these data suggest only that infants possess the ability to acquire such information.

What evidence is there, however, to support the notion that infants understand that different motion properties are related to different real world objects? A number of studies have illustrated that young infants are sensitive to dynamic cues and discriminate the motion characteristics commonly associated with animates and inanimates. For example, it has been shown that infants discriminate the agent of an action from the recipient of an action (e.g. Cohen, Rundell, Spellman, & Cashon, 1999; Leslie & Keeble, 1987) and contingent from noncontingent motion (e.g. Rochat, Morgan, & Carpenter, 1997). There is a relative dearth of evidence, however, on when and how infants *associate* animate- and inanimate-related actions to appropriate objects or object categories. For example, despite evidence that by 7 months of age infants distinguish an agent from a recipient in a causal event (Leslie & Keeble, 1987), there are no data to suggest that they expect particular ontological kinds to play these different roles.

Evidence that infants understand the properties associated with animates and inanimates—though not generally those associated with movement—is derived from a series of studies by Mandler and McDonough (1996, 1998) with the *inductive generalization*, or *generalized imitation*, technique. During the procedure in these studies, infants are first presented with a baseline condition in which they are given two exemplars from different categories—for instance, a cat and a truck—as well as a prop; for example, a key. After infants have played spontaneously with these toys, an experimenter performs an action with the prop and a novel exemplar; for example, “starting” a car with the key. While performing the action, the experimenter makes a noise that is congruous with the entity involved; for example, making a “broom broom” noise for the car. Infants are then given the prop—in this example, the key—and the two category exemplars from the baseline condition.

Mandler and McDonough (1996, 1998) predicted that if an understanding develops early in life that animate entities engage in certain actions and inanimate entities engage in different actions, infants will generalize the observed action to the appropriate novel category exemplar; for instance, putting the key to the truck rather than the cat. Consistent with this prediction, Mandler and McDonough (1996) found that infants between 9 and 14 months generalize animate and inanimate properties to objects from the same category as the model exemplar, and they did so even when the novel objects were nonprototypical category members such as an eagle, a fish, and a plane. In a later set of studies, Mandler and McDonough (1998) found that when infants were given a choice between two objects from within the same superordinate category (e.g. after seeing a dog drink, they were given a dog and a cat or a dog and a rabbit), they revealed no preference to model the events with the item from the same basic-level category as the one earlier observed. In other words, infants were just as likely to repeat the action with the cat or the rabbit as the dog. Finally, it is worth noting that these findings hold only for domain specific events—for example, vehicles go with keys, animals go to bed—and not for domain general events such as "going inside" buildings and being washed. That is, infants generalize domain general events both to animals and vehicles. Mandler interpreted these findings, in addition to those from categorization studies with the sequential touching and object examining paradigms (e.g. Mandler, Bauer, & McDonough, 1991; Mandler & McDonough, 1993, 1998), to mean that infants bring to the task knowledge about the kinds of activities engaged in by animates and inanimates.

A number of issues remain, however, concerning the early development of an understanding of the motion capabilities of animates and inanimates. First, although a number of theorists have suggested that motion characteristics are among the first learned by infants, there is little evidence to show when they develop knowledge about which objects exhibit animate and inanimate appropriate motions. According to the more conceptually-oriented view, infants begin to develop schemes for object kinds that encapsulate motion properties in the first year of life (Gelman, 1990; Mandler, 1992, 1998, 2003; Premack, 1990). Yet, the evidence that exists to support this view has generally relied on people, rather than animals, as an animate exemplar (e.g. Leslie, 1984; Spelke, Philips, & Woodward, 1995; Woodward, 1998, 1999), or has demonstrated that infants extend inferences of animacy to non-human entities but without a focus on the role of motion per se (e.g. Gergely, Nádasdy, Csibra, & Bíró, 1995; Johnson, Slaughter, & Carey, 1998). Those espousing a more perceptually-oriented view suggest that knowledge of objects' motion characteristics does not develop until the middle of the second year of life (Quinn & Eimas, 1997; Rakison & Poulin-Dubois, 2001, 2002). In this case, however, the available data is drawn from studies with novel stimuli (Rakison & Poulin-Dubois, 2002) or those in which the study of infants' knowledge of motion characteristics were not directly tested (e.g. Rakison & Cohen, 1999).

Second, the mechanism underlying infants' acquisition of knowledge about motion characteristics remains an open question. Proponents of the more conceptually-oriented view suggest that infants' ability to learn about the motion properties of objects is grounded in innate specialized processes that abstract perceptual information into a conceptual format that does not include the details of the objects in question. Thus, infants' early categorization and induction occurs not on the basis of perceptual features but instead a notion of kinds and an understanding that those kinds engage in different sorts of motions (Mandler, 1992; Mandler & McDonough, 1998). On the contrary, those who hold a more perceptually-oriented view claim that infants learn about objects' motions characteristics though associative processes that connect those motions with certain object features (e.g. legs, wheels, wings) (Eimas, 1994; Quinn & Eimas, 1997; Rakison, 2003; Rakison & Poulin-Dubois, 2001, 2002). According to this view, then, the initial basis for infants' categorization and induction has at its core the perceptual features of objects. A corollary of this perspective is that infants may inappropriately generalize a property to objects that possess the appropriate features or structure but that are from an inappropriate category (e.g. all things with four legs in a canonical structure move non-linearly).

The present studies were designed to address these issues: Thus, a first aim was to map the early development of knowledge acquisition about the motion properties of objects, and a second aim was to examine the basis for inductive generalizations of motion properties and thereby gain insight to the mechanisms underlying this knowledge acquisition. To address these issues, a novel version of the inductive generalization procedure was used in which infants were presented with simple motions typical of animates (nonlinear land movement and nonlinear air movement) and simple motions of inanimates (linear land movement and linear air movement). Path of motion was chosen as the motion property to be tested because a number of theorists have suggested that it is one of the first aspects of movement that infants represent (e.g. Gelman, 1990; Mandler, 1992; Rakison & Poulin-Dubois, 2001). In the modified version of the inductive generalization procedure, in the baseline and generalization phases of the task infants were presented with four objects rather than two. This design allowed not only for systematic examination of the basis for infants' choice of object to generalize the observed actions but also an investigation of whether this understanding develops contemporaneously for the domains of land- and air-movement.

2. Experiment 1

In this experiment, simple motions appropriate for animals and vehicles that move on land or in the air were modeled to 18- and 22-month-old infants. Infants were tested at the specified ages because evidence from recent work suggested that it is not until the second half of the first year of life that infants start to associate motion properties to different object kinds (Rakison & Poulin-Dubois, 2002). The nonlinear land related animal motion was a dog walking, or hopping, and the nonlinear air related animal motion was a bird flying. The linear land related vehicle motion was a car moving along a horizontal surface and the linear air related vehicle motion was a plane flying.

Based on previous work with the sequential touching and habituation paradigms (Rakison & Cohen, 1999; Rakison & Poulin-Dubois, 2002), it was predicted that younger infants would imitate the observed land motions with objects that possessed the appropriate functional parts (i.e. legs, wheels) for the motion. It was expected that infants would generalize on this basis to objects that do not belong to the appropriate category (e.g. nonlinear motion to a bed) because previous research has shown that 18-month-olds treat objects with the same structure as equivalent (Rakison & Butterworth, 1998b). It was also predicted that older infants, who have generalized this part-motion association to whole objects, would imitate only with the object that matched the model in overall appearance. The predictions for the air motions were somewhat different because of the less obvious relationship between bird and plane wings and flying. It is unlikely that young infants would associate the wings of a plane with flying because those wings do not move. It is also probably difficult for infants to associate the wings of a bird with flying not only because birds in flight are often at a distance but also because bird wings move intermittently as a bird flies. Consequently, it was predicted that on the air related tasks infants in both age groups would imitate actions only with the exemplar that shared parts and category membership with the model.

2.1. Method

2.1.1. Participants

Forty infants participated in the experiment, 20 with a mean age of 18 months, 6 days (range = 17; 16–18; 17) and 20 with a mean age of 22 months, 8 days (range = 21; 15–22; 19). There were 12 boys and 8 girls in the 18-month-old group and an equal numbers of boys and girls in the 22-month-old group. Fifteen further infants were tested but not included in the final sample, four because of fussiness, six because of experimenter error, four because of equipment failure, and one for failing to engage in the task. Infants were recruited through birth lists obtained from a private company and were given a small gift for their participation.

2.1.2. Objects and properties tested

Four different simple motions were used in the studies reported here, two nonlinear motions typical of animals (one for land and one for the air) and two typical nonlinear motions typical of vehicles (one for land and one for the air). In one animal event, a cat was moved horizontally in a curvilinear up-and-down motion, and in the other animal event a bird was moved horizontally in a curvilinear up-and-down motion through the air. The intention was to convey to infants the notion of nonlinear movement on land or in the air and not necessarily "walking" or "flying" (though these actions could be interpreted in such a way). In one vehicle event, a car was moved horizontally in a straight line on a flat surface, and in the other vehicle event, an airplane was moved in a straight line horizontally through the air. Movable object parts (e.g. wheels) were glued to standardize the stimuli and to minimize any extraneous salience that may have resulted from the parts' movement. The events all occurred on (for land motions) or above (for air motions) a simple rectangular wooden block. As in the studies by Mandler and McDonough (1996, 1998), each event was accompanied by a non-verbal vocalization by the experimenter: "Whoop" for the nonlinear land motion, "Tum, Tum, Tum, Tum" for the nonlinear air motion, "Wee" for the linear land motion, and "Yoo-hoo" for the linear air motion. Novel vocalizations were used to minimize the number of additional cues concerning movement patterns of the objects.

In contrast to previous studies with the inductive generalization procedure (e.g. Mandler & McDonough, 1996, 1998; Rakison, 2003), infants were presented with four novel stimuli during the baseline and generalization phase of the task. The model and test stimuli are presented in Table 1 and they are illustrated in Fig. 1. One of the stimuli was an appropriate category member for the motion and possessed appropriate functional parts (SPSC: same parts, same category). For example, when the cat was the model exemplar the SPSC exemplar was a dog. Another test stimulus was from an inappropriate category but had the appropriate parts for the motion (SPDC: same parts, different category). For example, when the cat was the model exemplar the SPDC exemplar was a bed (with four legs). Another test stimulus was drawn from the appropriate category for the motion but did not possess appropriate parts for the motion (DPSC: different parts, same category). For example, when the cat was the model exemplar the DPSC exemplar was a dolphin. Finally, one stimulus was from both an inappropriate category and possessed no appropriate parts for the motion

Table 1
Model and test exemplars used in Experiment 1

Motion events	Model	SPSC	SPDC	DPSC	DPDC
Linear land movement	Car	RV	Stroller	Boat	Cow
Nonlinear land movement	Cat	Dog	Bed	Dolphin	Truck
Linear air movement	Cargo Plane	Fighter plane	Dragonfly	Car	Duck
Nonlinear air movement	Eagle	Parrot	Spy plane	Dog	Grasshopper

Note: SPSC refers to same parts and same category as model; SPDC refers to same parts and different category as model; DPSC refers to different parts and same category as model; DPDC refers to different parts and different category as model. The same test exemplars were also used in Experiment 2 although the labels refer to the parts and category appropriate for the task rather than their relation to the model exemplar.

(DPDC: different parts, different category). For example, when the cat was the model exemplar the DPDC exemplar was a car. The stimuli were not modified in any way.

The colors of the stimuli varied within and between the categories. Across infants within each age group, each test exemplar was used equally often in the baseline and the generalization phase of the experiment. The order in which the motions were modeled and the location of the test exemplars in front of the infants were counterbalanced.

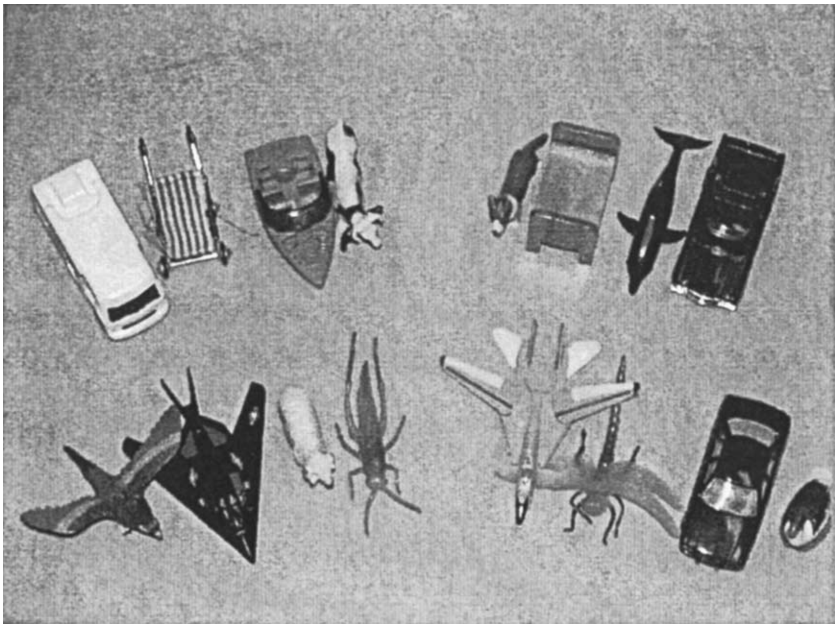

Fig. 1. Stimuli used in Experiments 1 and 2.

2.1.3. Procedure

Participants were tested in a small, quiet room. Each infant sat on their parent's lap across the table from the experimenter. Parents were asked not to guide their infant's behavior or to comment in any way. To accustom the infants to the procedure, two warm-up tasks were conducted at the beginning of the study. In the first task, the experimenter dropped a block made from Lego (1″ square) into a cup and said "Clop-Clop", and in the second task, the experimenter put the inverted cup on top of the wooden block and said "Oh-Oh". For each warm-up task the event was modeled three times, after which the participants were given the stimuli and encouraged to imitate the action. As with the generalization tasks that followed, participants were praised for their response whether or not it was the same as the action modeled by the experimenter.

Infants' behavior with the test exemplars was evaluated twice, once before each motion event was modeled (baseline) and once after each motion was modeled (generalization). In the baseline phase, infants were given four test exemplars and the wooden block on which the events were to be modeled. The stimuli and the block were presented on a large tray. The experimenter did not model any action with the stimuli or in any way prompt infants to respond. Baseline exploration was allowed to continue for approximately 45 s or until the infants stopped manipulating the stimuli. At this point, the experimenter removed the stimuli and the block by pulling the tray away from the infant. The block and tray were then re-introduced with the appropriate exemplar (e.g. car) for the modeling phase of the trial. As in the warm-up task, the experimenter demonstrated the target motion with the model exemplar three times with the appropriate utterance (e.g. "Yoo-hoo"). The direction of the event (e.g. moving linearly on the surface) was counterbalanced across infants. After modeling, the experimenter removed the model exemplar by withdrawing the tray, placed the appropriate test stimuli on the tray in front of the block, and pushed the tray forward until all of the stimuli were within reach of the infant. The experimenter encouraged the infant to interact and imitate the motion by saying, for example, "Can you show me Yoo-hoo?" while simultaneously repeating with one hand the general linear or nonlinear movement of the event. Infants were allowed to respond in any way they wished with no further prompting from the experimenter, and the task ended when activity with the stimuli ceased or after approximately 1 min had passed.

Each infant was involved in two such tasks, one for a land-moving object and one for an air-moving object. No infant received two tasks with vehicles as the model or two tasks with animals as the model; thus, infants observed the car moving linearly and the bird moving nonlinearly or the cat moving nonlinearly and the plane moving linearly. The order of the two tasks was counterbalanced across infants in each age group. All the tasks were videotaped for later analysis.

2.1.4. Scoring

Coding and scoring were similar to that used in previous studies with the inductive generalization technique; that is, infants were coded for their production of the modeled events. However, because there were four test stimuli in this experiment rather than two, coding included the first, second, third, and fourth choice of exemplar used by infants to model a motion event. (Note that in this and the other experiments reported here infants very rarely demonstrated more than four actions.) With all of the actions, a liberal coding scheme was adopted such that a clear effort to repeat the action was judged as imitation of the event. For the nonlinear land motion, infants were coded as having successfully demonstrated the motion if they moved an object up-and-down in an arc at least once while making contact with the table, block, or tray. An up-and-down motion was only coded as such if infants were clearly moving the object in a motion-like curve, and not if they simply picked up an object, moved it vertically in the air, and then put it down vertically on the surface. Similarly, infants were coded as having successfully demonstrated the nonlinear air motion if they moved an object up-and-down in an arc at least once without making contact with the table. Infants were coded as having performed a linear land motion if they moved an object in a straight line along one of the available flat surfaces (table, tray, block), and they were coded as having performed a linear air motion if they moved an object in a straight line through the air. Infants were coded as having used the same exemplar for two consecutive demonstrations of a motion as long as they released the object completely (i.e. for more than 2 s) between each imitation.

Three judges independently coded 20% of the infants (four infants from each age group). Three judges were used because of initial concerns over the difficulty of coding the motions made by infants with the toys; that is, it was not clear how easy it would be for coders to discern, for example, linear air motion from nonlinear air motion. Interrater reliability was obtained by calculating a percentage agreement between the primary coder and the other two coders for the objects touched and the actions demonstrated with those objects. That is, reliability was established between the coders not only for the object that infants chose to grasp but also for the movements that were demonstrated with those objects. In Experiment 1, and the other experiments reported here, the judges could not see the object used as the model exemplar and they could not see the motion (linear or nonlinear) that was performed. Percentage reliability for objects touched and actions performed by the infants in Experiment 1 was 95% (between the primary coder and 2nd coder) and 97% (between the primary coder and the 3rd coder). The primary coder scored the remaining infants and tasks.

2.2. Results

Initial analyses revealed no effect for the type of object used to model the events within each movement domain. That is, infants responded equivalently on the linear and nonlinear land-moving events and the linear and nonlinear air-moving events. Consequently, infants' behaviors on the two land motion conditions and on the two air motion conditions were collapsed. Initial analyses also revealed no effect of task order either for domain (i.e. air related task followed by land related task vs. land related task followed by air related task) or for movement path (linear motion followed by nonlinear motion vs. nonlinear motion followed by linear motion). In line with the analyses presented by Mandler and McDonough (1998), the primary dependent measure in each task was the number of motion properties demonstrated by each participant. The dependent measure was the number of appropriate motions (range = 0–4, maximum score across the objects for each infant = 4) made with any of the four objects. To allow comparison across experiments and to make the data more straightforward to interpret, the results and figures are presented as percentages of maximum responding. To simplify interpretation of the analyses in this and the other experiments, and because of the different predictions for the two movement domains tested, infants' behavior in the land- and the air related tasks were analyzed separately.

2.2.1. Land motions

The first test on the data from infants' performance with the land actions was conducted with a mixed design analysis of variance (ANOVA) with age (18 months vs. 22 months) as the between-subjects factor and exemplar (SPSC vs. SPDC vs. DPSC vs. DPDC) as a within–subjects factor. The analysis revealed a main effect for exemplar, $F(3,114)=10.33$, $P<0.001$, which was qualified by an interaction between age and exemplar, $F(3,114)=2.87$, $P<0.05$. These data are presented in Fig. 2. Planned comparisons revealed that infants at 18 months of age demonstrated the land motions with the SPSC exemplar ($M=35\%$) more often than with the DPSC exemplar ($M=10\%$), $F(1,19)=8.64$, $P<0.01$, and DPDC exemplar ($M=13\%$), $F(1,19)=10.49$, $P<0.005$. Likewise they performed more land motions with the SPDC exemplar ($M=33\%$) than with the DPSC exemplar ($M=10\%$), $F(1,19)=5.63$, $P<0.025$, and DPDC exemplar ($M=13\%$), $F(1,19)=7.03$, $P<0.025$. Infants at 18 months were just as likely to demonstrate land motions with the SPSC ($M=33\%$) as with the SPDC ($M=30\%$) exemplar and equally likely to use the DPSC exemplar as the DPDC exemplar (both $M=10\%$).

As illustrated in Fig. 2, the 22-month-olds' pattern of behavior was somewhat different. Infants in this age group demonstrated the land motions with the SPSC exemplar ($M=40\%$) significantly more often than with the SPDC exemplar ($M=10\%$), $F(1,19)=11.03$, $P<0.005$, DPSC exemplar ($M=15\%$), $F(1,19)=8.88$, $P<0.01$, and DPDC exemplar ($M=5\%$), $F(1,19)=15.26$, $P<0.001$. However, they were equally likely to perform

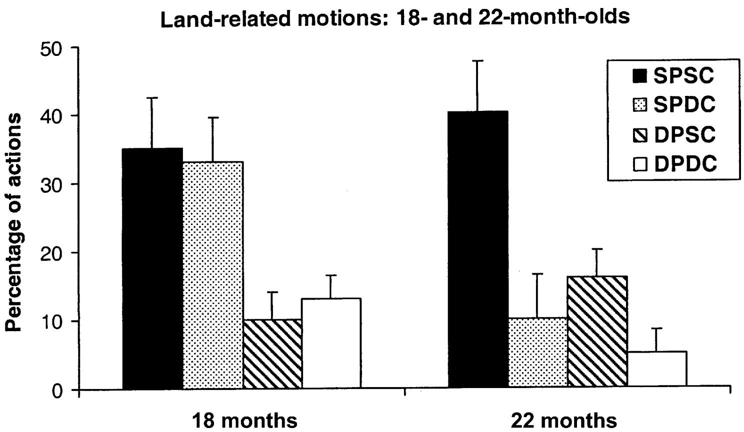

Fig. 2. Percentage and standard errors of 18- and 22-month-olds demonstrating motions during the generalization phase of the land events in Experiment 1 (appropriate model). The dependent measure was the number of appropriate motions (range=0–4, maximum score across the objects for each infant=4) made with any of the four objects.

motions with the SPDC exemplar ($M = 10\%$), DPSC exemplar ($M = 15\%$), and DPDC exemplar ($M = 5\%$).

2.2.2. Air motions

Infants' performance with the air related motions was first analyzed in the same way as that for the land motions. The data for the two age groups are presented in Fig. 3. The analysis revealed a main effect for age, $F(1,38) = 5.18$, $P < 0.05$, which indicated that the 22-month-olds ($M = 65\%$) performed reliably more actions overall than the 18-month-olds ($M = 38\%$). The analysis also revealed a main effect of exemplar, $F(3,114) = 5.56$, $P < 0.005$. Further analyses of the data across the two age groups revealed that infants demonstrated the air motions with the SPSC exemplar ($M = 25\%$) more often than with the SPDC exemplar ($M = 10\%$), $F(1,39) = 5.75$, $P < 0.025$, the DPSC exemplar ($M = 10\%$), $F(1,39) = 6.27$, $P < 0.025$, and the DPDC exemplar ($M = 5\%$), $F(1,39) = 14.18$, $P < 0.001$. Infants were just as likely to perform the air actions with the SPDC exemplar ($M = 10\%$), DPSC exemplar ($M = 10\%$), and the DPDC exemplar ($M = 5\%$). There was no significant age $\times$ exemplar interaction

2.2.3. Across domain comparisons

A second analysis was performed to examine whether there were any differences in performance between the air- and land–related tasks. An ANOVA comparing the two conditions across the two age groups (with domain and exemplar as within-subjects measures) revealed that infants demonstrated more land actions (68%) than air actions (50%), $F(1,38) = 4.89$, $P < 0.05$. There was also a significant interaction between age and domain, $F(1,38) = 4.86$, $P < 0.05$, with infants at 18 months performing more land actions ($M = 36\%$) than air actions ($M = 18\%$) but infants at 22 months demonstrating land and air actions equally (land $M = 35\%$; air $M = 32\%$). There was also a significant main effect for exemplar, $F(3,114) = 14.54$, $P < 0.001$. Further analyses of the data across the two age

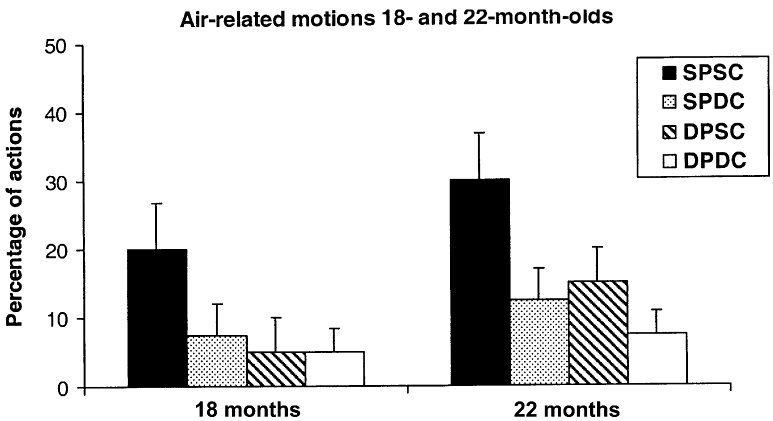

Fig. 3. Percentage and standard errors of 18- and 22-month-olds demonstrating motions during the generalization phase of the air events in Experiment 1 (appropriate model). The dependent measure was the number of appropriate motions (range = 0–4, maximum score across the objects for each infant = 4) made with any of the four objects.

groups revealed that infants demonstrated motions with the SPSC exemplar ($M=31\%$) more often than with the other three exemplars (SPDC $M=15\%$, $F(1,39)=7.93$, $P<0.01$; DPSC $M=10\%$, $F(1,39)=22.95$, $P<0.001$; DPDC $M=6\%$, $F(1,39)=36.44$, $P<0.001$). Infants also demonstrated more actions with the SPDC exemplar ($M=15\%$) than the DPDC exemplar ($M=6\%$), $F(1,39)=7.47$, $P<0.01$. There were no further significant effects.

2.2.4. Baseline measures

The rationale for the baseline measure was to compare infants' behavior with the stimuli prior to the modeling event with that observed after the modeling event. Because of the different patterns of performance of the 18- and 22-month-olds on the two movement domains observed in the primary measures presented above, separate baseline analyses were performed on the land related and air related tasks. The primary baseline measure for each movement domain compared the baseline and generalization performance with a mixed design ANOVA with condition (baseline vs. generalization) and exemplar (SPSC vs. SPDC vs. DPSC vs. DPDC) as the within-subjects factors and age as the between subject factor.

For the land related tasks, the main results of interest were a significant main effect of condition, $F(1,38)=14.91$, $P<0.0001$, which indicated that infants demonstrated more motions after the modeling phase than before the modeling phase, and a significant condition × exemplar interaction, $F(3,114)=4.01$, $P<0.01$. Further analyses revealed that across the two age groups infants demonstrated significantly more motions with the SPSC exemplar in the generalization phase ($M=38\%$) than the baseline phase ($M=13\%$), $F(1,39)=11.74$, $P<0.001$. Similarly, infants demonstrated reliably more actions with the SPDC exemplar in the generalization phase ($M=22\%$) than in the baseline phase ($M=7\%$), $F(1,39)=5.27$, $P<0.05$. However, infants were just as likely to demonstrate motions with the DPSC exemplar (baseline: $M=4\%$; generalization: $M=13\%$; $F(1,39)=2.30$, $P>0.1$) and the DPDC exemplar (baseline: $M=7\%$; generalization: $M=7\%$; $F(1,39)=0.81$, $P>0.3$) in the baseline phase as in the generalization phase. There was no significant effect of age ($P>0.4$) and no significant interaction between age, condition, and exemplar.

For the air related tasks, the main results of interest were a significant main effect of condition, $F(1,38)=36.89$, $P<0.0001$, which was mediated by a significant interaction between condition and exemplar, $F(3,114)=3.01$, $P<0.05$. Additional investigation of the data showed that that across the two age groups infants demonstrated significantly more motions in the generalization phase than the baseline phase with the SPSC exemplar (baseline: $M=6\%$; generalization: $M=25\%$; $F(1,39)=19.29$, $P<0.0001$), SPDC exemplar (baseline: $M=0\%$; generalization: $M=10\%$; $F(1,39)=9.75$, $P<0.005$), and DPDC exemplar (baseline: $M=0\%$; generalization: $M=5\%$; $F(1,39)=4.33$, $P<0.05$). Infants were just as likely to use the DPSC exemplar in the baseline phase ($M=5\%$) as in the generalization phase ($M=10\%$), $F(1,39)=1.35$, $P>0.2$.

2.3. Discussion

Experiment 1 was designed to examine the basis for infants' generalization of simple motion properties such as nonlinear and linear land motion—"walking" and "rolling"—and nonlinear and linear air motion—bird and plane flying. The data reveal that, as predicted, 18-month-old infants imitate land actions with objects that possess the appropriate parts for the motion in question (i.e. wheels, legs) even if they are drawn from an inappropriate category. In contrast, 22-month-old infants imitate land actions only with the object drawn from the appropriate category and with the appropriate parts (e.g. the dog when the cat was modeled walking). In contrast, both age groups performed similarly when air motions were modeled in that they imitated only with the exemplar from the appropriate category and with appropriate parts. However, infants at 22 months performed significantly more air actions overall than did infants at 18 months.

This pattern of results provides evidence that for land-based objects, infants may initially associate the motion of an object with the parts that are causally related to that motion; that is, infants first learn that “things with legs walk” and that “things with wheels roll”. It has been suggested that this process is mediated by the conjoint movement of functional parts and the object as it travels along a motion trajectory such that the salience of movement attracts infants’ attention and makes it more likely that such relations will be encoded (Rakison, 2003; Rakison & Poulin-Dubois, 2002). Clearly, however, infants overgeneralize this relation initially to things that possess the appropriate features and feature structure (e.g. a bed) but that are not from the appropriate category. The idea that the dynamic nature of specific object features is important in learning about motion properties is perhaps supported by infants’ performance in the air related motions. It was predicted that infants would be less likely to associate the wings of a bird or a plane with air related motion because the relation between wings and flying is more opaque than that between legs and wheels and land-based movement. This is because the wings of a plane do not move as a plane is in flight, and because birds in flight are rarely close to an infant and bird wings move intermittently as a bird flies. Consistent with this prediction, infants at 18 months behaved quite differently in the air related tasks than the land related tasks; that is, they imitated the bird and plane flying only with a highly similar exemplar (e.g. using a parrot having seen an eagle as the model exemplar) and not with the other object in the stimulus set that possessed wings (e.g. a plane). Thus, it appears that infants at 18 and 22 months have not associated wings with linear or nonlinear air movement in the same way that they associated wheels with linear land movement and legs with nonlinear land movement. It is possible that the inclusion of the grasshopper, which could be viewed as belonging to the same category as the eagle, affected infants’ pattern of responses on the nonlinear air motion. However, this is unlikely given that infants’ performance across the two air motions was not significantly different.

An important question relates to why infants imitated only with the SPSC exemplar at 22 months in the land related tasks. This issue is clarified by the results of Experiment 2, but is worth brief discussion here. One explanation is that infants chose only the SPSC exemplar because they understood, in a conceptual sense, that it was the same *kind* as the model (e.g. animals walk). Although the data from this experiment do not provide definitive evidence to resolve this issue, the fact that infants at 18 and 22 months did not use the DPSC exemplar to imitate either land or air actions suggests that an understanding of kinds alone did not guide their behavior. For example, dogs and dolphins are both mammals that move nonlinearly—albeit one on land and one in the water, yet infants rarely used the dolphin to model the observed motion. An alternative possibility is that infants interpreted the modeled action with the cat as “walking” or as “land motion”, and they would not repeat that action with an animal that moves in the water. According to one view of conceptual development (e.g. Gelman, 1990; Mandler, 1992, 2003), motion properties are initially conceptualized in an abstract, rather than specific, form. Thus, infants learn that animates and inanimates engage in specific actions or motions rather than learning that land animals or vehicles behave one way (e.g. “walk”) and sea animals or vehicle another way (e.g. “swim”). For example, when infants at 14 months observed a dog drinking from a cup they generalized to other mammals as well as fish and birds, and when they observed a car giving a ride they generalized that action to diverse vehicles including airplanes (Mandler & McDonough, 1996). At the same time, work by Oakes, Coppage, and Dingel (1997) showed that infants as young at 13 months can categorize static land animals from static sea animals. In conjunction, these findings suggest that one explanation for the data is that infants can categorize land and sea animals as different but will generalize actions but not motion properties from instances of one domain to the other.

An alternative explanation for infants’ exclusive choice of the SPSC exemplar is that they generalized to this stimulus on the basis of one or more surface properties. It has been suggested that after initially associating the causally relevant parts of an object to a motion property (e.g. legs and walking), infants may generalize this relation to other aspects of the object that are not causally related to the initial relation (e.g. eyes and walking) (Rakison, 2003; Rakison & Poulin-Dubois, 2002). In the current experiment, the SPSC exemplar on the land tasks (as well as the air tasks) possessed a similar overall shape and structure as the model exemplar and possessed a number of similar parts such as legs, eyes, and tails in the case of the cat and the dog, and wings, tail fins, and windows in the case of the plane and spy plane. It is unclear, however, to which of these features infants may have attended in the present study. Finally, it is possible that infants at 22 months have learned that not all features are comparable even though they may appear so on the surface. Perhaps younger infants generalize linear and nonlinear land motion on the basis of the structure and appearance specified by legs and wheels, irrespective of the nature of those legs and wheels. However, by 22 months they have learned that not all legs are alike—despite their similarity, animal legs are different from furniture legs in a number of ways (e.g. inflexion points).

An important question that remains unanswered from Experiment 1 concerns infants’ knowledge of the motion properties of objects in the tasks. Infants generally demonstrated motions with exemplars that shared one of more perceptual properties with the model exemplar (i.e. the SPSC and SPDC exemplars) and only rarely demonstrated motions with the exemplar that was perceptually different but that was the same ontological kind as the model item (i.e. the DPSC exemplar). However, at this point it is not possible to establish whether infants’ pattern of behavior in Experiment 1 indicates an understanding of real world objects’ surface and motion properties or on-line similarity judgments made on the basis of the properties of the toys at hand.

Either of these accounts fits with the finding that the SPSC and SPDC exemplars shared some perceptual features with the model whereas the DPSC exemplar shared few features with the model. Discriminating these underlying bases for behavior—that based on knowledge versus that generated on-line—is a problem rife in infant studies on early categorization that has proved difficult to tackle. In particular, it is common in procedures that rely on presenting infants with toys; namely, the sequential touching, object examining, and generalized imitation tasks (e.g. Mandler & McDonough, 1993, 1998; Oakes, Madole, & Cohen, 1991; Rakison & Butterworth, 1998a). Nonetheless, because of the interactive aspect of the generalized imitation procedure it is possible to modify the task to begin to address this issue by minimizing the information given to infants about the identity of the model exemplar. This was the approach adopted in Experiment 2.

3. Experiment 2

In Experiment 2, the same motion events were modeled to infants and they were presented with the same test stimuli as those in Experiment 1; however, an ambiguous block was used as the model exemplar for all the events. The rationale for using such a block is that if infants have associated an object, an object category, or specific object parts with a particular motion, they will imitate specifically with one or more of the four available exemplars. For example, if infants have learned through experience with real world objects that animals move nonlinearly, they will imitate the walking motion with the SPSC and DPSC exemplars (i.e. the dog and dolphin). However, if they have learned that things with legs move nonlinearly they will imitate with the SPSC and SPDC exemplars (i.e. the dog and table). Finally, if infants have learned something about the identity of objects that move on land, they will imitate with the SPSC and DPDC exemplars (i.e. dog and car).

An alternative possibility is that infants bring little knowledge to the task of the motion properties of objects or their features; in other words, their behavior could be generated on-line. If this were the case, infants in the current experiment would be expected to use all four exemplars equally to imitate the observed motions because no featural information is given about the identity of the objects that typically perform those motions.

3.1. Method

3.1.1. Participants

Thirty-two infants participated in the experiment, 16 with a mean age of 18 months, 5 days (range = 17; 16–18; 21) and 16 with a mean age of 22 months, 7 days (range = 21; 26–22; 19). There were 9 males and 7 females in both age groups. Five further infants were tested but not included in the final sample, two because of fussiness and three because of experimenter error. Infants were recruited from the same source as Experiment 1 and were given a small gift for their participation.

3.1.2. Objects and properties tested

Infants were tested with the same air and land motions used in Experiment 1. The object used to model all of the events was an ambiguous u-shaped block made from red clay. The block is illustrated in Fig. 5. The rationale for using the block was to minimize the information given to infants about the identity of the exemplars that performs air and land motions. Each motion event was accompanied with the same non-verbal vocalization as those used in the first experiment, and the test stimuli were identical to those used in Experiment 1. The order in which the motions were modeled and the location of the test exemplars during the baseline and generalization phase was counterbalanced.

3.1.3. Procedure, coding, and scoring

The procedure was identical to that used in Experiment 1, except that the experimenter modeled each event with the block shown in Fig. 4. Infants were first presented with two warm-up tasks, after which they were tested with one land related motion (linear or nonlinear in contact with a flat surface) and one air related motion (linear or nonlinear movement without touching a flat surface). All tasks were videotaped and scored in the same format as in Experiment 1. It is worth noting that although the same labels used in Experiment 1 are applied here, they refer to the features and category identity of the objects that would typically perform animate and inanimate motions rather than a direct relation to the model exemplar. For instance, for the land actions the term SPSC refers to the exemplar (e.g. dog) that possesses the same features (e.g. legs, eyes) and belongs to the same category (i.e. animals) as the kind of things that would typically move nonlinearly on land. The primary judge was the same as that in Experiment 1. As in Experiment 1, two additional judges independently coded four separate infants from each age group (in total 50% of infants tested). Percentage reliability for the primary coder and the second and third judge for objects touched and actions performed by the infants in Experiment 1 were 94% and 96% respectively. The primary judge coded the remaining infants.

3.2. Results

The primary measure of behavior in the tasks was the infants' choice of objects with which to demonstrate the motion events. As in Experiment 1, the primary dependent measure was the sum in each task of imitated actions observed using either the first, second, third, or fourth objects selected by the infant. Thus the dependent measure was the number of appropriate motions (range = 0–4, maximum score across the objects for each

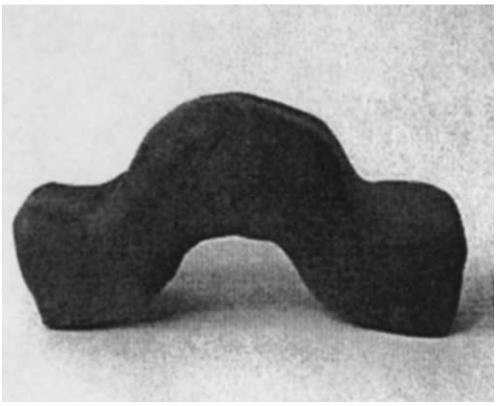

Fig. 4. Ambiguous block used as model stimulus in Experiment 2 and Experiment 3.

infant = 4) made with any of the four objects, but the data are presented as percentages of maximum responding. As in the first experiment, preliminary analyses showed that infants' behavior was not significantly different on the two land-moving events and on the two air-moving events and also that there was no effect of task order for domain of movement or for type of movement path. Consequently, the data for the two land related tasks were combined and the data for the two air related tasks were combined. To allow comparison between this experiment and the previous one, as well as comparison across the two age groups and tasks, infants' data are reported in percentages.

3.2.1. Land motions

As in Experiment 1, infants' imitation behavior on the two land related tasks was investigated with a mixed design ANOVA with age (18 months vs. 22 months) as the between-subjects factor and exemplar (SPSC vs. SPDC vs. DPSC vs. DPDC) as the within-subjects factor. The data are presented in Fig. 5. The ANOVA showed that infants in the two age groups were just as likely to imitate the observed motions (18 months: 23%; 22 months: 20%), $F(1,30) = 0.46$, $P > 0.5$. However, the analysis revealed a main effect for exemplar, $F(3,90) = 6.21$, $P < 0.001$, which was mediated by a significant interaction between age and exemplar, $F(3,90) = 4.31$, $P < 0.01$. Planned comparison revealed that, consistent with Experiment 1, 18-month-olds demonstrated the land motions with the SPSC exemplar ($M = 31\%$) more often than with the DPSC exemplar ($M = 16\%$), $F(1,15) = 4.32$, $P < 0.05$, and DPDC exemplar ($M = 6\%$), $F(1,15) = 6.00$, $P < 0.025$. Similarly, they performed more land motions with the SPDC exemplar ($M = 38\%$) than with the DPSC exemplar ($M = 16\%$), $F(1,15) = 4.62$, $P < 0.05$, and DPDC exemplar ($M = 6\%$). $F(1,15) = 12.10$, $P < 0.005$. However, 18-month-olds demonstrated land motions equally with the SPSC exemplar ($M = 31\%$) as with the SPDC exemplar ($M = 38\%$),

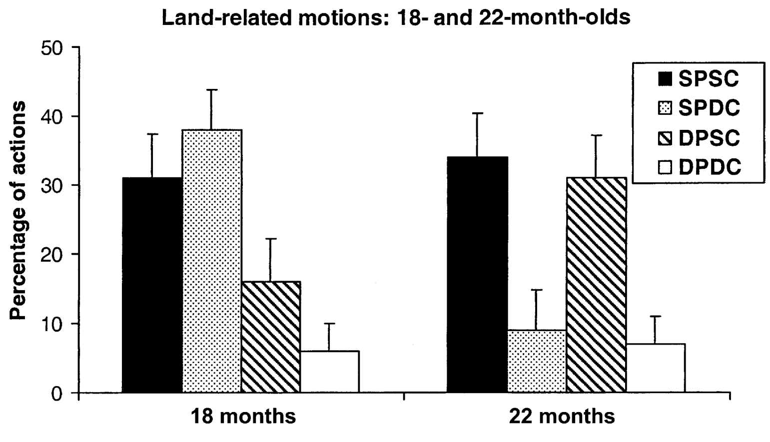

Fig. 5. Percentage and standard errors of 18- and 22-month-olds demonstrating motions during the generalization phase of the land events in Experiment 2 (ambiguous block as model). The dependent measure was the number of appropriate motions (range = 0–4, maximum score across the objects for each infant = 4) made with any of the four objects.

$F(1,15)=0.48$, $P>0.4$, and equally with the DPSC exemplar ($M=16\%$) as the DPDC exemplar ($M=6\%$), $F(1,15)=1.00$, $P>0.3$.

As can be seen in Fig. 5, the 22-month-olds' pattern of choices were somewhat different from that of the 18-month-olds. The 22-month-olds demonstrated the land motions with the SPSC exemplar ($M=34\%$) significantly more often than with the SPDC exemplar ($M=9\%$), $F(1,15)=7.73$, $P<0.025$, and DPDC exemplar ($M=7\%$), $F(1,15)=12.79$, $P<0.005$. They also demonstrated more land motions with the DPSC exemplar ($M=31\%$) than with the SPDC exemplar ($M=9\%$), $F(1,15)=4.62$, $P<0.05$, and DPDC exemplar ($M=7\%$), $F(1,15)=7.50$, $P<0.025$. The 22-month-olds were just as likely to demonstrate motions with the SPSC ($M=34\%$) and DPSC ($M=31\%$) exemplars, $F(1,15)=0.11$, $P>0.5$, and they were equally likely to use the SPDC ($M=9\%$) and DPDC ($M=7\%$) exemplars, $F(1,15)=0.32$, $P>0.5$.

3.2.2. Air motions

As in Experiment 1, infants' imitating behavior with the air related motions was analyzed in the same way as that for the land motions. The data for the two age groups are presented in Fig. 6. The analysis revealed that there was no reliable difference in the level of imitation across the two age groups (18 months $M=10\%$; 22 months $M=9\%$), $F(1,30)=0.61$, $P>0.5$. The analysis revealed a main effect of exemplar, $F(3,90)=2.88$, $P<0.05$. Further analyses of the data across the two age groups revealed that infants demonstrated the air motions with the DPSC exemplar ($M=18\%$) significantly more often than with the SPDC exemplar ($M=6\%$), $F(1,31)=4.43$, $P<0.05$, the DPDC exemplar ($M=6\%$), $F(1,31)=5.17$, $P<0.05$, and marginally more often than the SPSC ($M=8\%$), $F(1,31)=3.52$, $P<0.07$. Infants in the two age groups were just as likely to perform air actions with the SPSC ($M=8\%$), DPSC ($M=6\%$), and the DPDC ($M=6\%$) exemplars. There was no significant interaction between age and exemplar.

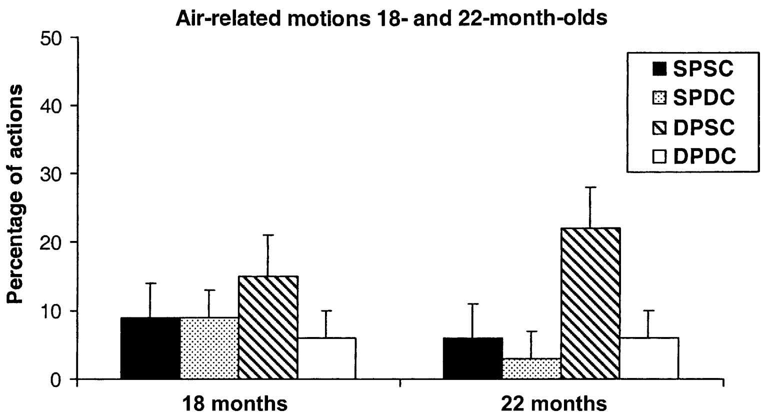

Fig. 6. Percentage and standard errors of 18- and 22-month-olds demonstrating motions during the generalization phase of the air events in Experiment 2 (ambiguous block as model). The dependent measure was the number of appropriate motions (range=0 4, maximum score across the objects for each infant=4) made with any of the four objects.

3.2.3. Across domain comparisons

As in Experiment 1, a second analysis compared performance on the two kinds of the tasks (land versus air) across the two age groups. As in the first experiment, infants made significantly more imitations in the land tasks (43%) than in the air tasks (22%), $F(1,30)=19.99$, $P<0.001$. There was also a main effect for exemplar, $F(3,90)=5.67$, $P<0.001$, which was mediated by a significant interaction between exemplar and domain, $F(3,90)=4.59$, $P<0.005$. Additional analyses revealed that across the two age groups infants demonstrated with the SPSC exemplar more often on the land actions ($M=33\%$) than the air actions ($M=8\%$), $F(1,31)=20.67$, $P<0.001$. A similar effect was found for the SPDC exemplar (land $M=23\%$; air $M=6\%$), $F(1,31)=8.87$, $P<0.01$. Infants demonstrated actions with the DPSC exemplar, $F(1,31)=0.65$, $P>0.7$, and DPDC exemplar, $F(1,31)=0.88$, $P>0.7$, equally as often for the land and air actions. There were no further significant effects in the main analysis.

3.2.4. Baseline measures

For the land related tasks, the main results of importance were a significant main effect of condition, $F(1,30)=25.09$, $P<0.0001$, which indicated that infants demonstrated more motions after the modeling phase than before the modeling phase. This effect was mediated by a significant condition × exemplar interaction, $F(3,90)=5.57$, $P<0.001$, and a significant age × condition × exemplar interaction, $F(3,90)=3.47$, $P<0.025$. To investigate this three way interaction, additional repeated-measure ANOVAs were performed for each age group with condition and exemplar as the within subjects variables.

The analysis for the 18-month revealed that infants demonstrated more motions during the generalization phase ($M=23\%$) than the baseline phase ($M=9\%$), $F(1,15)=10.95$, $P<0.005$, and across both conditions they used the SPSC ($M=22\%$) and SPDC ($M=27\%$) exemplars to demonstrate motions significantly more often than the DPSC ($M=8\%$) and DPDC ($M=6\%$) exemplars, $F(1,45)=5.49$, $P<0.002$. There was no significant effect of condition on infants' choice of object with which to demonstrate a motion, $F(1,45)=1.92$, $P>0.1$. The analysis for the 22-month-olds showed that infants were more likely to demonstrate motions after the modeling phase ($M=20\%$) than the baseline phase ($M=9\%$), $F(1,15)$ 16.30, $P<0.001$, though this effect was mediated by a significant interaction between condition and exemplar, $F(3,45)=6.95$, $P<0.001$. Further investigation of the data revealed that the 22-month-olds were significantly more likely to demonstrate motions with the SPSC exemplar (baseline: $M=9\%$; generalization: $M=34\%$; $F(1,15)=4.55$, $P<0.05$) and DPSC exemplar (baseline: $M=0\%$; generalization: $M=31\%$; $F(1,15)=6.82$, $P<0.025$) following the modeling phase than prior to it. However, infants at 22 months of age were just as likely to demonstrate motions with the SPDC (baseline: $M=9\%$; generalization: $M=9\%$; $F(1,15)=0.45$, $P>0.4$) and DPDC (baseline: $M=4\%$; generalization: $M=7\%$; $F(1,15)=1.1$, $P>0.3$) exemplars in either phase of the experiment. The baseline analysis for the air tasks revealed that across the two age groups infants performed significantly more actions during the generalization phase ($M=10\%$) than the baseline phase ($M=4\%$), $F(1,30)=7.62$, $P<0.025$. There was no significant main effect of exemplar or age and no significant interaction between any of the variables.

3.3. Discussion

The aim of this experiment was to explore the content of infants' knowledge of land and air motions by examining their generalizations when provided with no information about the identity of the objects that perform those motions. As such, the experiment was designed to test the relative influences of prior knowledge versus on-line decision making in infants' generalization behavior for motion properties. Consistent with Experiment 1, infants at 18 months in the land related tasks showed a preference to demonstrate motions with the objects that have appropriate parts for linear and nonlinear motions (e.g. legs and wheels); that is, they predominantly demonstrated land motions with the SPSC exemplar and the SPDC exemplars. This finding is consistent with the hypothesis that a first step in learning about objects' motion characteristics is to associate causally relevant features with those characteristics. Furthermore, because infants could not use the ambiguous model exemplar as the basis for this behavior, they must have applied their knowledge about the objects or features of objects that are typical of these motions. That infants will demonstrate motions with objects from an inappropriate category that possesses the appropriate parts for those motions (e.g. moving a table nonlinearly) suggests that the association between parts and a motion property may be initially overextended.

Infants at 22 months in the land related tasks also performed similarly to those in Experiment 1 in that they tended to demonstrate actions with the SPSC exemplar. However, unlike their same age counterparts in Experiment 1, infants in the current experiment also showed a preference to demonstrate actions with the DPSC exemplar. This suggests that by 22 months infants may have begun to extend certain motion properties to objects beyond those simply sharing certain object parts and instead to category members that are perceptually diverse and that move in somewhat different domains (e.g. boats move on water). An important question is why the 22-month-olds infants in Experiment 1 did not perform in a similar way to those in the current experiment; that is, why did they not also imitate with the appropriate but dissimilar same-category member. The most plausible explanation, given the pattern of results obtained across the experiments presented here, is that at least until 22 months of age infants are influenced in their imitation behavior by the identity of the model exemplar. Thus, infants may be biased to choose objects that have the same shape or parts as the model exemplar even if they have knowledge about the identity of differently moving real-world objects.

Infants in the air related task performed somewhat differently from infants in Experiment 1 who chose the SPSC exemplar at both 18 and 22 months. Somewhat surprisingly, the main finding of the current experiment was that infants across the two age groups chose the DPSC exemplar to imitate the observed actions. Thus, infants chose the car to imitate linear air actions and the dog to imitate nonlinear air actions. What can explain this seemingly anomalous behavior? One explanation for this finding is that the ambiguity of the block caused infants to interpret the modeled air related motions more broadly as nonlinear and linear motion or as nonlinear and linear land motion. Consequently, the car and dog would be the most appropriate of the test exemplars to repeat such a general movement pattern. Alternatively, it is possible that in the absence of specific knowledge about air motion infants chose the most familiar available objects, and in the air related tasks these stimuli were the car and the dog. That infants did not follow a similar pattern of responses in Experiment 1 suggests not only that infants' choice in the generalized imitation task is influenced by the identity of the model exemplar but also that they may not have a well developed understanding of the identity of things that move linearly and nonlinearly in the air. This latter conclusion is supported by the finding that infants in the current experiment demonstrated more land than air related motions.

4. Experiment 3

Although the results of Experiments 1 and 2 are generally consistent with each other, it is possible that infants' behavior in the tasks were overly affected by the specific stimuli that were chosen as the test exemplars. For example, for the nonlinear land motion condition the bed did not possess particularly elongated legs and the stroller could be interpreted as a vehicle with wheels. Furthermore, the DPSC exemplars in the land motion tasks were from a different movement domain entirely—namely, a dolphin and boat—and younger infants may have had difficulty generalizing from a land based object to a water based object. Because of these concerns, it is important to establish that the pattern of behavior observed in the first two experiments was not driven by the particular exemplars involved. Experiment 3 was designed to address this issue by testing 18- and 22-month-old infants with linear and nonlinear land-related motions with a different set of stimuli. The land motions were chosen because infants' performance in Experiments 1 and 2 were more consistent on the land motions than the air motions and because they were more revealing about the represented relation between object features and motion trajectories. The block employed in Experiment 2 was again used as the model exemplar.

4.1. Method

4.1.1. Participants

Thirty-two infants participated in this experiment. There were 16 infants with a mean age of 18 months, 2 days (range = 17; 17–18; 15) and 16 infants with a mean age of 21 months, 30 days (range = 21; 17—22; 12). There were an equal number of males and females in both age groups. Seven further infants were tested but excluded from the final sample, four because of fussiness, two because of failure to engage in the task, and one because of experimenter error. Infants were recruited from the same source as the first two experiments and were given a small gift for participating.

4.1.2. Objects and properties tested

Infants were tested with the same linear and nonlinear land motions used in Experiments 1 and 2. The object used to model all of the events was the ambiguous u-shaped block from Experiment 2. Each motion event was accompanied with the same non-verbal vocalization that was used in the first experiments. The test stimuli were completely different from those in Experiments 1 and 2. The stimuli are listed in Table 2. For the linear motion events the SPSC exemplar was a sports car, the SPDC exemplar was a lawnmower (with a handle and not the kind that can be sat on), the DPSC exemplar was a snowmobile (without wheels), and the DPDC exemplar was a horse. For the nonlinear motion events

Table 2
Model and test exemplars used in Experiment 3

Motion events	Model	SPSC	SPDC	DPSC	DPDC
Linear land movement	Block	Sports car	Lawnmower	Snowmobile	Horse
Nonlinear land movement	Block	Sheep	Table	Snake	Bus

the SPSC exemplar was a sheep, the SPDC exemplar was a table (with four legs), the DPSC exemplar was a snake, and the DPDC exemplar was a bus. The order in which the motions were modeled and the location of the test exemplars during the baseline and generalization phase was counterbalanced.

4.1.3. Procedure, coding, and scoring

The procedure was identical to that of the first experiments except that infants were tested on two land motions instead of one land and one air motion. All tasks were videotaped and scored in the same format as in Experiment 1 and 2. As in Experiment 2, it is important to note that the labels applied to the stimuli (i.e. SPSC, SPDC, DPSC, DPDC) refer to the features and category identity of the objects that would typically perform animate and inanimate motions rather than a direct relation to the model exemplar. The primary judge was not the same as that in the first two experiments. Two additional judges independently coded four separate infants from each age group (in total 50% of infants tested). Reliability for the primary coder and the second and third judge for objects touched and actions performed by the infants in Experiment 1 were 97% and 93%, respectively. The primary judge coded the remaining infants.

4.2. Results

The primary measure of behavior in the tasks was the infants' choice of objects with which to demonstrate the motion events. The primary dependent measure was again the sum of imitated actions observed using either the first, second, third, or fourth objects selected by the infant (with repetitions allowed). Thus the dependent measure was the number of appropriate motions (range = 0–4, maximum score across the objects for each infant = 4) performed with any of the four objects. Preliminary analyses showed that infants' behavior across the two tasks was not significantly different and that there was no effect of task order or sex. The data for the two land related tasks were subsequently collapsed.

The data from the generalization phase were entered into a mixed design ANOVA with age (18 months vs. 22 months) as the between-subjects factor and exemplar (SPSC vs. SPDC vs. DPSC vs. DPDC) as the within-subjects factor. The data are presented in Fig. 7. The analysis revealed no main effect for age, $F(1,30)=1.32$, $P>0.2$. However, it did reveal a main effect of exemplar, $F(3,90)=5.82$, $P<0.001$, which was mediated by a significant age × exemplar interaction, $F(3,90)=2.77$, $P<0.05$. Planned comparisons revealed that 18-month-olds demonstrated motions with SPSC exemplar ($M=38\%$) more often than with the DPSC exemplar ($M=9\%$), $F(1,15)=9.57$, $P<0.01$, and DPDC

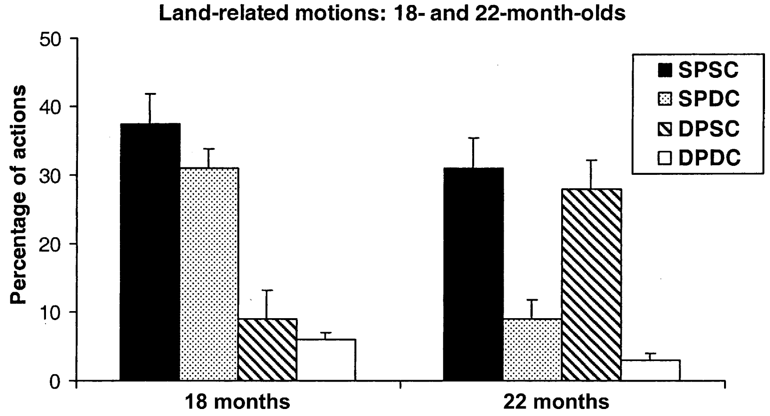

Fig. 7. Percentage and standard errors of 18- and 22-month-olds demonstrating motions during the generalization phase of the events in Experiment 3 (ambiguous block as model). The dependent measure was the number of appropriate motions (range=0 4, maximum score across the objects for each infant=4) made with any of the four objects.

exemplar ($M=6\%$), $F(1,15)=12.10$, $P<0.005$. They also performed significantly more motions with the SPDC exemplar ($M=31\%$) than with the DPDC exemplar, $F(1,15)=6.00$, $P<0.05$, and marginally more motions with the SPDC than with the DPSC exemplar, $F(1,15)=3.85$, $P<0.07$. Thus, infants at 18 months of age tended to demonstrate motions with the SPSC and SPDC exemplars more than the other two exemplars. Planned comparison on the 22-month-olds' data showed that they demonstrated motions with SPSC exemplar ($M=31\%$) more often than with the SPDC exemplar ($M=9\%$), $F(1,15)=5.79$, $P<0.05$, and the DPDC exemplar ($M=3\%$), $F(1,15)=9.57$, $P<0.01$. They were also more likely to perform motions with the DPSC exemplar ($M=28\%$) than with the DPDC exemplar, $F(1,15)=10.00$, $P<0.01$, and marginally more motions with the DPSC exemplar than with the SPDC exemplar, $F(1,15)=3.76$, $P<0.08$. Thus, infants at 22 months of age tended to demonstrate motions with the SPSC and DPSC exemplars more than the other two exemplars.

4.2.1. Baseline measures

The primary baseline measure examined infants' behavior during baseline and generalization with a mixed design ANOVA with condition (baseline vs. generalization) and exemplar (SPSC vs. SPDC vs. DPSC vs. DPDC) as the within-subjects factor and age (18 months vs. 22 months) as the between subject factor. The main result of theoretical importance was a significant main effect of condition, $F(1,30)=18.45$, $P<0.001$, which indicated that infants demonstrated more motions after the modeling phase than before the modeling phase.

4.3. Discussion

Experiment 3 was designed to corroborate the findings of Experiment 1 and 2 with a different set of stimuli. The results are entirely consistent with those of Experiment 2:

Infants at 18 months of age demonstrated nonlinear and linear motion paths with stimuli that possessed the appropriate object features (i.e. legs and wheels) whereas infants at 22 months of age demonstrated the motion paths with stimuli from the appropriate category (i.e. animals and vehicles). This pattern of results provides further support for the idea that infants initially associate an object's motion characteristic with a specific feature possessed by that object. Initially, this may lead to overgeneralization of the motion to objects that possess the appropriate features and feature structure (e.g. nonlinear motion to all things with legs in a canonical configuration). In time, infants constrain the objects and object features to which they will generalize a motion property such that they no longer extend it to objects solely on the basis of appropriate features or feature structures. It is, however, unclear from this study whether older infants' appropriate generalization results from an understanding of category relations (e.g. all animals move nonlinearly) or from extension to objects that possess specific features (e.g. things with eyes move nonlinearly).

5. General discussion

A fundamental debate in the developmental literature is when and how infants learn about the properties of objects that are not constantly available in the perceptual array. Among the first of these properties hypothesized to be acquired relates to the movements of objects such as agency, self-propulsion, and path of motion (Gelman, 1990; Mandler, 1992; Rakison & Poulin-Dubois, 2001). However, to date there is little or no empirical evidence to confirm how and when infants learn about the identity of objects that perform the various kinds of these movements. The experiments reported here were designed to address these issues by focusing on two specific aims: (1) to map out the developmental trajectory of infants' generalization of linear and nonlinear land and air movements; and (2) to determine the basis for such generalizations, specifically the role of object parts versus conceptual knowledge of common kinds (Mandler & McDonough, 1996, 1998). To address these issues, the experiments reported here used a novel variation of the generalized imitation procedure in which four rather than two objects were presented during the baseline and generalization phases of the task. The advantage of this variation of the task is that rather than presenting infants with test exemplars that do or do not belong to the same category as the model exemplar, it is possible systematically to choose exemplars that are appropriate for an action or movement in one or more ways.

The studies constitute one of the first systematic investigations of the early acquisition of knowledge for motion properties. The data suggest a developmental trend whereby infants at 18 months have associated particular object features to linear and nonlinear movement patterns for land objects, but they have developed little knowledge about the identity or features of objects that move in the air. In contrast, by 22 months infants have learned that it is not only objects with particular appropriate parts that are capable of particular linear or nonlinear land movement; they also understand that perceptually distinct objects—such as a car and boat—engage in similar linear motions, and presumably this understanding is based on category knowledge. Infants at 22 months often also imitated more air motions than infants at 18 months, which suggests that by this age they have started to learn about the motions of objects other than those that move on land.

These findings are consistent with the view that infants learn about a number of the movement properties typical of animates and inanimates by associating moving object parts with those movement properties (Rakison, 2003; Rakison & Poulin-Dubois, 2001). For instance, the data support the notion that infants by 18 months of age start to associate the movements of land-based objects with the dynamic features that are causally relevant to those movements. Thus, infants may initially connect legs with nonlinear land movement and wheels with linear land movement (Rakison, 2003; Rakison & Poulin-Dubois, 2001, 2002). Evidence to support this claim was found in Experiment 1 in which 18-month-olds imitated land movements with exemplars that were appropriate for linear or nonlinear motion in terms of object parts (the SPSC and SPDC exemplars). It is of note that infants' performance in this regard was consistent across the linear and non-linear motions. That is, infants learn about linear and nonlinear motion in the same way—by associating object parts with a specific trajectory—and they do so at the same time. In all likelihood, the fact that the developmental trajectory is comparable for learning about linear and nonlinear motions reflects the emergence of improving attentional, perceptual, and cognitive skills that allows dynamic information more easily to be represented.

This initial association may lead infants to overextend motion properties to objects that have legs in the appropriate structure (all four legs underneath the body or trunk of the object) even if they are not animal legs. This finding is coherent with research that showed that 18-month-olds categorize animal legs and furniture legs as equivalent (Rakison & Butterworth, 1998b). It is also in accord with research that showed that 18-month-olds treat violations of part structure that do not affect the integral configuration of parts as equivalent to normal part structures but do not treat violations that affect the configurational aspect of parts as equivalent to normal part structures (Rakison & Butterworth, 1998a). The current experiments extend these findings because they show that infants associate motion characteristics with such features and use them as a basis for induction. Indeed, 18-month-olds in Experiments 2 and 3 imitated with the two exemplars with appropriate parts even though no information about the identity of the object that performed the movement was present in the modeling phase. Thus, infants brought to the task knowledge of the motion characteristics of land objects and the features of those objects rather than generating on-line their choices of which exemplar to demonstrate the motions.

Although the 18-month-olds behaved quite differently in the air related tasks than they did in the land related tasks, their performance is consistent with this conclusion. That is, the wings of planes are not dynamic and the wings of birds are only intermittently so and are often too distant from the infant to be perceived. It would not be expected, therefore, that infants would learn that wings and flying are correlated with each other. In line with this view, infants in both age groups in Experiment 1 imitated with the SPSC exemplar but failed to reveal any evidence that they had specifically associated wings with flying by choosing the SPDC exemplar. This could be interpreted to mean that infants in these tasks generalized the flying movements on the basis of overall shape or category membership. However, when the block was used to model air movement in Experiment 2, 18-month-olds showed no preference for any exemplar and 22-month-olds tended to choose the land-based objects to demonstrate motions. Taken together, this pattern of behavior implies that infants as old as 22 months have not yet learned about the identity of objects that move through the air, and rather in ambiguous cases—such as when the block acts as the model—the default interpretation is that the linear or nonlinear movement relates to objects that move on land or to familiar objects. This is not to say, however, that the learning process for air related movement is different from that for land related movement; instead, it is suggested that it is not until some point after infancy that children associate wings and flying.

More generally, the results from the experiments reported here appear to be incompatible with the view that within the first year of life infants form rudimentary concepts that encapsulate abstract characteristics of objects' movement that are unconnected to the appearance of those objects (Mandler, 1992, 2003). According to this view, by 9–12 months of age, or even earlier, infants have developed a concept of animacy that includes a representation of the way that objects begin to move, the trajectory that objects follow, and whether they act as causal agents or recipients. It is suggested that these concepts of animacy, and the abstract characteristics embodied therein, act as the basis for categorization and induction (Mandler, 1992). This view is clearly stated by Mandler and McDonough (1998) who concluded that by 14 months of age, "infants are indifferent to whether they use a dog, cat, or rabbit to imitate an event modeled with a dog, because they consider them all to be the same kind of thing. They can see the perceptual differences among these items, but their imitations are based on their conceptual interpretations of what they have observed, not the physical appearance of the items per se" (p. 37).

The data presented in this article suggest a somewhat different interpretation of infants' behavior in the generalized imitation task and of the knowledge base underlying this behavior. No evidence was found that infants younger than 22 months possess a concept of animacy that incorporates the movement patterns of objects and that is abstracted from appearance. That is, infants as old as 18 months did not display behavior to suggest that they understood that cars, ATVs, and boats, or that cats, dogs, and dolphins are the "same kind of thing". Instead, the data reveal that infants do not start to develop knowledge about the motions of land-based objects until 18 months or so, and this knowledge appears to be grounded in specific causally appropriate features. And it is not until between 18 and 22 months that infants begin to generalize from these associations to members of the same category that do not possess the appropriate parts. It is perhaps at this point at which infants may have started to develop a broader concept of objects that includes a wider range of features and movement patterns. For instance, toward the end of the 2nd year infants begin to put greater emphasis on the presence of eyes in categorization and word learning (Jones & Smith, 1993; Jones, Smith, & Landau, 1991), and it is possible that they may begin to generalize associations involving, for example, legs and nonlinear land movement to objects that do not necessarily possess legs but that do possess eyes.

The mechanism that underlies this form of concept development is posited to be associative learning, with concepts becoming enriched over time as ever more complex static and dynamic information is encoded (Rakison, 2003; Rakison & Poulin-Dubois, 2001, 2002). Thus, infants' early representations for objects and entities will include primarily information about static features such as legs, eyes, and wheels. As the perceptual system become more sensitive to fine-grained information and as information-processing abilities become more competent, so dynamic information about motion properties, category-specific actions, and even psychological characteristics will be attached to these early representations.

Whether it is necessary to reinterpret previous findings on infants' generalized imitation for animate and inanimate actions remains an open question. An informal analysis of the stimuli used by Mandler and McDonough (1996, 1998) indicated that alternative explanations of their data cannot, at this point, be eliminated. For example, infants generalized actions in their studies to all objects that shared the same parts (e.g. dogs, cats, and rabbits all have legs, mouths, and eyes) and not to objects that did not share such parts (e.g. land vehicles do not have legs, mouths, and eyes). Similarly, infants generalized an action from one dog to another dog with the same parts but not to a category exemplar that possesses quite different parts such as a bird (Mandler & McDonough, 1998 do not specify whether the toy bird possessed legs). It remains to be seen whether infants in the studies by Mandler and McDonough (1996, 1998) may have generalized on the basis of features such as legs and wheels or on the basis of features that were more causally relevant to the action. For example, under the theoretical perspective presented here it would be predicted that infants would associate mouths with drinking and would therefore generalize drinking on the basis of mouths rather than, for example, legs. An interesting avenue of future research would be to address this issue directly by providing infants with objects that possessed features that are causally (e.g. mouths for drinking) or not causally related (e.g. legs for drinking) to an action.

Although the experiments presented here provide evidence concerning the development of infants' knowledge about motion properties for objects that move on land and in the air, it is worth noting some potential limitations of the experimental design and procedure. First, it is possible that infants were partly confused by the fact that the experimenter made the model exemplar move. This is particularly the case for the animals because in the real world they tend to move on their own. This issue is intrinsic in the generalized imitation task, and could similarly be levied at previous work such as when, for example, an experimenter makes an animal drink from a cup (humans rarely "make" an animal drink) or, more crucially, makes an animal or vehicle go into a building (Mandler & McDonough, 1996, 1998). It seems unlikely, however, that infants were confused or surprised by the fact that an adult modeled the motions of animals. Not only is such modeling common in the real world—parents often model with a toy an action or motion typical of its real world counterpart—but also infants' behavior in Experiments 2 and 3 suggests that they had no problem interpreting the modeled actions as relating to the movement of specific objects. Why else would infants who have seen linear and nonlinear land motions modeled with an ambiguous block demonstrate those motions with objects possessing the appropriate parts (at 18 months) or that belong to the appropriate category (at 22 months).

Second, it could be argued that it is difficult to assess infants' knowledge of real-world objects when scale model toys are used in the experimental task. This issue is inherent in a number of procedures used to test infants (e.g. sequential touching, object examining). According to one view, infants understand that the toys are symbolic representations of their real-world counterparts (Mandler, 1992; Mandler & McDonough, 1993, 1996, 1998) and it is argued that categorization of these stimuli suggests that infants apply their knowledge to them. This view has been challenged directed in the literature. For example, Tomasello and Striano (2001) and Tomasello, Striano, and Rochat (1999) have shown that before 2 years of age children have symbolic skills with gestures but not with objects, and consequently they argue that symbolic understanding of objects is extremely limited until early in the third year of life. Similarly, Younger and Johnson (2004) used an imitation procedure to show that infants younger than 2 years of age rarely comprehend that scale model objects are symbols for the "real" objects that they represent. Following from this view, the assumption that infants view the toy stimuli as symbolic representations of real world object was not taken in the present series of studies. Instead, the rationale for using scale models as stimuli was that they possess similar features, shape, and structures as real-world objects, and the basis for infants' generalization from one stimulus to another (e.g. from a dog to a cat) might match that which would occur in the real-world. Of course, the fact that the stimuli were scale models or an ambiguous block means that dynamic cues at the local level were minimized, and it is possible that infants may have performed differently if such cues were available. For example, 18-month-olds may have performed more like the 22-month-olds if the legs of the objects moved or the wheels rolled. At the same time, it is also plausible that highlighting such cues might have served to increase attention to object features. Future research that examines infants' understanding of motion properties as well as domain-specific actions (e.g. drinking) could address this question by manipulating the presence or absence of dynamic cues.

Finally, it is possible that infants' performance across the three experiments was idiosyncratic to the stimuli that were used. Perhaps, for example, infants would have chosen the DPSC exemplar in Experiment 1 if it were more alike—in terms of perceptual cues and category closeness—to the model exemplar. Likewise, it is possible that differences in infants' behavior on the various domains could have resulted from differences in the contrasts between the test items used in each condition rather than a different understanding of air and land motions. For example, it could be argued that the contrast between the stroller and the car was not as strong as the contrast between the cargo plane and the dragonfly. The first argument is partially undercut by infants' generalization behavior that was largely predicted based on the theoretical position outlined here. The second claim is addressed to a degree by Experiments 2 and 3 in which there was no contrast between the block used to the model the events and the test stimuli, and because of the consistency of the findings across those two experiments. Nonetheless, future studies with the same procedure could help to establish the generalizability of the present data.

To conclude, the set of experiments reported here constitutes one of the first systematic attempts to examine infants' knowledge about the motions of animals and vehicles that move on land and in the air. It has previously been proposed that infants develop concepts of animates and inanimates in the first year of life, and these early concepts incorporates motion characteristics that represent, for example, nonlinear and linear movement (Mandler, 1992). The present experiments support a different view of the development of knowledge about objects' motion properties that has at its core the notion that concepts are grounded in perceptual information and that the mechanism underlying concept acquisition is a constrained form of domain general associative learning (Rakison, 2003).

To this end, the experiments provide evidence that infants do not start to form concepts about the movement characteristics of animals and vehicles—in particular, linear and nonlinear motion—until after the first year of life, and more specifically until approximately 18 months. It is argued that these early concepts do not embody motion properties in an abstract form. Instead, infants' initial concepts for the way that land objects move are grounded in the relationship between dynamic features and the motions with which they are causally relevant. The experiments also show that infants, particularly those under 22 months, are affected in their behavior by the choice of the model stimulus, and accordingly care should be taken in interpreting data generated from the inductive generalization procedure. Finally, the novel variation of the inductive generalization procedure used here has the potential to provide considerable insight into infants' developing concepts because it allows the experimenter to manipulate precisely the available bases for generalization. An interesting and potentially fruitful goal of future research will be to examine with this procedure more specifically how infants associate specific attributes with distinct motion characteristics, and to determine how such associations ultimately evolve into full fledged concepts for animates and inanimates.

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References

Cohen, L. B., Rundell, L. J., Spellman, B. A., & Cashon, C. H. (1999). Infants' perception of causal chains. *Psychological Science*, *10*, 412–418.

Eimas, P. D. (1994). Categorization in infancy and the continuity of development. *Cognition*, *50*, 83–93.

Gelman, R. (1990). First principles to organize attention to and learning about relevant data: Number and the animate–inanimate distinction as examples. *Cognitive Science*, *14*, 79–106.

Gelman, R., Durgin, F., & Kaufman, L. (1995). Distinguishing between animate and inanimates: Not by motion alone. In D. Sperber, D. Premack, & A. J. Premack (Eds.), *Causal cognition* (pp. 150–184). Oxford: Clarendon Press, 150–184.

Gergely, G., Nádasdy, Z., Csibra, G., & Bíró, S. (1995). Taking the intentional stance at 12 months of age. *Cognition*, *56*, 165–193.

Gogate, L. J., & Bahrick, L. E. (1998). Intersensory redundancy facilitates learning of arbitrary relations between vowel sounds and objects in seven-month-old infants. *Journal of Experimental Child Psychology*, *69*, 133–149.

Gopnik, A., & Meltzoff, A. N. (1997). *Words thoughts, and theories*. Cambridge, MA: MIT Press.

Haith, M., Wentworth, N., & Canfield, R. (1993). The formation of expectations in early infancy. In C. Rovee Collier, & L. P. Lipsitt, *Advances in infancy research* (Vol. 8) (pp. 217–249). Norwood, NJ: Ablex, 217–249.

Johnson, S., Slaughter, V., & Carey, S. (1998). Whose gaze will infants follow? The elicitation of gaze-following in 12-month-olds. *Developmental Science*, *1*, 233–238.

Jones, S. S., & Smith, L. B. (1993). The place of perception in children's concepts. *Cognitive Development*, *8*, 113–139.

Jones, S. S., Smith, L. B., & Landau, B. (1991). Object properties and knowledge in early lexical learning. *Child Development*, *62*, 499–516.

Leslie, A. M. (1984). Infant perception of a manual pick-up event. *British Journal of Developmental Psychology*, *2*, 19–32.

Leslie, A. M., & Keeble, S. (1987). Do six-month-old infants perceive causality? *Cognition*, *25*, 265–288.

Leslie, A. (1995). A theory of agency. In D. Sperber, D. Premack, & A. J. Premack (Eds.), *Causal cognition* (pp.121–141). Oxford: Clarendon.

Mandler, J. M. (1992). How to build a baby: II. Conceptual primitives. *Psychological Review*, *99*, 587–604.

Mandler, J. M. (1998). Representation. In W. Damon (Series Ed.) & D. Kuhn & R. S. Siegler (Vol. Eds.), Handbook of child psychology: Vol. 2. Cognition, perception, and language (pp. 255–308). New York: Wiley.

Mandler, J. M. (2000). Perceptual and conceptual processes in infancy. *Journal of Cognition and Development*, *1*, 3–36.

Mandler, J. M., Bauer, P. J., & McDonough, L. (1991). Separating the sheep from the goats: Differentiating global categories. *Cognitive Psychology*, *23*, 263–298.

Mandler, J. M., & McDonough, L. (1993). Concept formation in infancy. *Cognitive Development*, *8*, 291–318.

Mandler, J. M., & McDonough, L. (1996). Drinking and driving don't mix: Inductive generalization in infancy. *Cognition*, *59*, 307–335.

Mandler, J. M., & McDonough, L. (1998). Studies in inductive inference in infancy. *Cognitive Psychology*, *37*, 60–96.

Mandler, J. M. (2003). Conceptual categorization. In D. H. Rakison, & L. M. Oakes (Eds.), *Early category and concept development: Making sense of the blooming, buzzing confusion* (pp. 103–131). New York: Oxford University Press.

Oakes, L. M., Madole, K. L., & Cohen, L. B (1991). Infant habituation and categorization of real objects. *Cognitive Development, 6*, 337–392.

Oakes, L. M., Coppage, D. J., & Dingel, A. (1997). By land or by sea: The role of perceptual similarity in infants' categorization of animals. *Developmental Psychology*, *33*, 396–407.

Oakes, L. M., & Madole, K. L. (2003). Principles of developmental change in infants' category formation. In D. H. Rakison, & L. M. Oakes (Eds.), *Early category and concept development: Making sense of the blooming, buzzing confusion* (pp. 159–192). New York, NY: Oxford University Press, 159–192.

Premack, D. (1990). The infant's theory of self-propelled objects. *Cognition*, *36*, 1–16.

Quinn, P. C., & Eimas, P. D. (1996). Perceptual organization and categorization. In C. Rovee-Collier, & L. Lipsitt, *Advances in infancy research* (Vol. 10) (pp. 1–36). Norwood, NJ: Ablex, 1–36.

Quinn, P. C., & Eimas, P. D. (1997). A reexamination of the perceptual-to-conceptual shift in mental representations. *Review of General Psychology*, *1*, 271–287.

Quinn, P. C., Johnson, M., Mareschal, D., Rakison, D., & Younger, B. (2000). Response to Mandler and Smith: A dual process framework for understanding early categorization? *Infancy*, *1*, 111–122.

Rakison, D. H. (2003). Parts, categorization, and the animate-inanimate distinction in infancy. In D. H. Rakison, & L. M. Oakes (Eds.), *Early category and concept development: Making sense of the blooming buzzing confusion* (pp. 152–192). New York, NY: Oxford University Press, 152–192.

Rakison, D. H., & Butterworth, G. (1998a). Infants' use of parts in early categorization. *Developmental Psychology*, *34*, 49–62.

Rakison, D. H., & Butterworth, G. (1998b). Infant attention to object structure in early categorization. *Developmental Psychology*, *34*, 1310–1325.

Rakison, D. H., & Cohen, L. B. (1999). Infants' use of functional parts in basic-like categorization. *Developmental Science*, *2*, 423–432.

Rakison, D. H., & Poulin-Dubois, D. (2001). The developmental origin of the animate–inanimate distinction. *Psychological Bulletin*, *127*, 209–228.

Rakison, D. H., & Poulin-Dubois, D. (2002). You go this way and I'll go that way: Developmental changes in infants' attention to correlations among dynamic features in motion events. *Child Development*, *73*, 682–699.

Roberts, K. (1998). Linguistic and nonlinguistic factors influencing infant categorization: Studies of the relationship between cognition and language. In C. Rovee Collier, & L. P. Lipsitt, *Advances in infancy research* (Vol. 11) (pp. 45–107). London: Ablex, 45–107.

Rochat, P., Morgan, R., & Carpenter, M. (1997). Young infants' sensitivity to movement information specifying social causality. *Cognitive Development*, *12*, 441–465.

Spelke, E. S., Philips, A., & Woodward, A. L. (1995). Infants' knowledge of object motion and human action. In D. Sperber, D. Premack, & A. J. Premack (Eds.), *Causal cognition* (pp. 150–184). Oxford: Clarendon Press, 150–184.

Tomasello, M., & Striano, T. (2001). Social and object support for early symbolic play. *Developmental Science*, *4*, 442–455.

Tomasello, M., Striano, T., & Rochat, P. (1999). Do young children use objects as symbols? *British Journal of Developmental Psychology*, *17*, 563–584.

Tincoff, R., & Jusczyk, P. W. (1999). Some beginnings of word comprehension in 6-month-olds. *Psychological Science*, *10*, 172–175.

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition*, *69*, 1–34.

Woodward, A. L. (1999). Infants' ability to distinguish between purposeful and non-purposeful behaviors. *Infant Behavior and Development* , 22.

Younger, B. A., & Cohen, L. B. (1986). Developmental change in infants' perception of correlations among attributes. *Child Development*, *57*, 803–815.

Younger, B. A., & Johnson, K. E. (2004). Infants' comprehension of toy replicas as symbols for real objects. *Cognitive Psychology*, *48*, 207–242.